Arctic Weather

Today, the Arctic is rapidly becoming 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. As we learn more and more about Arctic weather and its effects on flying, Arctic flying will become even more common.

To understand some of the important weather problems of the Arctic, the broad, underlying causes of Arctic climate must be understood.

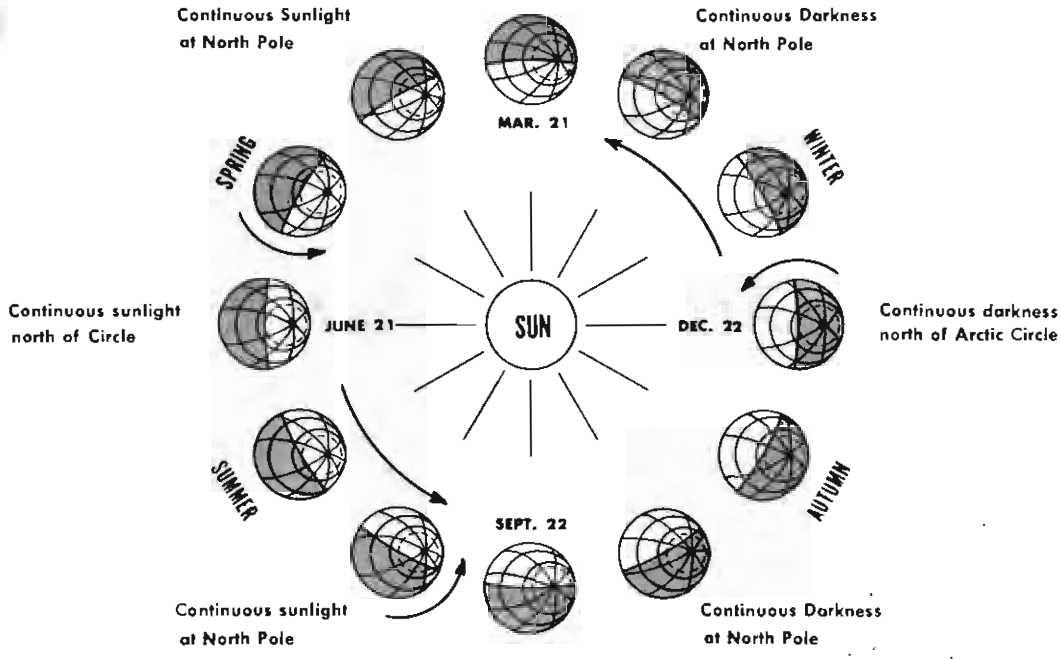
SEASONAL TEMPERATURE VARIATIONS

The most important factor that determines the climate of any area is the amount of energy it receives from the sun. The quantity of energy received by a given area of the earth depends, among other things, on the angle at which the sun's rays strike the earth (angle of incidence) and on the duration of the sunlight. It is easy to see that the total amount of energy received by the earth decreases toward the poles and that the amount varies from season to season. As shown in the accompanying illustration, during the winter much of the Arctic receives little or no direct heat from the sun. In comparison, notice the amount of sunlight received at different latitudes. The cold, winter temperatures common in the Arctic result from a lack of the sun's energy, Figure 14-1.

If the energy from the sun were the only factor responsible, climate would be determined by latitude alone. Obviously, however, this is not the case, because there are tremendous variations in climate between points at the same latitude. The distribution of water and land, and the topography of the land help to account for these variations. The related illustration shows the land and water distribution in the arctic regions, Fig. 14-2.

Water Features

In the Northern Hemisphere, the water features are the Arctic, the North Atlantic, and the North Pacific Oceans. These bodies of water act as temperature moderators, since they do not have large seasonal temperature variations (except where ice-covered in winter). The land features are the northern bulk of Eurasia, the smaller continent of North America, the island area of Greenland, and the Canadian Archipelago. As opposed to the large water areas, the land areas tend to show the direct results of the extremes of seasonal heating and cooling by their large seasonal temperature variations.



Sunlight of the Northern Hemisphere at different seasons. The North Pole is aimed in the same direction throughout the year, but the zone within the Arctic Circle is completely in sunlight on 21 June, completely in darkness on December 22, and has 12 hours daylight and darkness on 21 Mar. and 22 Sept.

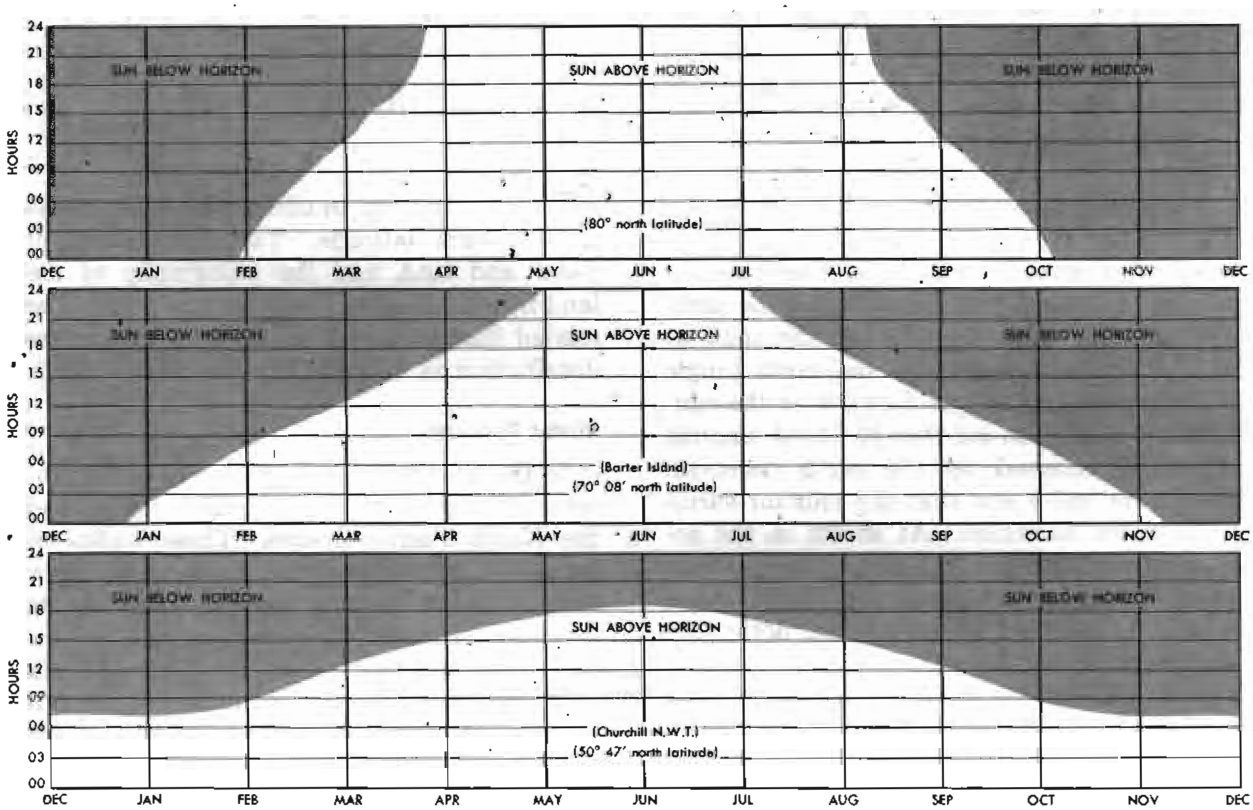


Figure 14–1. Number of Hours Sun is Above or Below the Horizon. Note: Vertical Lines Represent the 21st Day of the Month

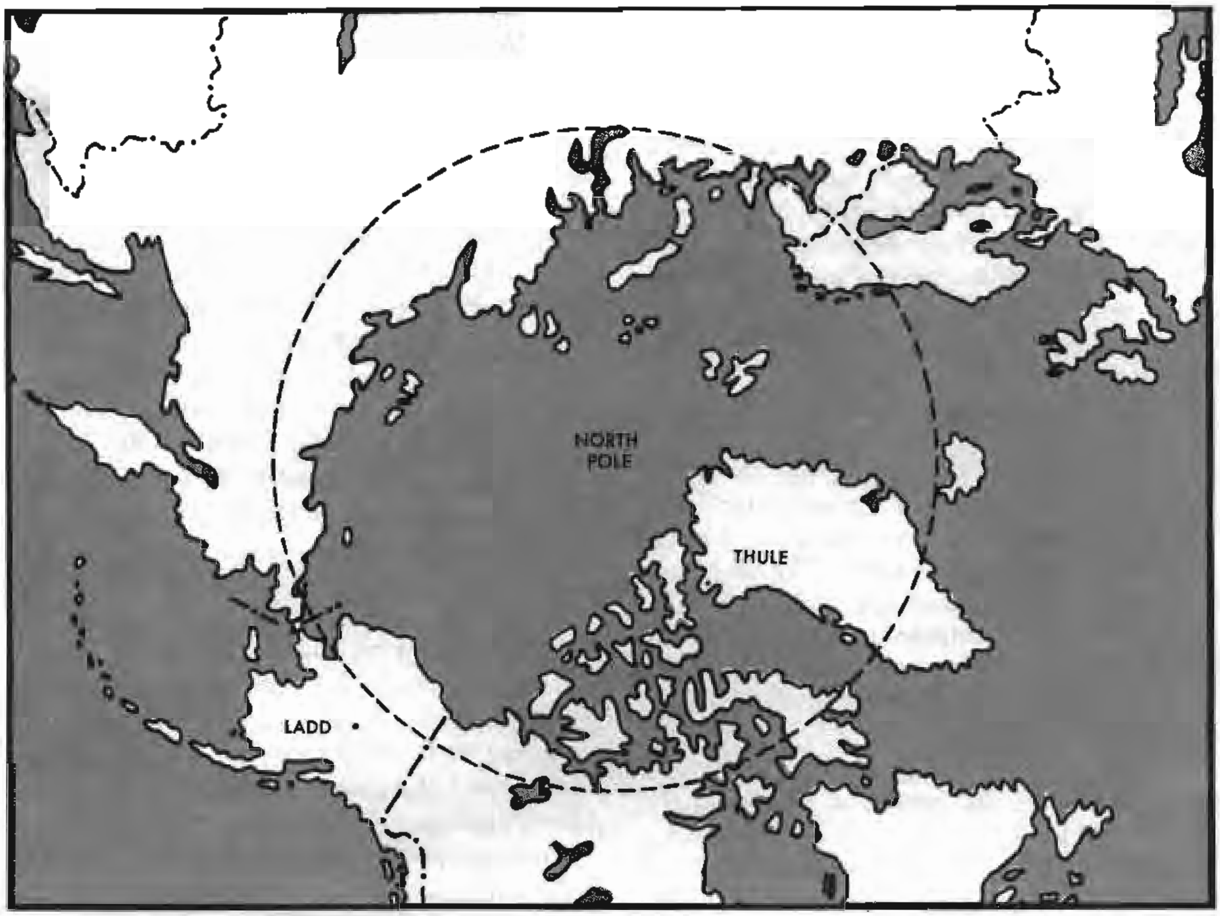


Figure 14–2. Water and Land Distribution in the Arctic Region

Mountains

The Arctic mountain ranges of Siberia and North America are factors which contribute to the climatic and air mass characteristics of the region. These mountain ranges are effective barriers which restrict the movement of air. During periods of weak circulation (wind) 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 ice and snow.

The Greenland ice cap is essentially a mountain range and rises to a height in excess of 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, resulting in some of the largest rates of falling pressure (other than hurricanes and tornadoes) recorded anywhere in the world. The deep low centers that move north along the west coast of Greenland are, in the main, primarily responsible for the occasional high winds that are recorded in that area. An example is Thule Air Base, Greenland. Notice Thule's position in the illustration showing the land and water distribution of the Arctic. However, some cyclonic disturbances reaching high levels can pass over Southern Greenland and redevelop on the lee side.

On some occasions, the 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 the air (foehn) as it often flows 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 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 semi-maritime 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 variabilities are slight.

During the winter months the air masses are formed over an area that is completely covered by ice and snow. Notice the Arctic wasteland shown in the associated illustration. 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 is directly dependent on the 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 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 water 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 result in a somewhat more abundant supply of moisture. Consequently, the largest amount of cloudiness and precipitation occurs during these summer months.

Arctic Fronts

The weather associated with a front in the Arctic has much the same cloud structure as with mid-latitude 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.

Figure 14–3. Typical Arctic Frozen Oceans, Snow Covered Ground and Mountain Peaks

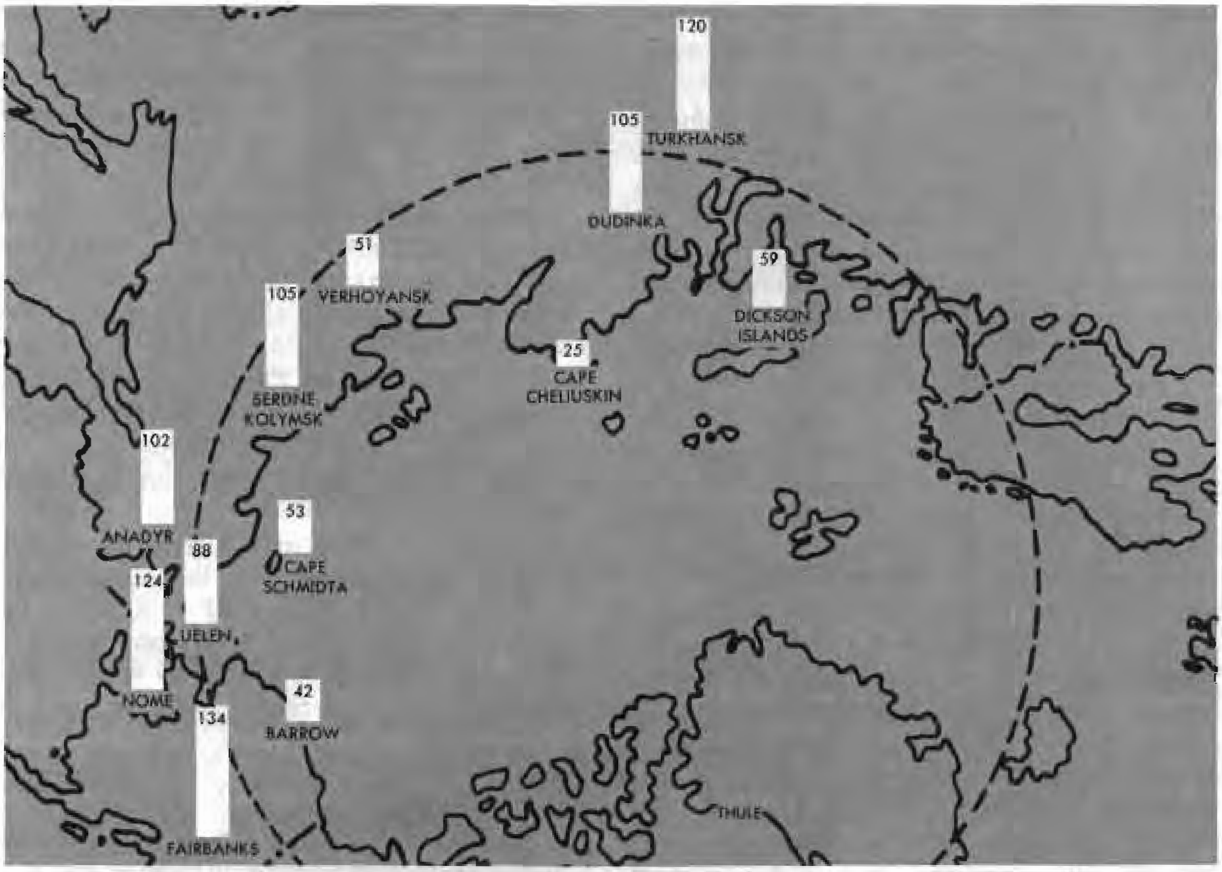


Figure 14–4. Average Number of Days Each Year When Minimum Temperature was Above Freezing

The best flying weather in the Arctic over land is most likely to occur in midsummer and midwinter; the worst (low ceilings and visibilities) in the transition periods between these 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-flight weather is generally good in winter; however, terminal conditions are frequently bad as a result of blowing snow, fog, and the like. In summer, there are fewer storm passages and the 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 windiness is less than in winter.

NOTE

The vapor pressure (pressure due to water vapor) at temperatures near 0°C. is not great. Therefore, it cannot be said that the open water expanses in summer in the Arctic regions are a spectacular source of water vapor. In fact, the dew point of the air cannot be raised above the underlying water temperature, which is about 35° in the Arctic summer.

During the transitional periods of spring and fall, operational flying conditions are usually worst. Frontal systems are usually well defined, active, and turbulent. Icing may extend to high levels. These are important elements to consider when planning flights into or through the Arctic region.

Temperatures of the Arctic

Temperatures in the Arctic, as one might expect, are very cold during much 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. The related illustration shows the average number of days during each year that the temperature does not fall below freezing. Notice the large temperature difference between the interior areas and the coastal areas.

In the interior areas during the summer days, temperatures often climb to the mid 60's or low 70's, frequently rise to the high 70's or 80's, and occasionally even into the 90's. 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 drifts southward over the middle latitudes. The coldest temperatures on record over the Northern Hemisphere have been established in north central Siberia and northern Canada. Verkhoyansk, Siberia, holds the record low with a temperature of –94°F. Snag, in the Yukon Territory of Canada, witnessed the coldest temperature in North America, –83°F.

In the northern areas of the interior regions during the winter months, temperatures are usually well below zero. In fact, during these long hours of darkness, the temperature normally falls to –20° 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° and –55°F.

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

Over the Arctic Ocean the temperatures are very similar to those experienced along the coast; however, the summer temperatures are somewhat colder. During the initial 22-month period that weather observations were recorded on Fletcher's Island (T–3) floating in the Arctic Ocean, the highest temperature that occurred was 36°F (does not include IGY observations). One would not expect the surface temperature to climb much above the freezing point because the ice pack surrounds the island during the entire year.

Winter temperatures along the Arctic coast are very cold, but not nearly as cold as those observed in certain interior areas. It is only on rare occasions that the temperature climbs to above freezing during the winter months. The coldest readings for these coastal areas are in the –60's and –70's of degrees Fahrenheit. The coldest temperature observed on Fletcher's Island during the period previously mentioned was –60°F.

These figures may seem surprising, since at first one might think that the temperatures near the North Pole would be colder than those over the northern continental interiors. Actually the flow of heat from the water under the ice has a moderating effect on the low temperature.

Cloudiness

Cloudiness over the Arctic is at a minimum during the winter and spring months and at a maximum during the summer and fall. The average number of cloudy days for two 6-month periods is shown in the accompanying sketch. This illustrates a general decrease in cloudiness in the entire Arctic area during the winter months.

During the warm summer afternoons in the interior regions, scattered cumulus clouds form and occasionally they develop into thunderstorms. The thunderstorms are normally scattered and seldom form a continuous line. Along the Arctic coast and over the Arctic Ocean thunderstorms occur very infrequently. Although tornadoes have been observed near the Arctic Circle, their occurrence is extremely rare.

Winds

Wind speeds are generally light in the continental interior during the entire year. The strongest winds in the interior normally occur in the summer and fall. During the winter, the interior continental regions are areas of strong anti-cyclonic activity (high pressure

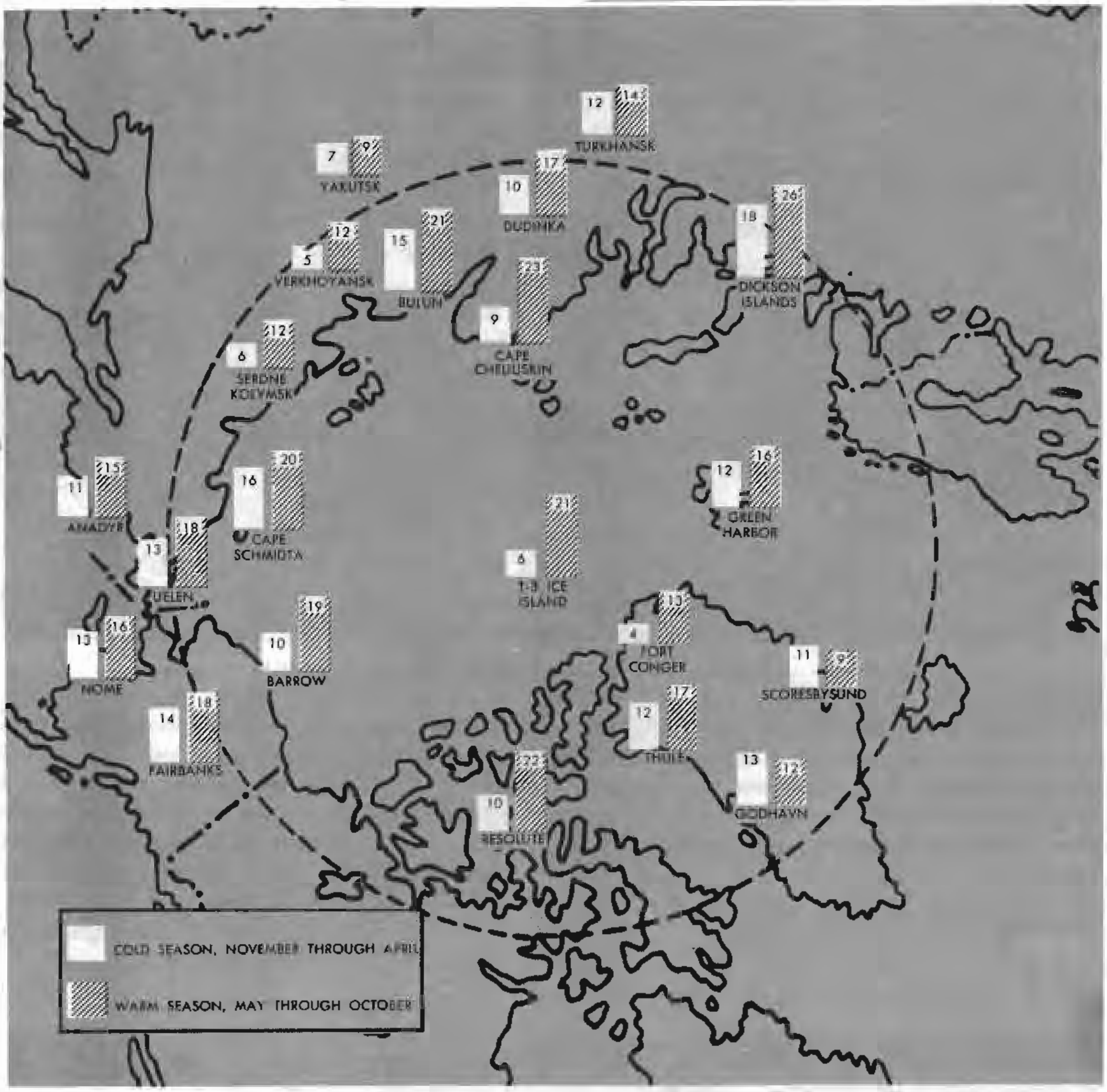


Figure 14–5. Average Number of Days per Month on which Cloudy Conditions Occurred

areas) which produce only light surface winds.

Strong winds occur more frequently along the Arctic coast than in the continental interior. The associated illustration shows the average number of days per year on which winds were reported at speeds of 28 knots or more at various locations in the Arctic. The frequency with which these high winds occur in coastal areas is greater in the fall and winter than during the summer. These winds frequently cause blowing snow.

Wind velocities greater than 70 knots have been observed at many Arctic coastal stations. It is interesting to note that the number of days during which high winds were reported is much less over the Arctic Ocean than along the coastal areas. At Fletcher's Island there were only two occasions during the period of observation mentioned that the wind equaled or exceeded 28 knots. The strongest wind observed there was 43 knots.

Strong winds are infrequent over the ice pack, but the wind blows continuously as

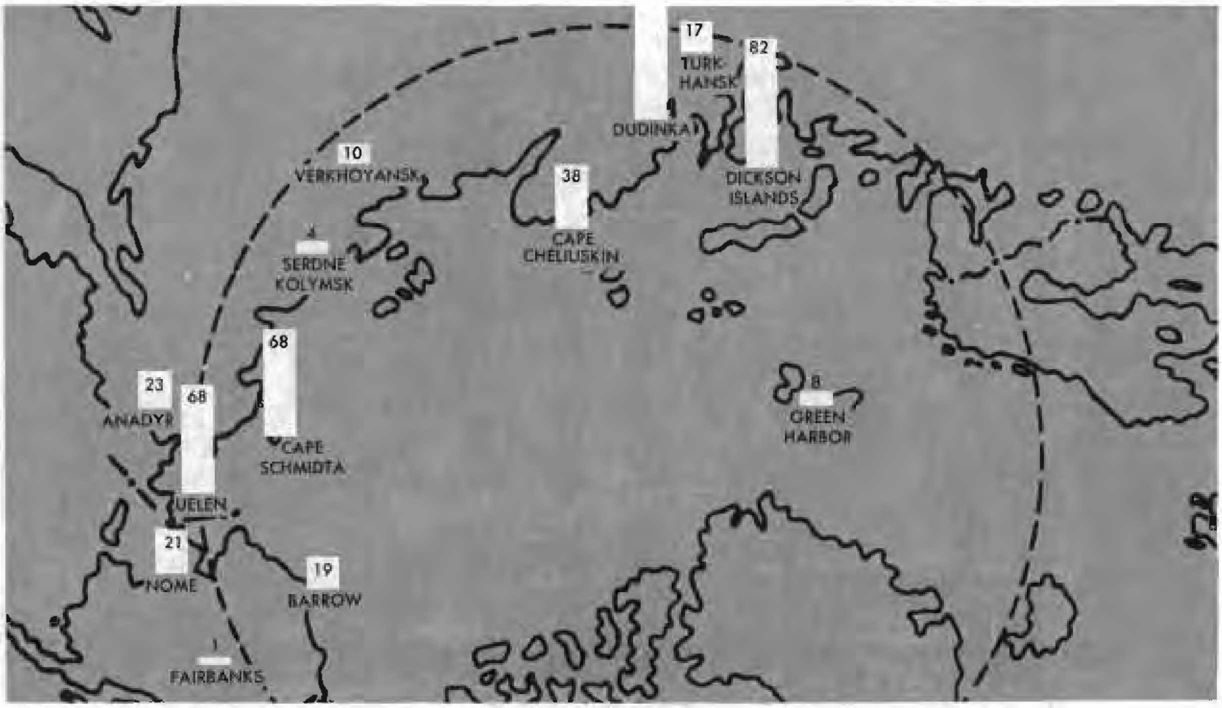


Figure 14–6. Average Number of Days Each Year with Winds of 28 Knots or More

there is no hindrance offered by natural barriers, such as hills and mountains. As a result of the combination of windspeed and low temperatures, the Arctic coastal area and the area over the ice pack are very uncomfortable and 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 United States. Most of the annual precipitation falls as snow on the Arctic Ocean and adjacent coastal areas and the ice caps. On the other hand, most of the annual precipitation falls as rain over the interior.

Figure 14–7. Blowing Snow Reduces Visibility at an Airfield

RESTRICTIONS TO VISIBILITY

Two conflicting factors make the subject of visibility in the polar regions very complex. Arctic air, being cold and dry, is exceptionally transparent and extreme ranges of sight are possible. On the other hand, there is a lack of contrast between objects, particularly when all distinguishable objects are covered by a layer of new snow ("whiteout"). Limitations to visibility in the Arctic are primarily blowing snow, fog, and local smoke. However, local smoke is serious only in the vicinity of the larger towns, and often occurs with the shallow radiation fogs of winter.

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 packed by gentle and moderate winds. Winds in excess of 8 to 12 knots may raise the snow several feet off of the ground, and the blowing snow may obscure surface objects such as runway markers. Notice this effect in the subject illustration.

Fog

Of all the elements that restrict flying in the Arctic regions, fog in most respects, is paramount. The two types of fog most frequent in the polar regions are *advection fog* and *radiation fog*.

Fog will be found most frequently along coastal areas, and usually lies in a belt parallel to the shore. In winter months, the sea is warmer than the land. The moisture in the relatively warm air moving from the sea condenses over the cool land causing fog. This fog may be quite persistent.

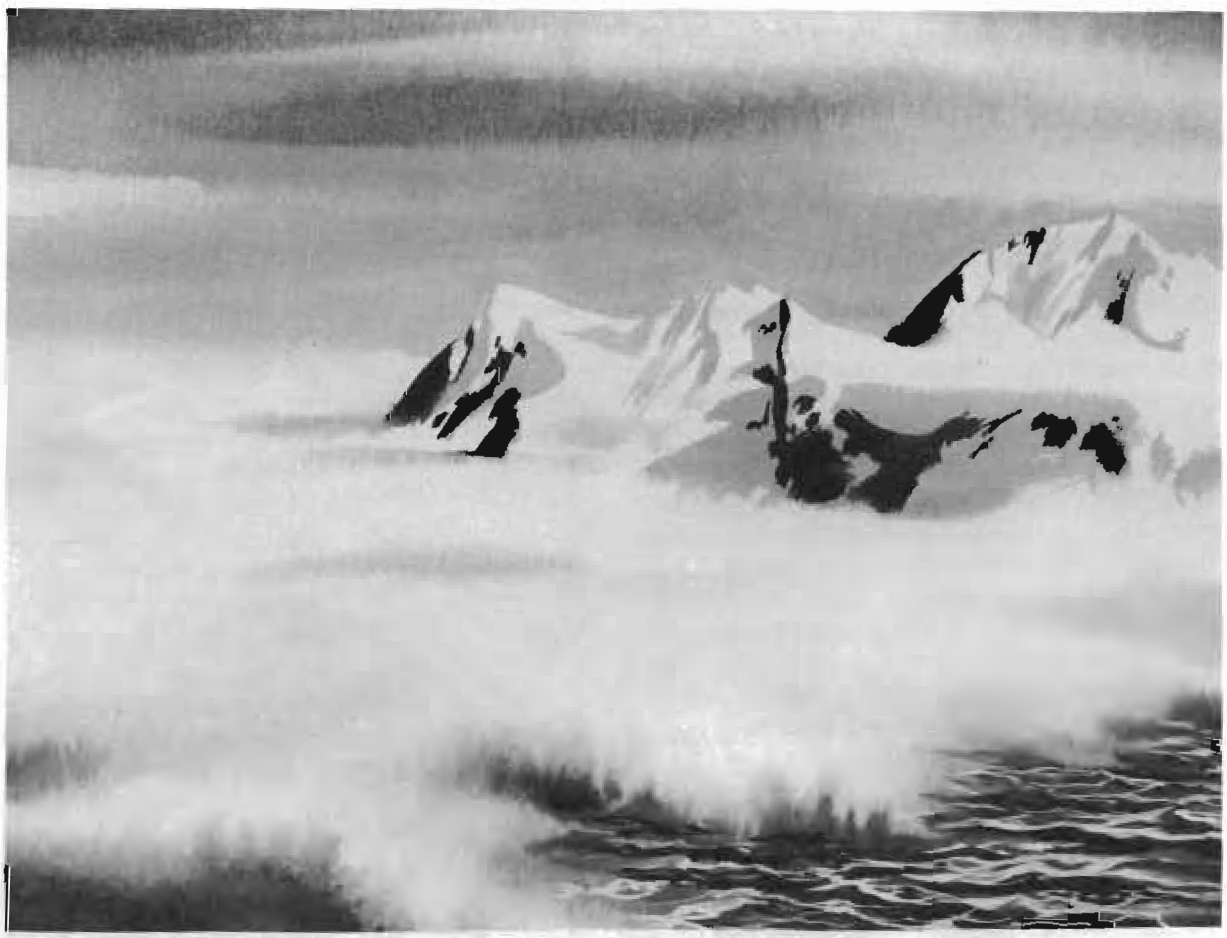


Figure 14–8. *Heavy Fog Along Arctic Coast*

Ice Fog

A fog condition peculiar to Arctic climates is ice fog. Ice fog is composed of minute ice crystals rather than the water droplets of ordinary fog, and is most likely when the temperature is about –40°F or colder. For more detailed information see section on ice fog in Chapter 9, *Restrictions to Visibility*.

Sea Smoke or Steam Fog

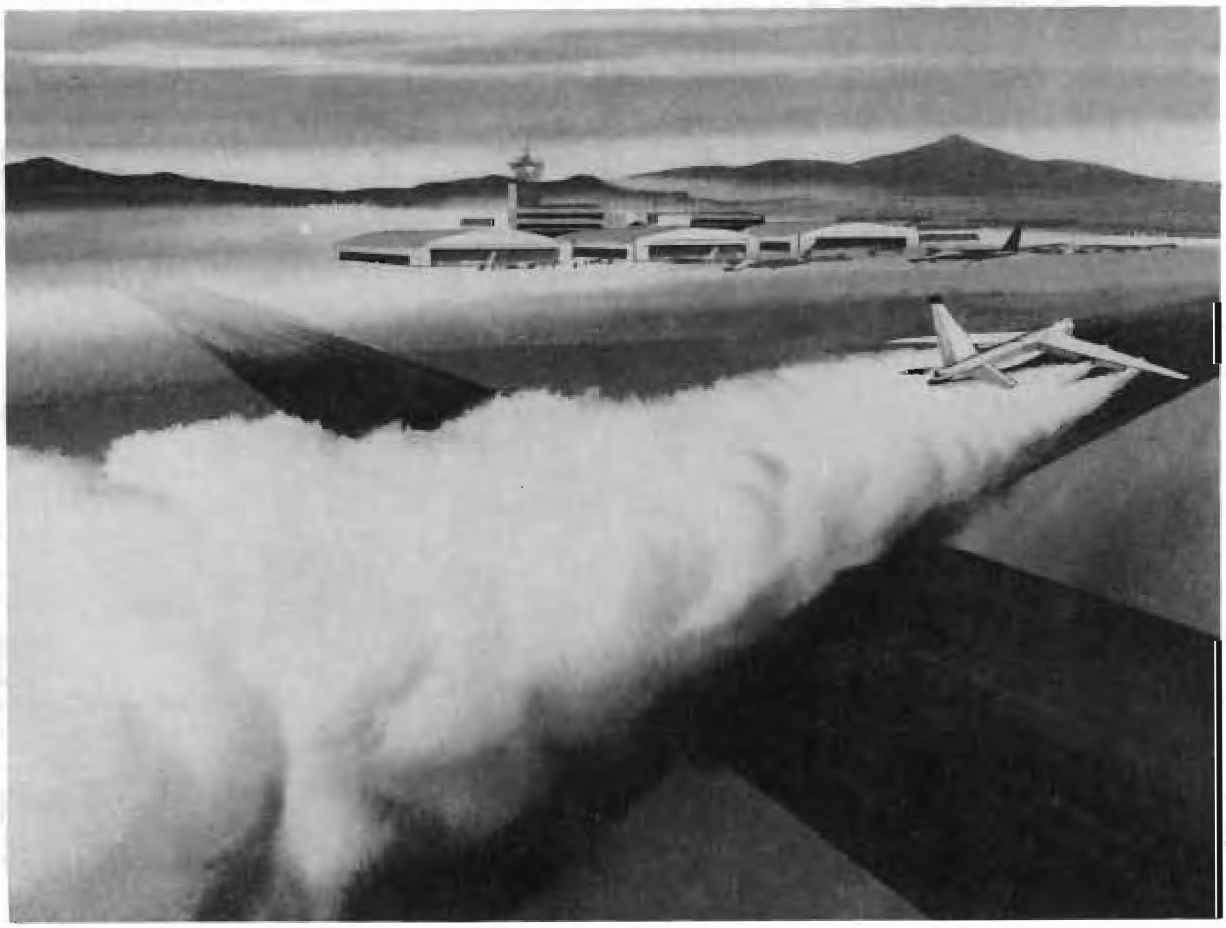
The cold temperatures in the Arctic may have effects which seem peculiar to people who are unfamiliar with the area. During the winter months, the inability of the air to hold moisture causes an unusual phenomenon called *sea smoke*. This is caused by open bodies of comparatively warm water occurring simultaneously with low air temperatures. Actually, this phenomenon is about the same as the familiar one of steam forming over hot water.

In the case of sea smoke, the temperature of both the air and water is much lower, of course, but the air temperature is still much the colder 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 in the ice pack, and is composed entirely of water droplets (which may soon freeze and "rain out" as ice particles).

Arctic Haze

This is a condition of reduced horizontal and slant visibility (but unimpeded 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*, and when the sun shines on the ice particles they are called *diamond dust*.

Figure 14–9. Ice Fog Forming in Wake of Aircraft



GROUND PROBLEMS

The greatest problems in Arctic operation of the Air Force are on the ground — working and living on the ground, getting aircraft ready to fly, and getting aircraft off and back onto the ground. Problems in in-flight operations are actually less severe, *on the average*, in the Arctic than in the latitudes with which we are more familiar. The term "on the average" is used because flying weather in the Aleutian Islands and certain parts of Greenland is probably the worst in the world. But over the whole Arctic area and throughout the year, flying weather is not severe. The most acute in-flight problems are concerned with communications and navigation.

Possibly the greatest hazard to operations in the Arctic area is the effect of polar lighting on depth perception, called *whiteout*. Under whiteout conditions, neither shadows, horizon, nor clouds are discernible; sense of depth and orientation is lost; only very dark, nearby objects can be seen. Even the height of objects, such as a high bank of snow along a road or runway only a few feet away, cannot be determined. This hazard results from several factors, such as the extremely clean, dry air, the lack of color differences, the areas of unbroken snow surfaces, and the diffusing effect of the crystalline surface on light. It is also often aggravated by certain weather conditions, and usually requires an overcast sky.

Altimetry

Large altimetry errors, caused by cyclonic activity and below-standard temperatures, are common in the Arctic and should be thoroughly understood by all who fly in this area. If these errors and their causes are understood, the hazard they represent can be almost completely eliminated. Flights can be planned to compensate for these differences by consulting the weather forecaster and learning the magnitude of the errors in altimeter readings that will be encountered en route. Altimeter errors as much as 2,000 feet, and more, are possible because of the presence of well-developed lows and below-standard temperatures. Significant errors of this magnitude — *on the dangerous side* — are not uncommon during the seasons of fall, winter and spring.

The requirement for oxygen by an aircrew member is determined by the actual pressure at which the aircraft is flying. Pressure altitude, corrected for the mean temperature of the layer of air between the aircraft and the ground, should be used as the oxygen-demand altitude instead of actual or true altitude. This should be remembered when an increase in (pressure) altitude is required to clear known obstacles on the proposed route of an aircraft. (For more on altimetry, refer to the related section in Chapter 6.)

ARCTIC WEATHER PECULIARITIES

The strong temperature inversions (rapid increase in temperature with height at low levels) 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, people's voices may be heard over extremely long distances as compared to the normal range of the human 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 beyond the horizon. This effect, known as "looming," is a form of mirage. Mirages of the type which distort the apparent shape of the sun, moon, and other objects near the horizon, are common under inversion conditions.

One of the most interesting phenomena in the Arctic is the Aurora Borealis (Northern Lights). These lights are by no means confined to the Arctic but are more noticeable at Arctic locations. When they are brightest, they appear as tinted bands of fluorescent light which constantly change their intensity and shape. 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 light 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 (rift in a glacier or mass of land ice) immediately in front of one may be undetected due to lack of contrast.

Pilots have reported that the light from a half-moon over a snow-covered field is sufficient for landing purposes. It is possible on occasions to read a newspaper with 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 overcast skies that the night darkness in the Arctic begins to approach the degree of darkness in lower latitudes. In latitudes north of 65° there will be long periods of moonlight. The moon may stay above the horizon for several days at a time.

Summary of Flying Conditions

Flying conditions in the Arctic areas are normally good, when considering an entire year. The extremely cold temperatures in the Arctic greatly affect ground maintenance, but rarely interfere with an aircraft at flight altitude.

Over the continental interior, good flying weather usually prevails throughout the year. Considering ceiling and visibility, the summer months provide the best flying weather. This is true, although the number of cloudy days during the summer will exceed the number of cloudy days during the winter. Frontal activity during the summer is weak and will very seldom cause severe turbulence, icing, or strong winds. Thunderstorms that develop during the summer months can usually be circumnavigated and do not greatly interfere with this area.

The major restriction to aircraft operation in the winter, besides the cold temperatures and regular water-droplet fog, is ice fog. Although it is not more hazardous to aircraft operations than ordinary fog, it constitutes a serious problem because of its frequency of occurrence and its tendency to persist for extended periods. Ice fog does not cause icing of aircraft because no water droplets are present.

During the winter, severe icing and turbulence will normally be experienced when strong frontal activity is present. This is especially true in mountainous areas.

Over the Arctic Ocean and along the coastal areas, the main hazards to aircraft operations are: blowing snow and strong surface winds during the autumn and winter, and fog during the summer. Blowing snow occurs frequently during winter months. This restriction to visibility may be deceptive to the inexperienced pilot, because the shallowness of the layer of blowing snow usually permits good vertical visibility at the same time that the horizontal visibility is very poor within the layer.

Along the Arctic coast during June, July, and August, fog occurs on an average of about 19 days each month. When the temperature is below freezing, the fog becomes a potential source of icing. Caution is required when operating an aircraft in fog when the temperature is between 30°F and −10°F.

Takeoffs should not be attempted when frost, ice, or snow is on the wings. Even a thin layer of snow may not blow off; and only a thin layer is necessary to cause loss of lift, hence influencing flight characteristics. When aircraft are left outside during the extreme cold, hoarfrost may form on the wings. This should always be removed before operating the aircraft.

In some ways, jet aircraft operations in the Arctic are simpler than conventional aircraft operations. Jet aircraft do not require a warm-up period after being exposed to the cold temperatures. Also, these aircraft do not require as long a runway in the Arctic as they do in more temperate climates. The length of runway needed for a jet takeoff varies considerably with air density. Cold dense air is present much of the time in Arctic areas, and cold dense air decreases the runway necessary for takeoff.

High Altitude Weather

As man flies higher and higher, he encounters atmospheric phenomena which he must explore and understand in order to conduct flights safely at these altitudes. The aircrews of the present day are confronted with such high troposphere and lower stratosphere weather phenomena as: the *tropopause*, the *jet stream*, *clear-air turbulence*, *contrails*, *haze layers*, and *canopy static*. In this chapter, we will discuss some of the physical characteristics of these high altitude phenomena.

THE TROPOPAUSE

The tropopause, the boundary between the troposphere and the stratosphere, is relatively high over the tropics (tropical tropopause) and relatively low over the poles (polar tropopause). Average heights for the tropopause might be 50,000 to 60,000 feet in the tropics, descending to 25,000 to 30,000 feet in the polar regions. However, there is generally a break in the tropopause in mid-latitudes, the polar tropopause ending and a higher tropical tropopause beginning; the two may overlap for some distance.

Perhaps the most important aspect of the tropopause to aircrews is its association with the jet stream, more particularly the *polar-front jet stream*. This jet stream is usually found in the regions of the break in the tropopause mentioned previously. It is located in the troposphere under the tropical tropopause, and just above the southern end of the polar tropopause, as shown in the related sketch.

NOTE

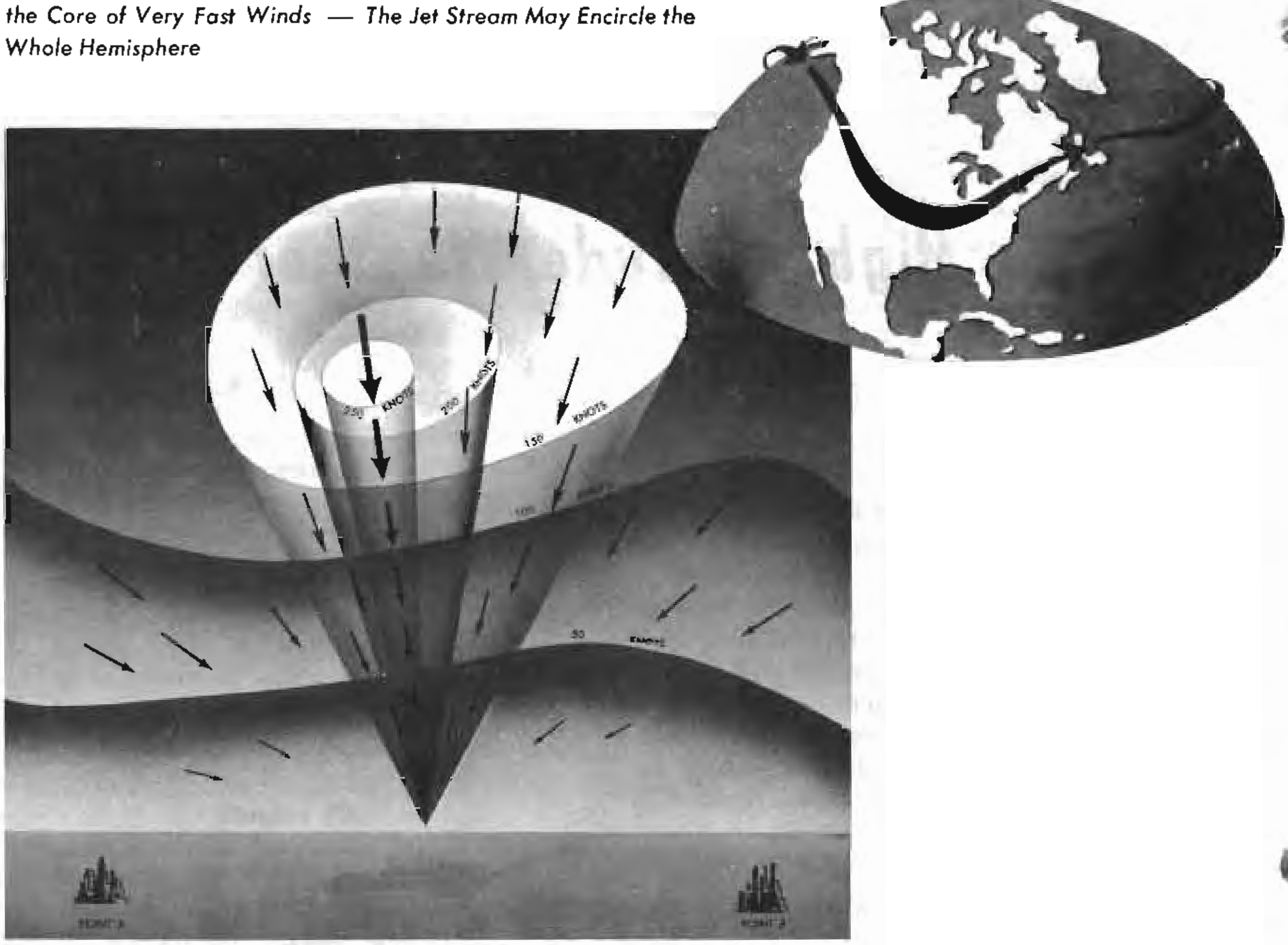
The tropopause is often a region of turbulence, due to the marked variations in vertical motions which occur in, at, or below the tropopause. The tropopause is often devoid of clouds, so that turbulence encountered at the tropopause will frequently be classified as clear-air turbulence.

JET STREAM

During World War II, bomber crews flying B-29's in the Pacific often encountered strong winds aloft over Japan. As reports of unusually high winds aloft became more and more frequent, investigations were initiated. These investigations uncovered an important weather phenomenon known today as a *jet stream*. Although several individual jet streams are listed, the one of most concern to the United States and the one we will treat here, is called the *polar-front jet stream*.

Jet streams are arbitrarily defined as narrow bands of high-velocity winds, above 50 knots, that are usually embedded in the prevailing wind circulation — in the case of the polar-front jet stream, the *prevailing westerlies*. The axis of the high velocities must generally have a length of approximately 300 nautical miles to be considered as a jet stream. Actually, there is not a band or tube which has an identifiable boundary, but the winds build up slowly from the peripheral regions to reach a maximum at the center (*core*) of the

Figure 15–1. Schematic Cross Section of a Jet Stream, Showing the Core of Very Fast Winds — The Jet Stream May Encircle the Whole Hemisphere



jet stream. Often the periphery of the jet stream is arbitrarily defined as the place where the wind speed is equal to one-half that of the core. The jet stream appears to have a life cycle of formation, intensification, movement, and dissipation related to the polar front. This wave-like meandering river of winds may be continuous around the hemisphere, but more often it is broken up into several discontinuous segments. The orientation, location, zones of maximum wind, and thickness of the jet core generally vary with latitude, longitude, altitude, and time.

Causes of the Jet Stream

The exact mechanism which maintains the jet stream is not as yet completely understood. The polar-front jet stream may often be associated with an outbreak of cold, polar air into the middle latitudes. The southward moving cold air causes a decrease in the altitude of the polar tropopause, which accentuates the slope of the mid-latitude tropopause to the point where a wide break occurs. Notice in the diagram Figure 15–2 that a large break occurs in the tropopause after the polar front has reached the mid-latitudes, allowing us to clearly distinguish the polar and tropical tropopauses.

Since the wind blows as a result of the forces acting upon it, it would lead us to believe that something must cause the forces to increase in magnitude, resulting in jet stream velocities, and that this increase is related to the movement and position of the polar front.

Perhaps the initial force acting to make the wind blow is the pressure-gradient force which, by definition, is directed from high pressure

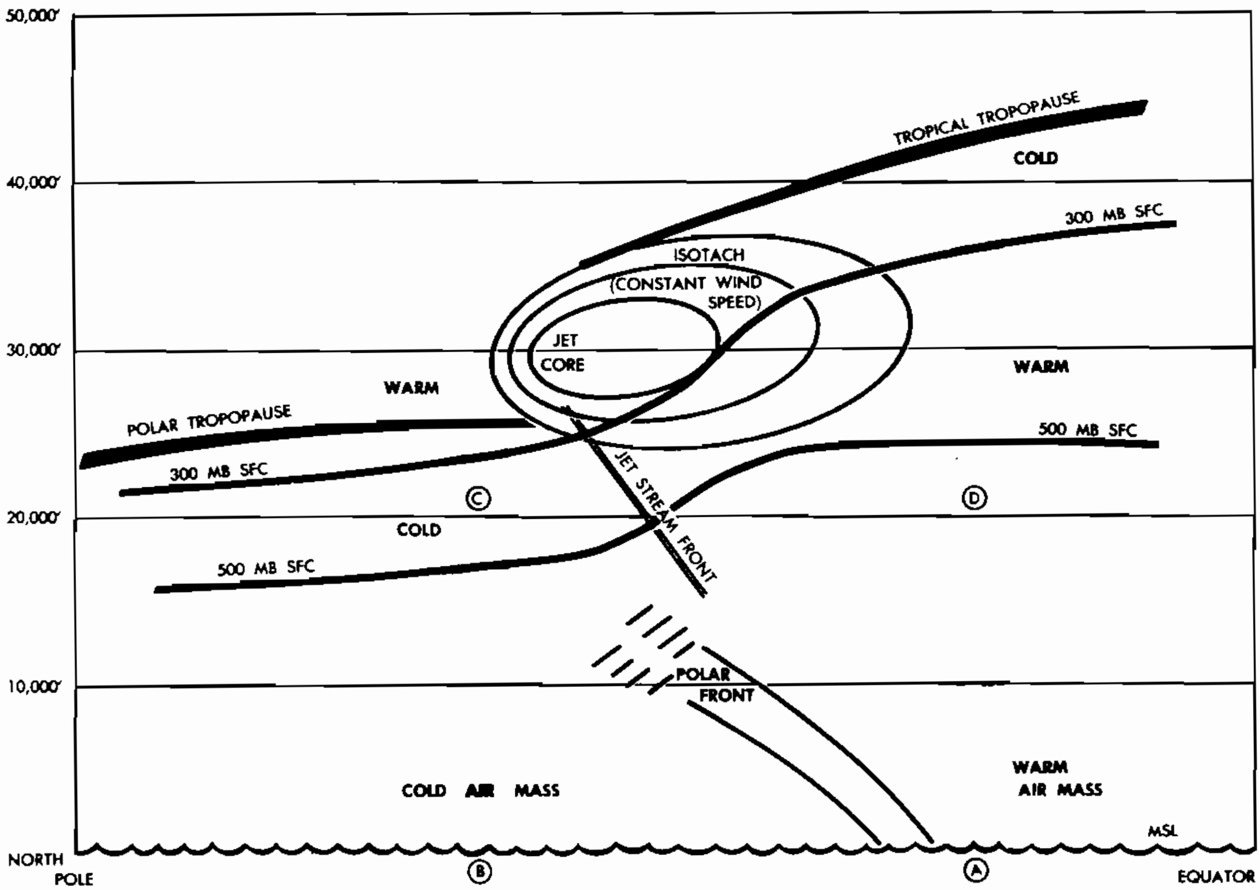


Figure 15–2. Diagram Showing Strong Horizontal Temperature Gradients Associated with a Jet Stream (Vertical Scale Exaggerated)

toward lower pressure. Let us consider, here, the pressure-gradient only in a horizontal plane. Notice again in the diagram that after the cold polar air mass has moved far enough south to have passed through column B, but not far enough to have passed through column A, that the pressure difference (pressure-gradient) between points D and C will be increased. That is, the mean temperature of column B is now colder than it was previously; the pressure surfaces will be more closely packed and at a lower altitude than previously, resulting in a decrease of pressure at point C.

Since the pressure at point D remains unchanged, and the pressure at point C has been decreased by the polar air mass, the pressure-gradient force has been increased (directed from D to C) which, in turn, results in an acceleration of the wind. Remember from Chapter 6, that the wind is inaugurated by the pressure-gradient force and given direction by the coriolis force. Since the westerly winds are already established before the polar outbreak occurs (a west wind would blow into the page in the diagram), the routine just discussed would increase the already-existing westerly winds to the velocities common to the polar jet stream, that is, as high as 150 knots (on rare occasions to as high as nearly 300 knots).

Observations in the vicinity of the jet stream have recently shown the occasional existence aloft, beneath the core itself, of a line of temperature change or demarcation which can be given the name *jet stream front*; however, it is found only with very intensely developed polar-front jet streams. Notice that the highest winds — the core — are found about 5,000 feet below the tropical tropopause and near

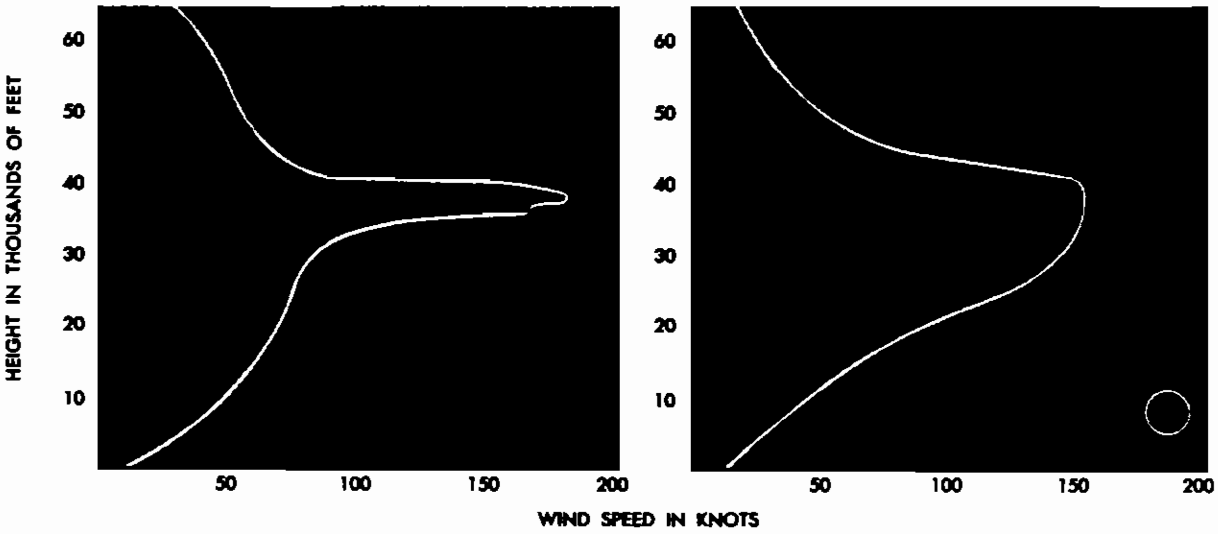
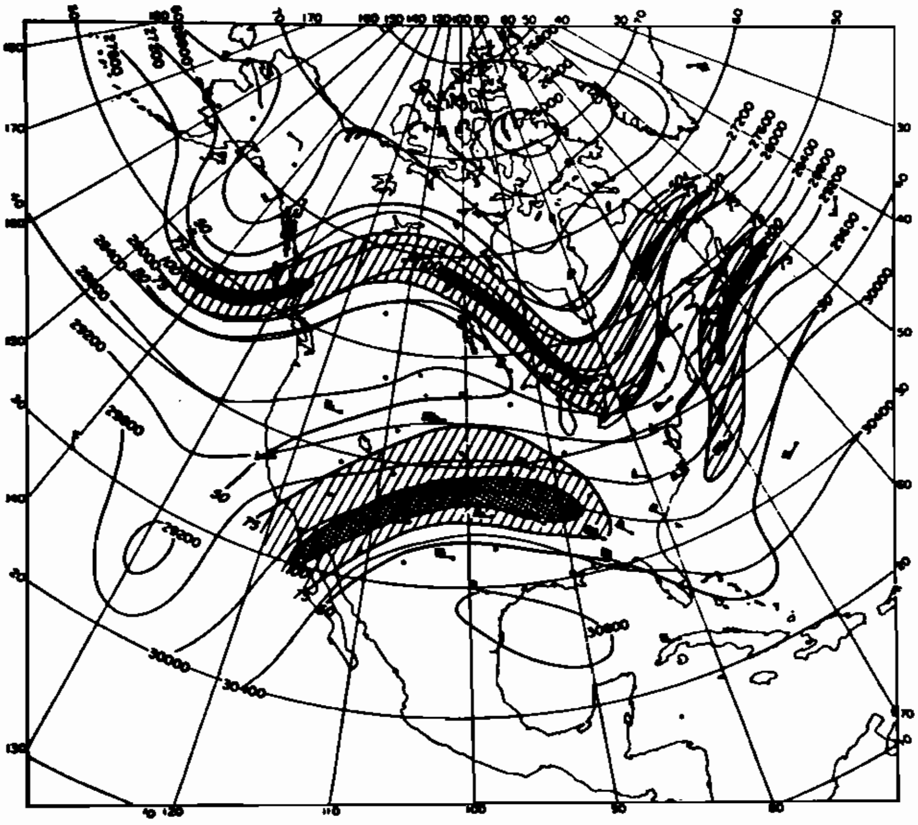


Figure 15–3. Vertical Profiles of Wind Speed (Type B is Perhaps Most Common)

the end of the polar tropopause, and that the rate of decrease of wind speed is considerably greater on the polar side of the core as contrasted to the equatorial side, that is, the magnitude of the wind shear is greater on the polar side than on the equatorial side.

Figure 15–4. Example of the Multiple Structure of a Jet Stream (The Dark-Shaded Areas are Areas of Highest Winds)



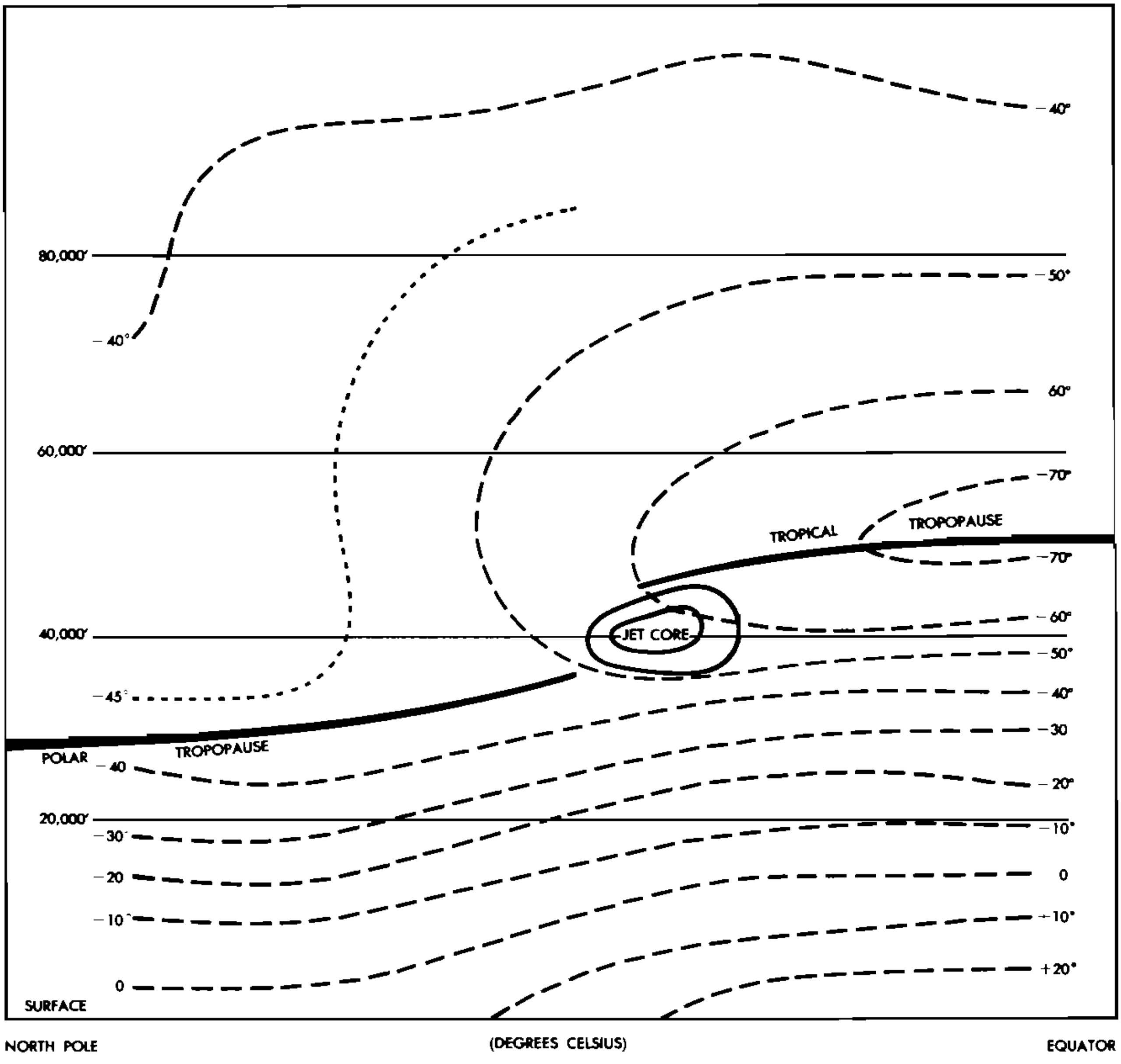
If the jet stream is defined as the band of winds where the periphery speed is equal to one-half that of the core, over-all dimensions for it might be 20,000 to 25,000 feet in depth, 100 to 300 miles in width, and 300 to several thousand miles in length. Notice the two different types of profiles in the associated sketch, showing wind speeds at various altitudes, and that jet streams may differ considerably in vertical distribution of wind speed.

Other Jet Stream Characteristics

When the jet stream is associated with a polar front, the jet is located in the warm air, either in or along the southern edge of the maximum temperature gradient between the polar and tropical air masses. Near the level of the jet core and below, temperatures are lower toward the polar side. At the level of the jet core the horizontal temperature change is essentially zero. At higher altitudes than the jet core the temperature is often lower on the tropical side.

As previously mentioned, the jet stream may be a continuous band around the hemisphere, but more often it is broken into a series of well-defined and disconnected segments, which undulate north and south as well

Figure 15–5. Temperature Distribution Around a Jet Stream (Mean July Temperatures used for Illustration)



as vertically. There may be two or more jet streams in existence at the same time. For example, one may find a jet stream along the northern portion of the United States and another well-defined stream across the southern states (subtropical jet).

In middle and high latitudes the strength of the jet streams is greater in the winter than in the summer. The mean position of the jet stream shifts south in winter and north in summer with the seasonal migration of the polar front. In the winter jet streams are often found as far south as 20°N. The core of strongest winds in the jet stream is generally found between 25,000 and 40,000 feet, depending on latitude and season.

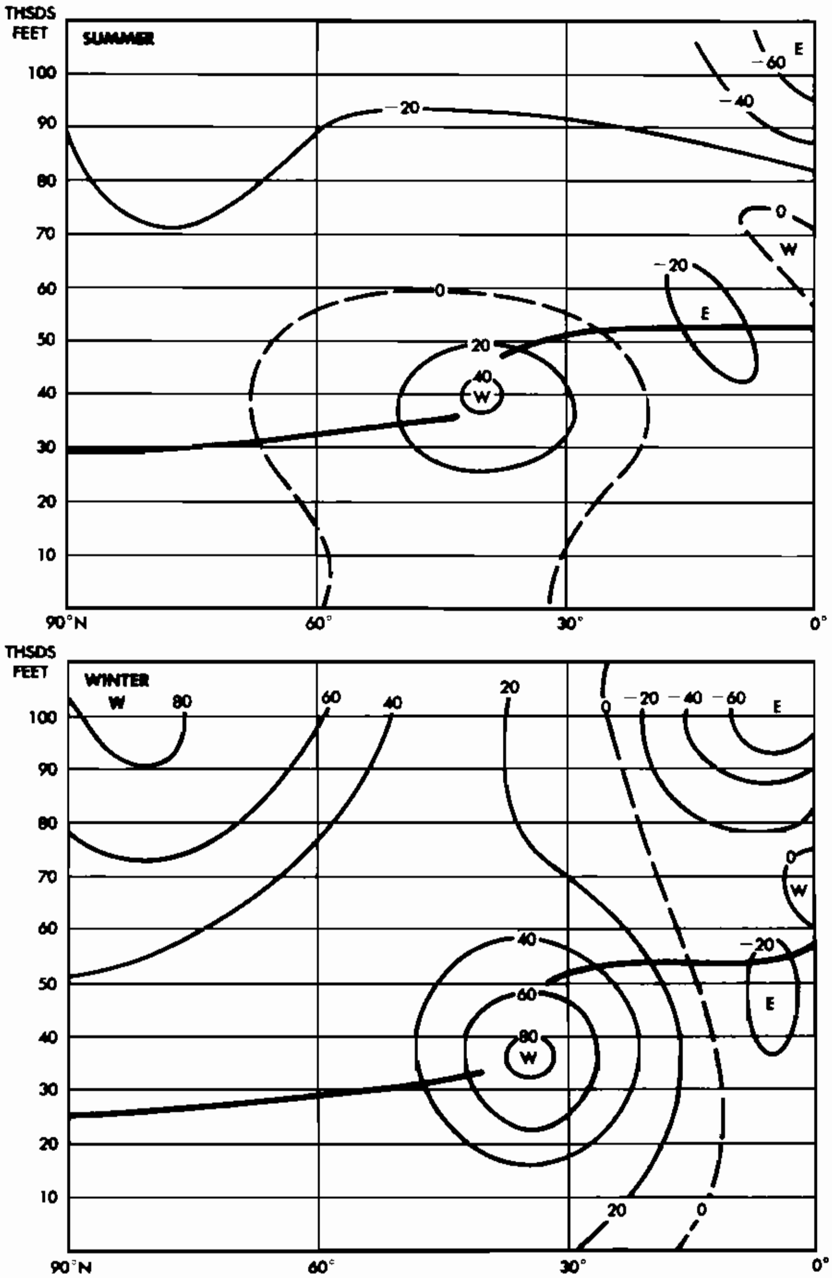


Figure 15–6. Ideal Wind Distribution and Tropopause for Summer and Winter. East Winds are Represented by Negative Numbers. West Winds are Positive Numbers. Wind Speeds are in Knots. Note: Jet Core is Lower in Winter

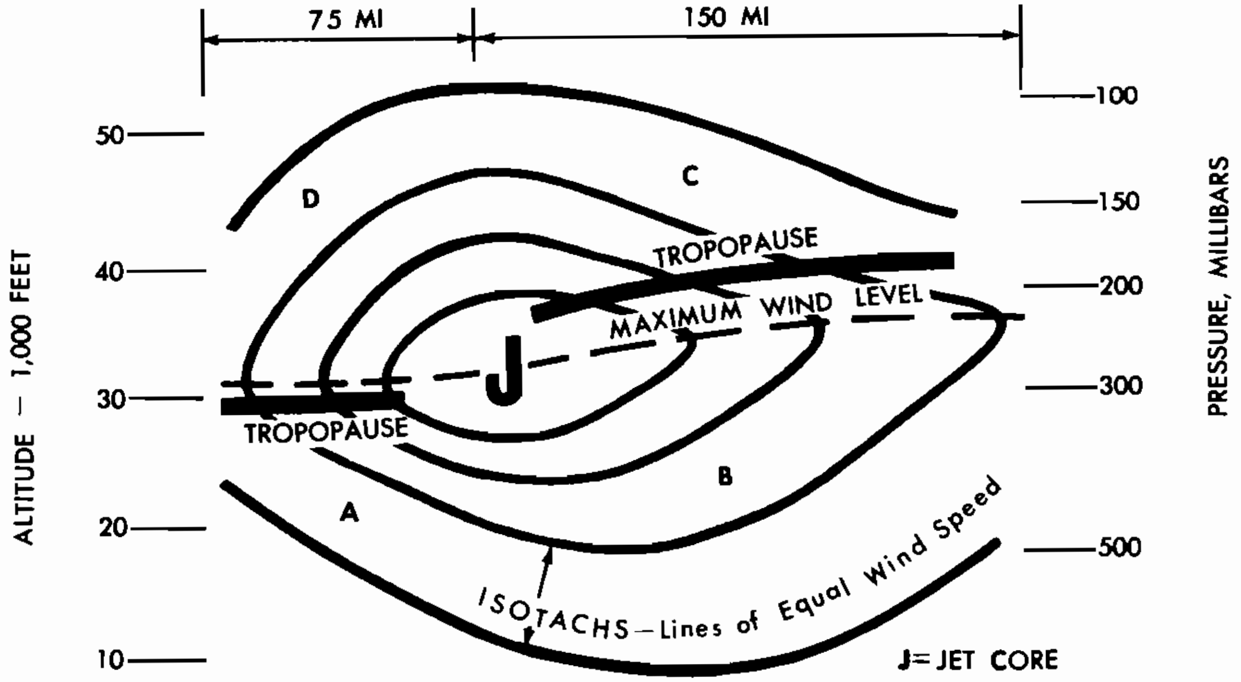


Figure 15–7. Jet Stream Turbulence (Looking Down Stream)

In the vicinity of the jet stream, cloud formations sometimes can give valuable information relative to its position and direction of flow. The sky is usually clear at the jet stream core level, but many times there is considerable cloudiness below. Cloud formations that do occur in the area of strong winds will usually be drawn out in longitudinal streaks in line with the wind direction.

CLEAR-AIR TURBULENCE

Clear-air turbulence (CAT) is a term commonly used to denote the rough, cobblestone-like bumpiness which is sometimes experienced while flying at high levels (above 15,000 feet) but which is not associated with convective activity—thermal or frontal (see Chapter 10). Although this turbulence sometimes occurs in cirrus clouds and/or haze layers not associated with thunderstorms, we use the term "clear-air turbulence" because almost 75 percent is not associated with clouds. This bumpiness, which has a maximum occurrence near 30,000 feet, can be of sufficient intensity to cause serious stresses on the aircraft and physical discomfort to its occupants, especially since the rough air occurs without any visual warnings.

Even though the high-level turbulence associated with a mountain wave (see Chapter 10) is usually considered clear-air turbulence, in this section we are considering "shear turbulence." The occurrence of clear-air turbulence is often associated with strong shears caused by marked changes in wind speed and/or direction with height (vertical wind shear) and/or in the horizontal (horizontal wind shear). These conditions most often occur near the maximum wind speed centers that move along the jet stream. The occurrence and intensity of CAT, therefore, is not constant along the entire course of a jet stream.

There is evidence that the maximum occurrence of the most intense clear-air turbulence in the vicinity of the polar-front jet streams is on the cold air (polar) side and below the jet-core level (quadrant A). Refer to Figures 15–7 and 15–8. The minimum occurrence is below and to the anticyclonic (warm air) side of the polar-jet core (quadrant B). About the level of

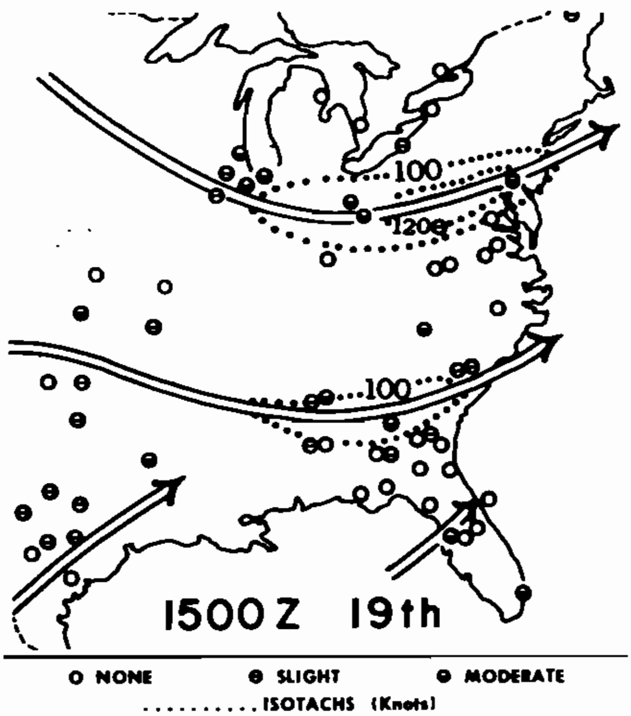


Figure 15–8. Distribution of Aircraft Reports of Clear Air Turbulence at 30,000 Ft. Along with the Main Jet Streams and Central Isotach Analyses from the Corresponding 300 MB Chart for 19 March 1953

the polar-jet core, CAT is believed to be more intense and frequent on the anticyclonic side (quadrant C) than on the cyclonic side (quadrant D).

The occurrence of CAT can extend to very high levels and can be associated with other wind-flow patterns which produce the necessary shears. A sharp trough aloft, especially one moving at a speed greater than 20 knots, can have clear-air turbulence in or near the trough, even though the wind speeds can be rather low as compared with the speeds near the jet stream. However, the winds on opposite sides of the trough can have a difference of 90 degrees or more in direction (see Figure 15–9. CAT can occur in the circulation around a closed low aloft, particularly if the flow is merging or splitting (see Figure 15–10), and to the northeast of a cut-off low aloft (see Figure 15–11).

High-level, clear-air turbulence is generally patchy. CAT patches have variable dimensions and have been known to be as much as 10,000 feet thick, 500 miles wide, and 1,000 miles long.

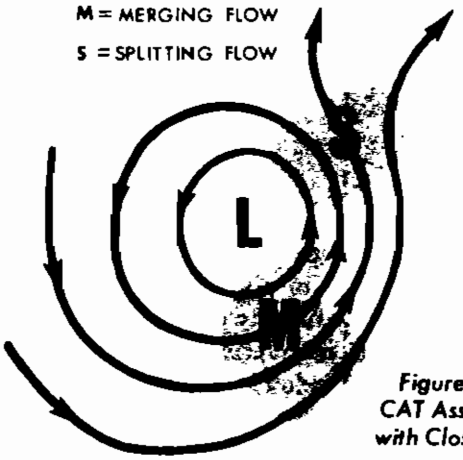


Figure 15–10. CAT Associated with Closed Low

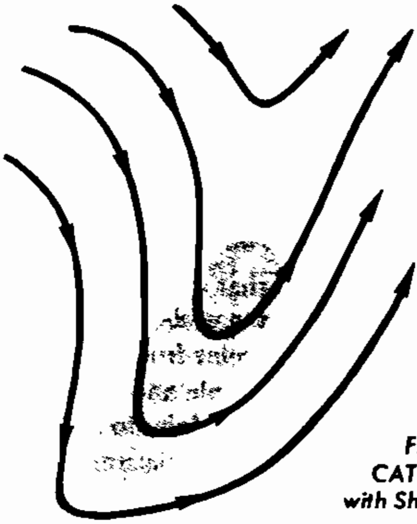


Figure 15–9. CAT Associated with Sharp Trough

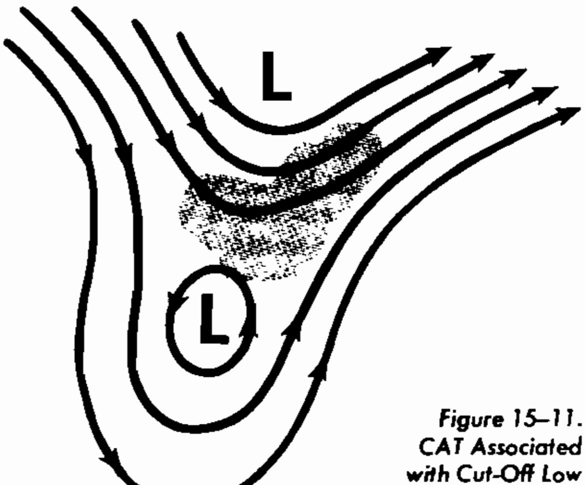


Figure 15–11. CAT Associated with Cut-Off Low

However, they average about 2,000 feet in depth, 20 miles in width, and 50 miles in length, elongated in the direction of the wind.

When anticipating or encountering CAT, attain the turbulent air penetration speed recommended in the flight manual for your aircraft. Ordinarily, this will reduce turbulence which is of moderate intensity to light or only perceptible intensity. However, if the intensity of the turbulence is such that further action is required, you may consider a climb or descent and/or *turning to either side to exit the turbulent zone, using information provided by the weather forecaster during preflight briefing or over pilot-to-forecaster facilities. In such situations, you should make very gradual climbs, descents, and turns.*

CONDENSATION TRAILS (CONTRAILS)

A *contrail* is generally defined as a cloud-like streamer often generated in the wake of aircraft flying in clear, cold, humid air. Two distinct types are observed; exhaust trails and aerodynamic trails. A third type, dissipation trail, will be mentioned.

Exhaust Contrails

This type of contrail is formed by the addition of sufficient water vapor to the atmosphere in the exhaust gases from an aircraft to result in saturation or supersaturation of the air. Heat is also added to the atmosphere in the wake of an aircraft, so the addition of water vapor must be of such magnitude as to saturate or supersaturate the atmosphere in spite of the added heat.

There is evidence to support the idea that necessary nuclei for condensation of sublimation may also be donated to the atmosphere in the exhaust gases of aircraft engines to aid the formation process. In fact, a recent concept used to prevent exhaust contrail formation is based on the idea of the addition of *nuclei material* (dust) to the air. Such condensation and sublimation onto many of these particles will result in more of the small particles which will not form visible cloud-like trails.

Aerodynamic Trails

In air that is clear and almost saturated, the aerodynamic pressure reduction that accompanies flow of air around propeller tips, wing tips, and the like, can cool the air enough to bring it to saturation and, hence, condensation. This type of trail is usually not as dense or as persistent as exhaust trails.

Dissipation Trail (Distrail)

This term applies to the rift in the clouds caused by the heat of the exhaust gases of an aircraft flying in a thin cloud layer. The exhaust gases so warm the air that the air is no longer saturated and the cloud is evaporated. The cloud must be thin and be relatively warm before a distrail will be observed; hence, distrails are not commonly seen.

HAZE LAYERS

In the upper troposphere there frequently exist haze layers which are not visible to ground observers, and do not appear to be as dense as ordinary cirrus clouds. Although the visibility above the haze is excellent, air-to-air and air-to-ground visibility in the haze layers are sometimes reduced to zero, depending on the position of the sun relative to the pilot. This high-level haze will not usually be present with a fresh polar outbreak, or if an air mass is moving. Generally, high-level haze will occur with stagnant air masses. Cirrus haze is common in the Arctic in winter and may extend from the ground to the tropopause.

CANOPY STATIC

Canopy static is the same as precipitation static encountered at lower levels. The solid particles which brush against the canopy or other *Plexiglas*-covered surfaces of aircraft during flight build up a static electric charge on the aircraft. When this static electricity is discharged onto a nearby surface or into the air, the accompanying noisy disturbance reduces radio reception. This charge and discharge of electricity can occur in rapid succession, and appear as an apparent continuous disturbance. The dust and ice crystals of cirrus clouds are primary producers of canopy static at high altitudes.

ICING CONDITIONS

Although not as common nor as extreme as at low altitudes, icing can occur in flight at high altitudes and should be avoided if possible. Ice can form very quickly on the airfoil and exposed parts of jet engines. Icing at high altitudes is associated with tops of cumulus buildups, anvils, and even some detached cirrus. Clouds over mountain areas are more apt to contain water and, hence, cause icing at high levels.

Structural icing at high altitudes is usually of the rime type, although clear ice is possible. Other than in thunderstorms, structural icing can usually be eliminated by changing altitude or varying course so as to avoid clouds.

If engine induction icing is encountered, immediate action should be taken to get the engine anti-icing system into operation; change altitude or vary course to avoid clouds; reduce airspeed when in icing areas; and reduce engine rpm, as necessary, to prevent any excessive tailpipe temperatures.

It is well to remember that present anti-icing systems are not always adequate protection from all meteorological conditions.

Weather Services and Facilities

There is a weather station at each United States Air Force air base. The function of the weather station is to make weather observations, to collect and distribute weather data and, probably most important from the aircrews' point of view, to make weather forecasts. A forecaster is normally on duty during operational hours to provide aircrews with weather information pertinent to their missions and flights.

Some weather stations have forecasters on duty 24 hours a day, while other stations have no forecasters on duty at night or on weekends where there is little or no requirement for forecasting duty. During these times, consult the USAF/USN Flight Information Publication En route-Supplement U.S. for methods to obtain weather information. The Air Weather Service (AWS) has a few weather stations at locations with no airfield facilities. These stations usually do not make weather observations, but are operated to provide specialized forecasting service.

In order to help you understand and take full advantage of the services available at weather stations, the services and facilities which support weather station operations will be covered briefly in this chapter.

SOURCES OF WEATHER DATA

The Air Weather Service (AWS) must have access to surface and upper air weather data from all regions of the world in order to provide our global Air Force with a world-wide forecasting service. The mass of weather data must be furnished at regular and frequent intervals from thousands of observing stations. Since the Air Weather Service has comparatively few weather stations, it depends on the civilian weather services of the United States, Canada, and Mexico for weather data concerning North America. The United States Navy and United States Coast Guard, in addition to their oceanic coverage, operate a few land weather stations which provide weather data. Ships of most nations and foreign weather services furnish the remainder of the data necessary to fill in the global picture.

The Air Weather Service also operates a number of aerial weather reconnaissance squadrons. Scheduled weather reconnaissance flights with trained weathermen aboard are made along fixed routes over relatively inaccessible land and water areas. Weather reconnaissance units also fly *hurricane hunter* missions in which they locate, penetrate, and track hurricanes or typhoons of the Atlantic and Pacific Oceans.

Last, but by no means of least importance, the Air Weather Service depends on weather reports from civilian and military pilots to supplement its other sources. Pilots can help themselves to a great degree by making accurate and timely reports of weather conditions encountered in flight, especially turbulence, icing, and so forth, because there is no way to measure or observe these elements, and it is extremely difficult for forecasters to forecast the intensity of these unobserved elements. Remember that weather stations are widely scattered, and in some cases hundreds of miles apart. Therefore, you should assist the forecasters by making in-flight weather reports as well as face-to-face reports to the forecaster upon landing.

THE COMMUNICATION OF WEATHER DATA

In order to insure a rapid and dependable means of continuously exchanging weather data, the Air Weather Service depends on landline (wire) and radio communications systems. The Air Force Communications Service (AFCS) maintains a world-wide communication service capable of handling a large volume of traffic for the United States Air Force. A lot of its effort is devoted to weather traffic. In the United States, leased civilian landlines are used in the teletype and facsimile circuits. Overseas communication is primarily in the form of radio teletype, and radio facsimile.

Teletype Services

Weather observations and analyzed weather data are transposed into standard codes which consist of numbers and/or symbols. These are then transmitted from the various points of observation or analysis to other weather stations, relay points, and collection agencies.

In the United States, weather data are initially transmitted on one of several weather-only teletype circuits. Weather Bureau observations are transmitted on circuits operated for them by the Federal Aviation Agency (FAA). Air Force observations are transmitted on AFCS circuits. Most data are relayed to neighboring circuits; there is also some exchange of data between the FAA and AFCS networks. All Air Force weather stations in the United States have teletype terminations on two AFCS circuits and on at least one of the FAA circuits.

Facsimile Services

The facsimile service utilizes equipment similar to that by which newspapers and press associations transmit pictures. Base weather stations receive much of the necessary weather data in the form of analyzed and forecast (prognostic) weather charts by facsimile. The facsimile network enables the weather services to centralize their analysis and general forecasting functions.

Skilled analysts are concentrated at central points where the great mass of weather data can be assembled and analyzed in detail. Forecast charts depicting the weather patterns expected to exist eighteen or more hours in the future are also prepared at these centers. Forecasters at field (base) weather stations can thus devote more time to their special job of forecasting for local operations. This centralized forecasting system enables the weather service to utilize more data, save on personnel, avoid overtaxing communications systems, and concentrate specialists where they can be best utilized.

Forecasting Facilities

The Air Weather Service centralizes its analysis and general forecasting facilities in large weather stations called *Weather Centrals* and *Forecast Centers*. In addition, the United States Weather Bureau operates an analysis and forecasting center called the *National Meteorological Center*.

National Meteorological Center

The National Meteorological Center (NMC), located near Washington, D.C., prepares analyses and prognoses (forecasts) for the entire Northern Hemisphere. Analysis and prognostic charts for surface and standard upper levels in the atmosphere are transmitted to all continental U.S. stations, both civil and military, via facsimile network and teletype bulletins.

The Analysis and Forecast Branch of NMC, formerly known as the National Weather Analysis Center (NAWAC), prepares the bulk of analyses and prognoses transmitted to the field. This branch also includes the analysis section of the Numerical Weather Prediction function.

The A and FB produces most of the analyses manually, while the prognoses for several pressure levels aloft are products of a high-speed electronic computer. Computer analyses even now are integrated into the manually prepared analyses and eventually the existing manual effort will be changed to electronic computer product.

Another section of the NMC is the Extended Forecast Branch, which prepares extended period forecasts and outlooks for intervals of from five to thirty days into the future.

Weather Centrals

These are very large Air Weather Service weather stations equipped and staffed to analyze weather data, and prepare forecasts on a world-wide basis in support of the global operation of the United States Air Force. Each Central analyzes weather data for the entire Northern Hemisphere, usually by supplementing and applying NMC products to military operations. In addition to the preparation of analyzed and forecast charts for the Northern Hemisphere, Weather Centrals prepare and disseminate operational and planning forecasts in support of strategic, tactical, and air defense operations. They also prepare and disseminate climatic studies as well as special meteorological studies and investigations for the Armed Forces.

Forecast Centers

Forecast Centers are large weather stations similar in some respects to Weather Centrals, but with a smaller area of responsibility. They supplement NMC and Weather Central products usually in support of a specific military operation. They prepare current and forecast charts for certain geographical areas in support of operational units within that area. Area Forecast Centers prepare and disseminate climatic studies when needed, as well as operational and planning forecasts.

Field forecasters forward all requests for operational or planning forecasts which are beyond their capabilities to Weather Centrals or Forecast Centers. Since it takes a considerable amount of time and planning to prepare nonroutine forecasts, they should be requested as early as possible. It is important that the requesting agency give the local forecaster all pertinent information so that additional time will not be consumed in the exchange of clarifying messages between the Forecast Center and the local station.

Terminal Forecast Facilities (TFF)

These Air Weather Service Centers make 24-hour terminal forecasts for all bases in their area of responsibility. This relieves the base forecaster to perform his many other duties, such as briefing aircrews, taking radar reports, and so forth.

Severe Weather Warning Facility

The Severe Local Storms (SELS) Unit, USWB, at Kansas City, issues severe weather forecasts related to thunderstorms. Similar severe weather warning services are provided by Air Weather Service overseas centers. These units prepare and issue severe weather advisories to Air Weather Service weather stations in the United States and overseas. The advisories give the time and geographical location of the areas for which one or more of the following elements are forecast:

- Tornadoes.
- Severe thunderstorms accompanied by wind gusts of 50 knots or more.
- 3/4 Hail, both at the surface and aloft, including estimated size.
- Areas of severe and/or extreme turbulence aloft.

The severe weather advisory is studied, supplemented and, if necessary, amended by the local forecaster to formulate a local forecast. This forecast is then disseminated to aircrews and local military using agencies.

HURRICANE WARNING SERVICE

The National Hurricane Center located at Miami, Florida, supervises and coordinates all efforts concerning hurricanes which may affect the southern and eastern portion of the United States. Aircraft of Air Weather Service reconnaissance squadrons and the United States Navy locate, track and penetrate hurricanes.

These *hurricane hunters* relay information to the Hurricane Warning Center for analysis and use in forecasts and bulletins. The following Weather Bureau stations serve as subcenters during the hurricane season: New Orleans, La., Washington, D. C., Boston, Mass., and San Juan, Puerto Rico. The United States Weather Bureau station at San Francisco, California, coordinates all efforts concerning hurricanes affecting the west coast of the United States.

Air Force advisories and bulletins are transmitted via AFCS teletype circuits to Air Force weather stations which in turn advise local Air Force and Army agencies. The United States Weather Bureau issues bulletins and advisories to the public and civilian agencies through the press, radio, and television.

In the Pacific area and the Far East, reconnaissance aircraft and Forecast Centers at Hawaii, Guam, and Tokyo, Japan, perform a corresponding service concerning Pacific typhoons for the benefit of U.S. military installations in those areas. In the Atlantic-European area a Forecast Center at Torrejon, Spain, performs a corresponding service concerning hurricanes for the benefit of U.S. military installations in those areas.

CLIMATIC SERVICES

Long range planners must have intimate knowledge of the type of weather that can be expected during a planned operation or mission. Although day-by-day forecasts will be used when the operation is carried out they are, of course, nonexistent when the plans are being formulated weeks or months ahead of the target date. Climatic studies of past weather furnish an insight into tbe type of weather which may prevail during the pending operation.

In order to have the necessary data available from which to prepare climatic studies when they are needed, the Weather Bureau, Air Force, and Navy operate a National Weather Records Center at Asheville, N.C. There they collect, tabulate, and store weather data from all parts of the world. Weather data from all sources is punched on cards after receipt at the center and stored. The punch-card system enables the unit to use the IBM (International Business Machine) type of machines for high-speed calculations and tabulation.

Field Climatology Sections are found at Air Weather Service wing and group headquarters. Requests for climatic studies are forwarded to them by the local forecaster. If the requests are beyond their capabilities, they are forwarded to the Air Weather Service Climatic Center, USAF, Washington, D.C.

As with the nonroutine forecasts, requests for climatic service should be made as far in advance as possible. Remember, for best possible results furnish the local forecaster with all pertinent information, such as the nature of the mission, geographical area and time, operational limits, degree of flexibility permitted in accomplishing the objective, and recommended form of presentation. In other words, the local forecaster and military planner should agree on the specific type of information desired before the request is forwarded to the Climatic Center.

Weather Station Services and Facilities

The current and forecast surface and upper air charts transmitted from NMC, Weather Centrals and Forecast Centers are used by field forecasters to make local area and operational forecasts. At some weather stations, forecasters prepare additional current and forecast charts in order to satisfy the special requirements of local agencies and study the details of weather affecting their area. When conditions are such that an adequate facsimile network cannot be maintained, field forecasters prepare their own current and forecast charts from available weather data.

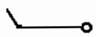
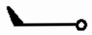
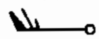
The phrase, *current weather charts*, refers to the latest surface and upper air analyses which are available in the station. It should be noted that these charts show the conditions which existed one or more hours before the time at which they are received and displayed in weather stations. This time lag is due primarily to the time consumed in collecting, plotting, and analyzing the data. It then takes approximately 12 to 25 minutes to transmit a chart by facsimile.

The weather data, charts, and other facilities available in weather stations will be treated in this chapter. The purpose of the discussion is to familiarize you with the tools and terms used by forecasters so that you may derive maximum benefit from weather briefings and be able to brief yourself when no forecaster is available.

SURFACE WEATHER CHARTS

The surface weather data which are observed and recorded almost simultaneously by weather stations throughout the world are collected and plotted on weather charts. When analyzed, these charts are called *surface synoptic charts* (surface weather maps). Surface synoptic charts are prepared and transmitted each three hours. From these charts, forecasters obtain a picture of the weather conditions which existed at the time the observations were made. Surface synoptic charts prepared by base weather stations look somewhat like the chart in Figure 17–1. An example of surface synoptic charts prepared by NMC and transmitted by facsimile is shown as Figure 17–2.

Symbols and numerals representing elements of the weather observed at a given station are grouped around a small circle printed on the map at the location of the station. This is known as the station circle. The station model, Figure 17–3, illustrates the specific positions in which the data are plotted around the station circle. The weather plotting symbols used are shown as Figure 17–4.

Wind direction is plotted to the nearest 10° on synoptic charts. The wind speed is plotted to the nearest 5 knots. A half barb () represents 5 knots, a full barb () 10 knots, and a pennant () 50 knots. The wind blows in a direction from the barb or pennant to the station circle. For example, a wind speed of 65 knots from 270° would be plotted as ().

The sea level pressure is plotted in tens, units, and tenths of millibars. The hundreds digits (usually a 9 or 10) are omitted. The

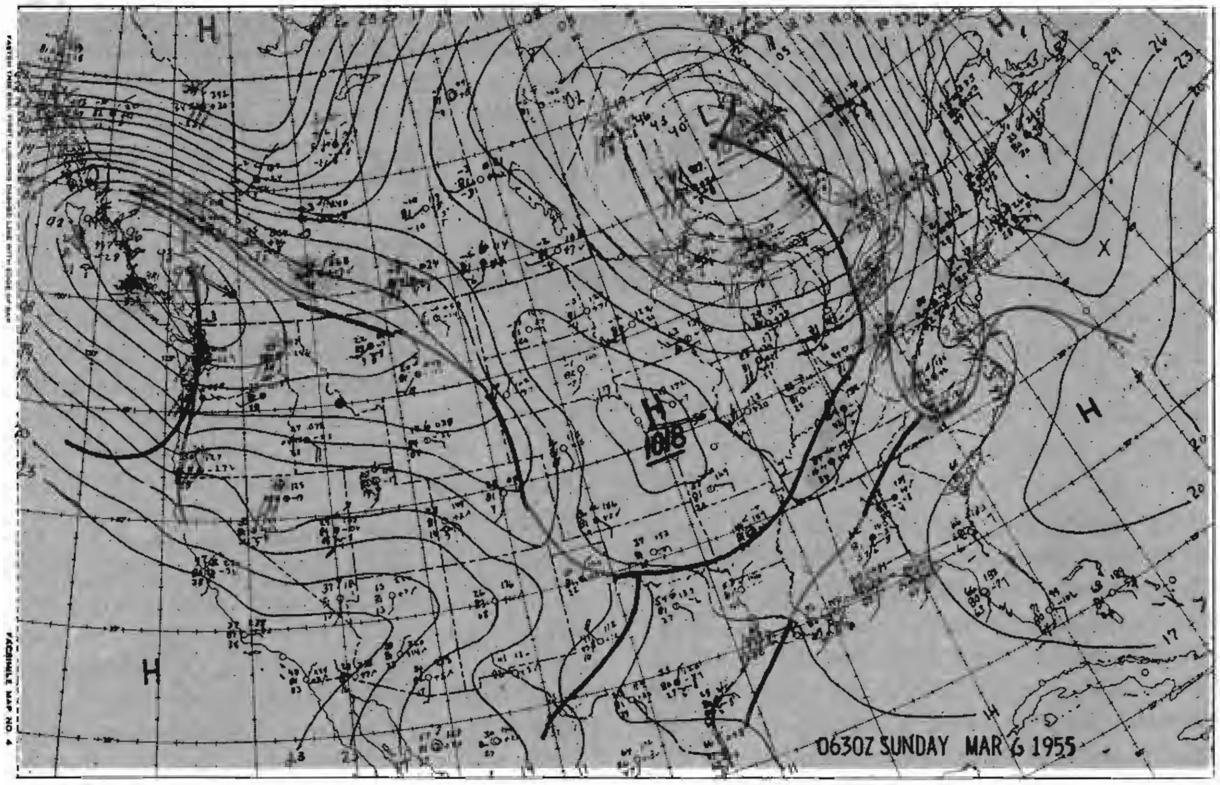


Figure 17–1. Surface Chart Prepared in Weather Station

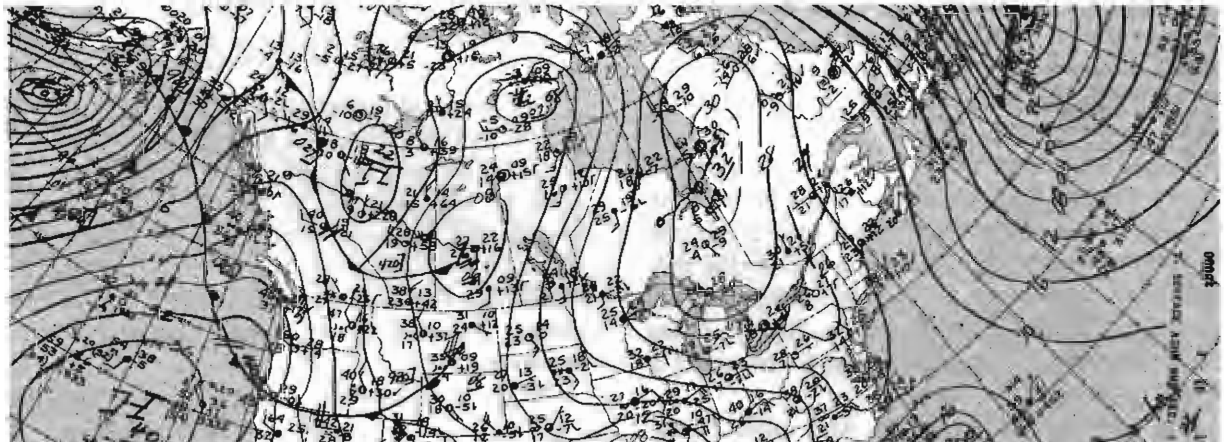


Figure 17–2. Surface Synoptic Chart Prepared by NMC

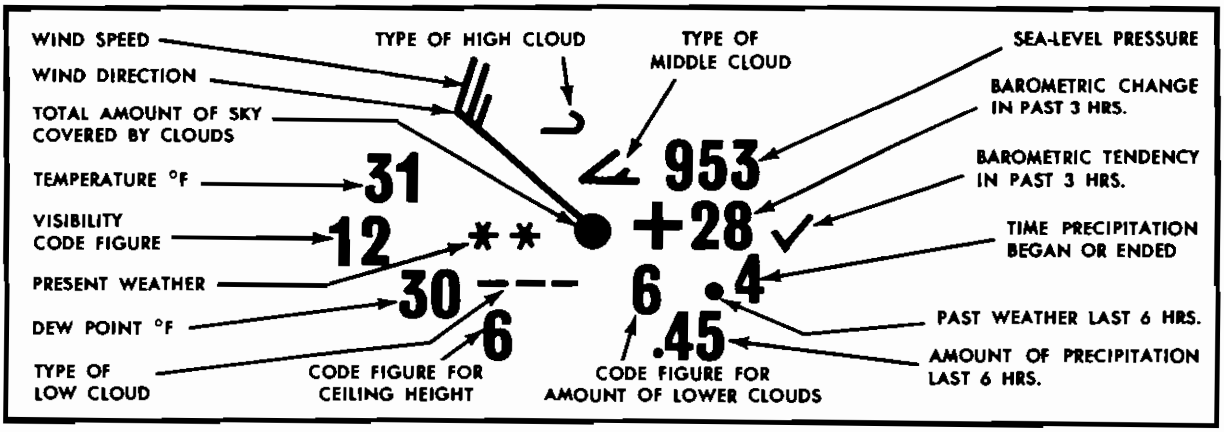


Figure 17–3. Plotted Data Around Station Circle on Surface Chart

plotted pressure value of 953 in the related illustration indicates a pressure of 995.3 millibars; similarly, 205 would indicate a pressure of 1020.5 millibars.

The station model, as illustrated, is used primarily by stations which prepare surface charts for their own use. When charts are prepared for facsimile transmission by NMC and Weather Central and Forecast Centers, only the most important weather elements are plotted, such as wind speed and direction, temperature, dew point, and existing weather. Most of the other elements are omitted in order to make the charts more legible.

The continuous dark lines on the synoptic charts are isobars. Only the tens and units digits are used to label the isobars (e.g., the 1020 isobar is labeled "20" and the 960 isobar is labeled "60"). Some of the isobars are more or less circular and inclose areas of high or low pressure. The centers of high pressure (highs) and low pressure (lows) are labeled with the capital letters "H" and "L" respectively. The values of the lowest and highest pressures in the centers are indicated. Although the wind flows slightly across the isobars (from higher to lower pressure) at the surface, isobars are good approximations of the direction of wind flow in the surface layer (lowest 2,000 feet) of the atmosphere.

On locally prepared charts, fronts are indicated and differentiated by color schemes. On facsimile charts, they are indicated by symbolized lines, which are usually colored after receipt at the local weather station. The color scheme and symbols used to indicate fronts are identified in Figure 17–5.

The following symbols and colors are used to indicate significant areas of weather on surface charts:

- Areas of continuous precipitation — *solid green shading*
- Areas of intermittent precipitation—*green hatching*
- Areas of fog—*solid yellow shading*
- Areas of blowing dust or sand—*solid brown shading*
- Drifting snow— *(Green)*
- Rain showers— *(Green)*
- Snow showers— *(Green)*
- Thunderstorms— *(Red)*
- Lightning— *(Red)*
- Hail— *(Red)*
- Sleet— *(Red)*
- Freezing Rain— *(Red)*
- Freezing Drizzle— *(Red)*
- Funnel clouds— *(Red)*

Note that *weather hazardous to flying is indicated in red symbols.*

In the illustration, Figure 17–6, you see a surface forecast (prognostic) chart which was prepared at NMC and transmitted by facsimile to the various weather stations. The expected position and orientation of fronts, pressure systems, and isobars 18 hours after the time of preparation are indicated on the

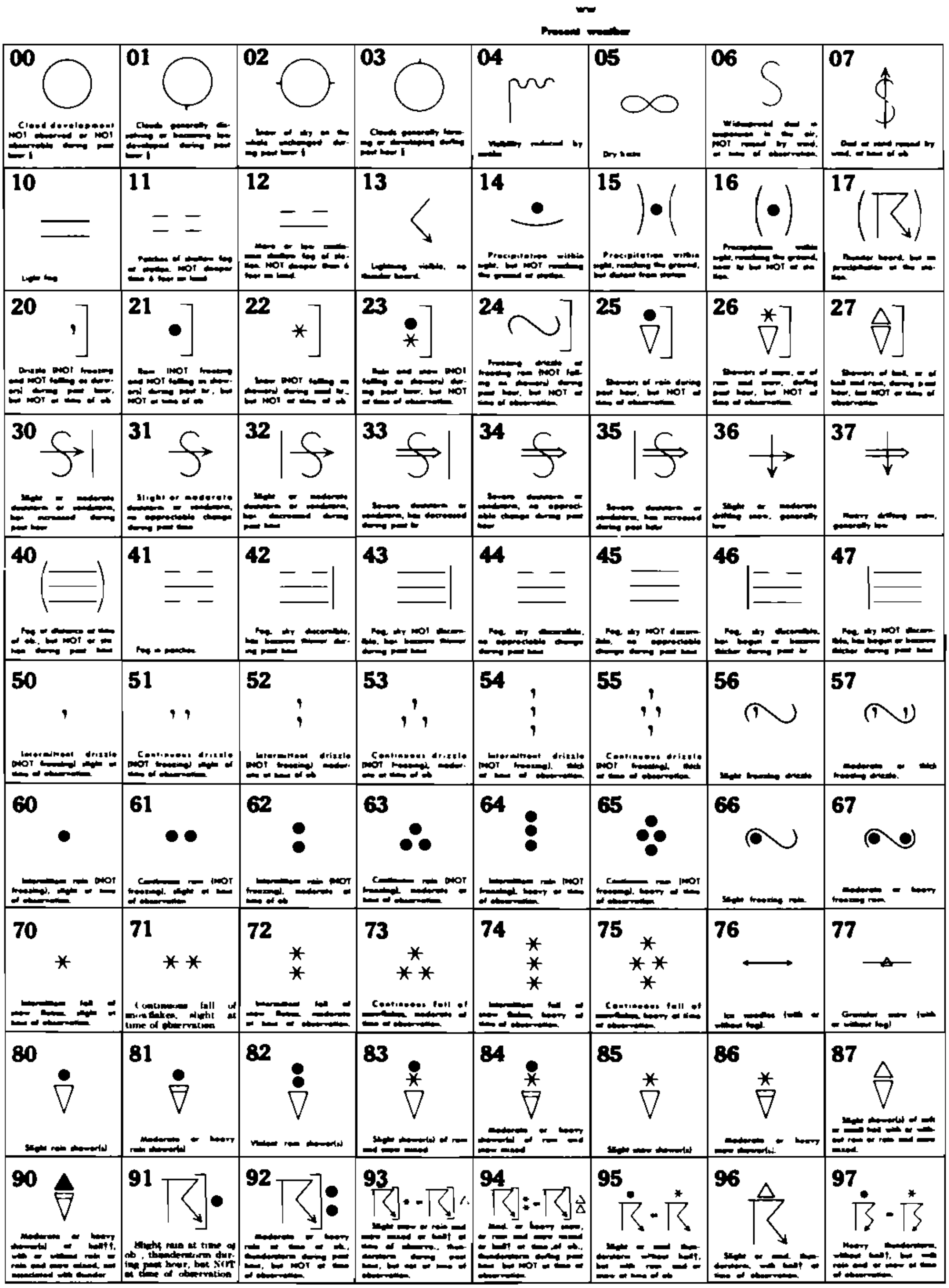


Figure 17–4a. Weather Plotting Symbols

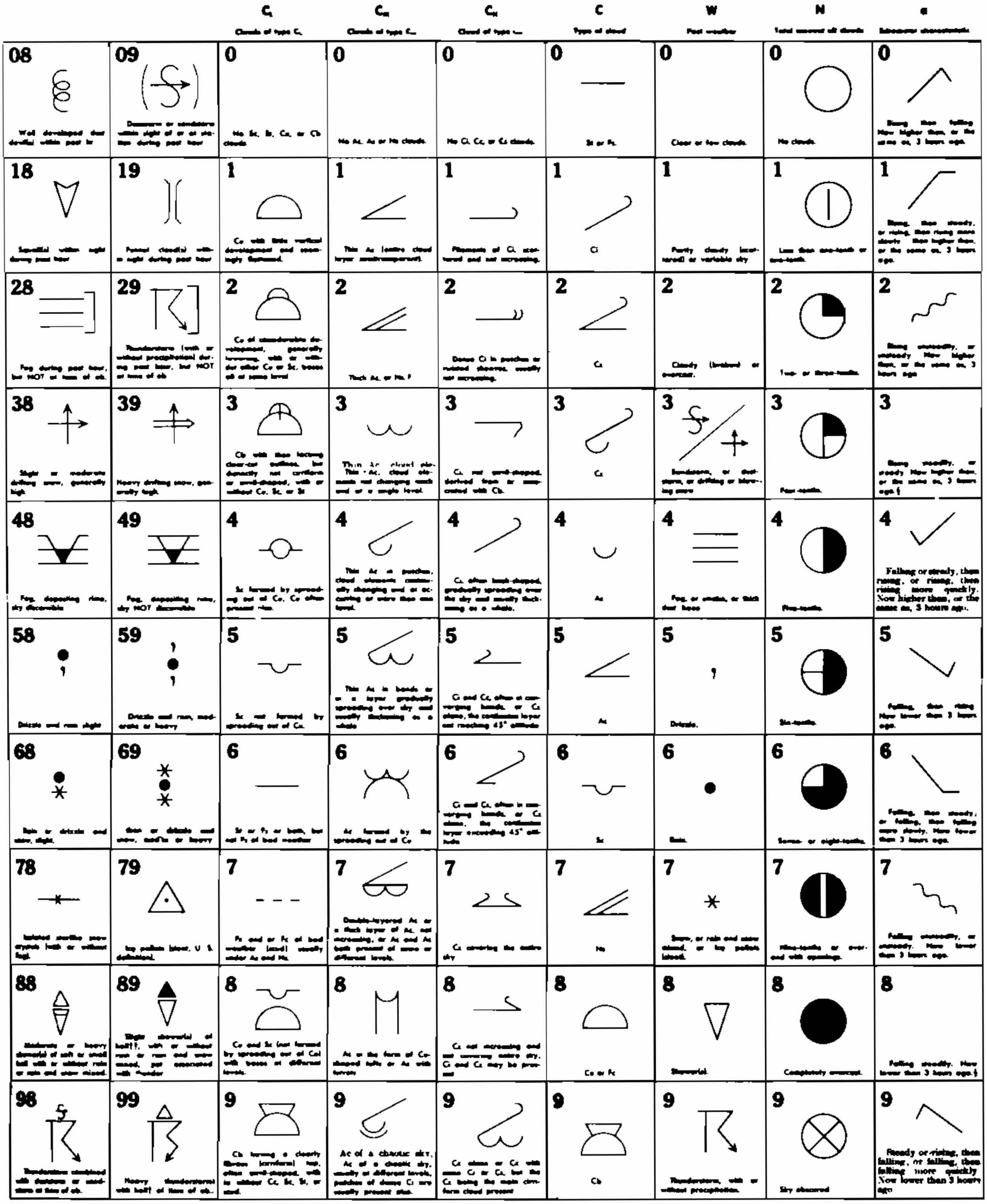


Figure 17–4b. Weather Plotting Symbols

COLOR SCHEME AND SYMBOLS FOR INDICATING FRONTS ON WEATHER MAPS

Type of Front	Color Scheme	Symbolized Lines
Cold Front	Blue	
Warm Front	Red	
Occluded Front	Purple	
Upper Cold Front	Blue	
Upper Warm Front	Red	
Stationary Front	Alternately Blue and Red	
Cold Frontogenesis	Blue	
Warm Frontogenesis	Red	
Cold Frontolysis	Blue	
Warm Frontolysis	Red	
Trough Line	Black	
Squall Line	Black	
Ridge Line	Brown	

Figure 17–5.

Figure 17–6. Surface Forecast (Prognostic) Chart

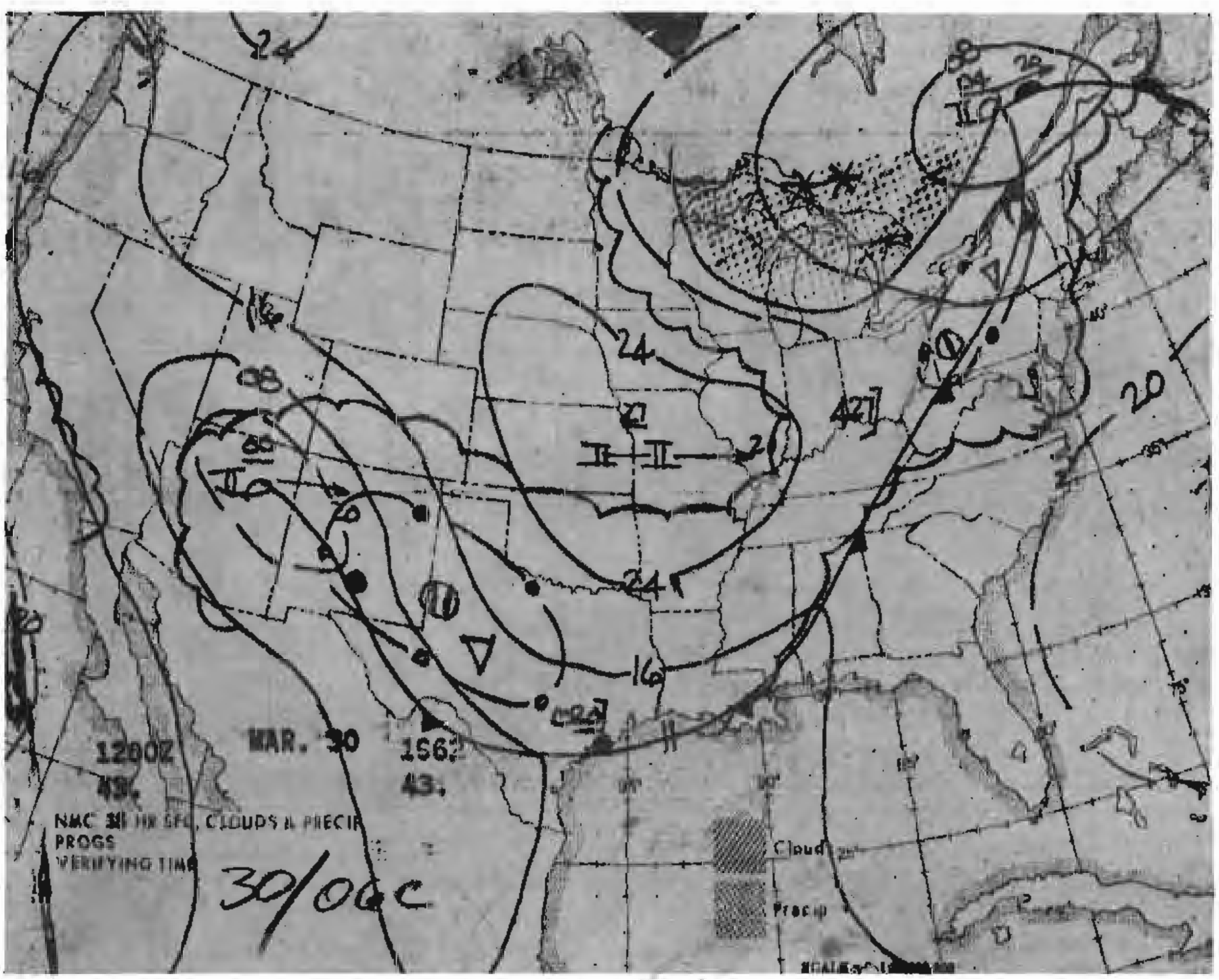


chart. After careful study of current and prognostic charts, the forecaster relies on his training, experience, and judgment to make local and operational forecasts.

CONSTANT PRESSURE CHARTS

The upper air data for selected *standard* pressure levels are plotted on charts and analyzed. These charts are called *constant pressure charts* since each represents a surface of constant pressure. The variation in height of these surfaces is shown by contour lines. Each chart shows the distribution of wind, temperature, and moisture at the time of the observation for a specific pressure level. Troughs, jet stream, and isotachs are also indicated on appropriate charts. The weather data used in the construction of constant pressure charts are obtained from *rawinsonde* observations.

The standard pressure levels for which constant pressure charts are constructed and their approximate altitudes are listed below.

Standard Pressure Level—Millibars (mb)	*Meters (MSL)*	*Approximate Height in Feet Above Mean Sea Level (MSL)*
1000	100	400
850	1,500	5,000
700	3,000	10,000
500	5,600	18,000
300	9,200	30,000
200	11,800	39,000
100	16,200	53,000
50	20,000	68,000

The constant pressure charts, together with surface synoptic charts and other charts and diagrams, present a three-dimensional picture of the atmosphere.

Beginning with the illustration, Figure 17–7, and continuing through Figure 17–11, are the 850, 700, 500, 300 and 200 mb constant pressure charts. These charts are prepared by NMC, Weather Centrals and Forecast Centers, and transmitted to the field via facsimile. The surface chart is illustrated in Figure 17–2. Surface synoptic charts are prepared from 0000Z, 0300Z, 0600Z, 0900Z, 1200Z, 1500Z, 1800Z and 2100Z observations, while upper air charts are prepared from 0000Z and 1200Z observations. (Z indicates Greenwich mean time.)

Figure 17–12 shows the plotting model used on upper air charts. The wind speeds and directions are plotted in the same manner as on surface charts with the following exceptions: (1) when the plotted wind is for the specified pressure level, the wind shaft is continued through the station circle and terminated as an arrow; (2) when the wind is for a level near the constant pressure level, the wind shaft is terminated at the station circle.

Heights are plotted in hundreds, tens, and units of meters on the 850-mb and 700-mb charts. For example, on the 850-mb chart "434" is a height of 1,434 meters; similarly, on the 700-mb chart "077" is a height of 3,077 meters. On the 500-mb, 300-mb, and 200-mb charts, heights are plotted in thousands, hundreds, and tens of meters. For example, on the 300-mb chart "929" is a height of 9,290 meters; on the 200-mb chart "197" is a height of 11,970 meters. Temperature and dew point are plotted to the nearest whole degree Celsius (centigrade).

The continuous dark lines on all constant pressure charts are contour (height) lines. These lines are labeled in thousands, hundreds, and tens of meters. For example, the 1,560-meter contour in the 850-mb chart is labeled 156, and the 11,880 meter contour on the 200-mb chart is labeled 188. Height lines are drawn for a 60-meter interval (about 200 feet) on 850-mb, 700-mb, and 500-mb charts; the interval is 120 meters (about 400 feet) on 300-mb and 200-mb charts.

Two general rules that can safely be used for flight planning purposes are: (1) the winds blow parallel to the contour lines with the low pressure to the left and the high pressure to the right; and (2) the speed of the wind is inversely proportional to the spacing of the contour lines (the closer the contour lines, the stronger the winds).

The *dashed lines are isotherms* (lines connecting points of equal temperature value). They are normally drawn for 5°C intervals. Isotherms are usually colored in *red* by personnel at field weather stations for easy identification.

Isotachs (lines connecting points of equal wind speeds) *are the dotted lines drawn on*

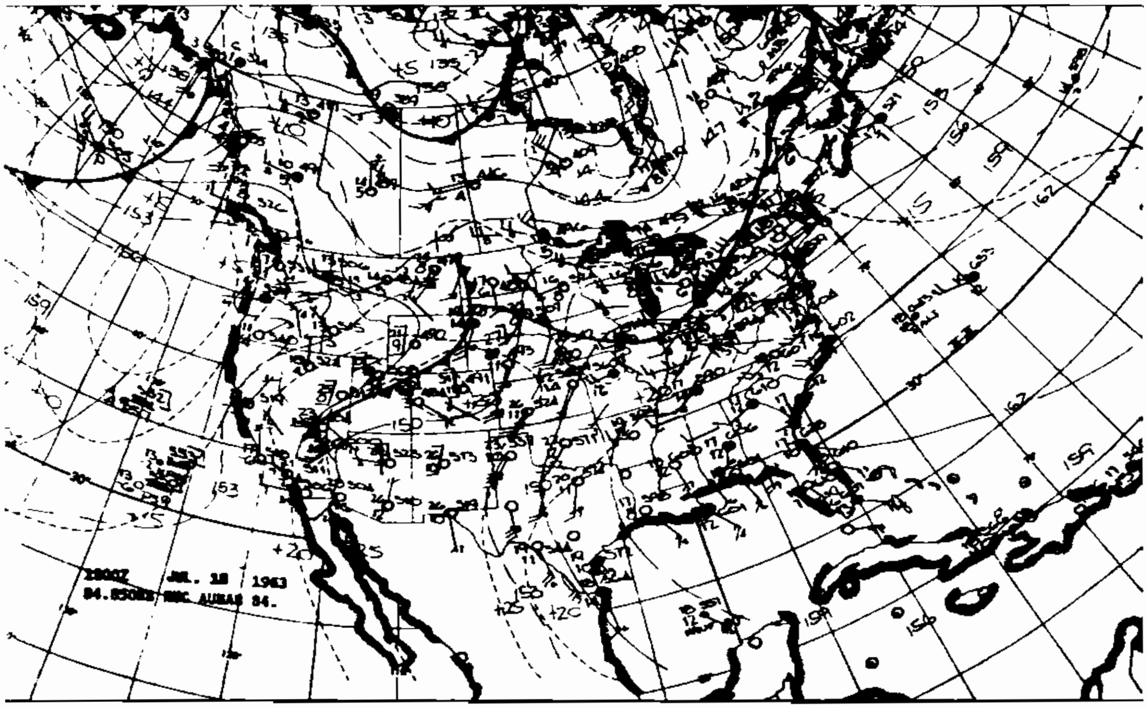


Figure 17–7. 850 MB Constant Pressure Chart

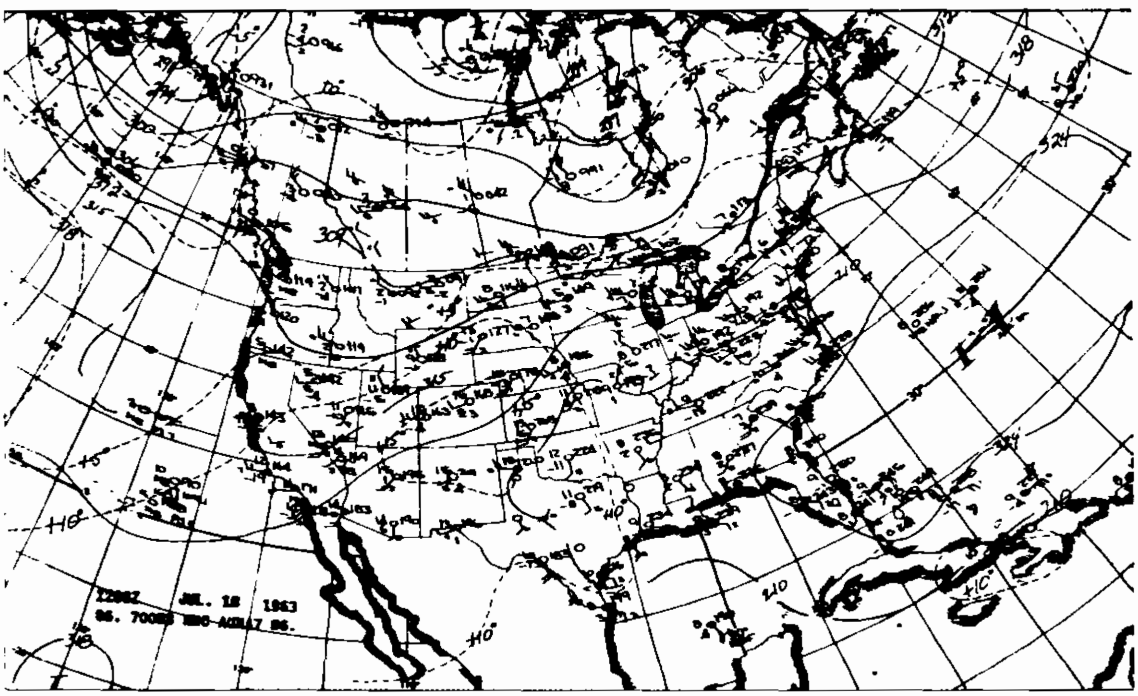
the 300, 200, 100 and 50-mb charts. These lines are labeled in knots.

A solid black line is currently used at weather stations to *depict lines of low pressure troughs.*

The *axis of the zone of maximum wind speed,* sometimes called the axis of the jet stream, *is indicated by a heavy broken dark line of arrows.*
This arrow is not necessarily parallel to the contour lines. Jet stream axes are indicated on the 300 and 200-mb charts.

Forecasters use constant pressure charts in conjunction with surface charts to ascertain such valuable weather information as the speed and direction of wind; temperatures and freezing levels; the intensity, speed, and direction of frontal and pressure systems; the amount, type and intensity of cloud forms and precipi-

Figure 17–8. 700 MB Constant Pressure Chart



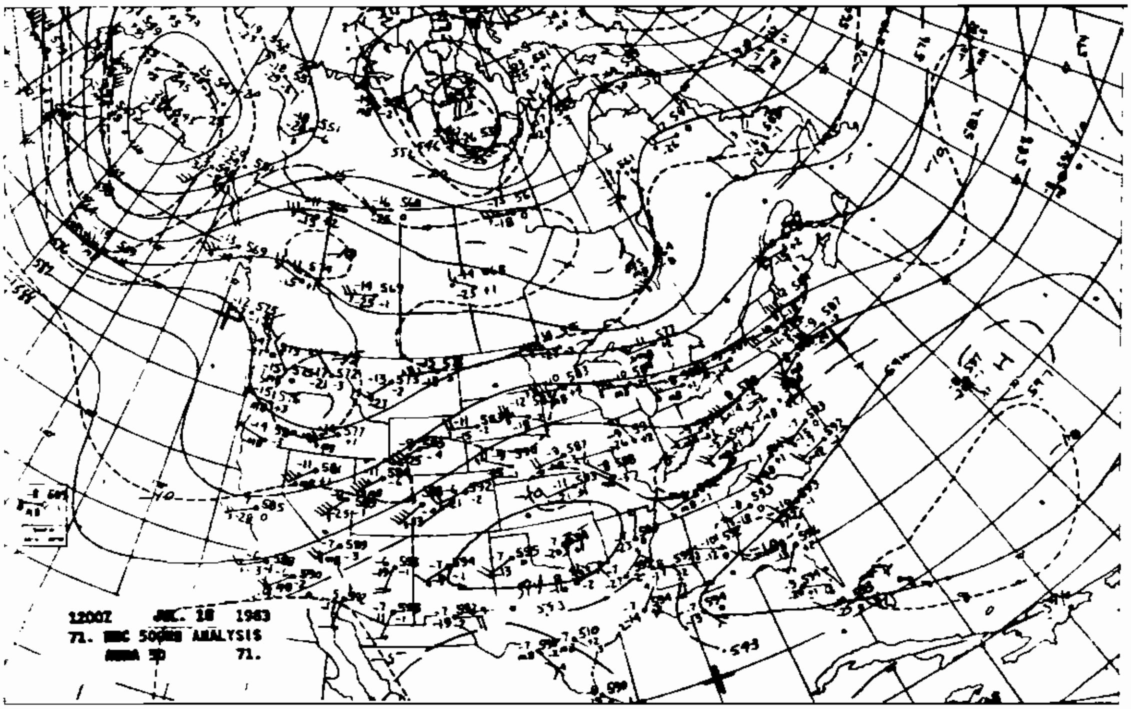


Figure 17–9. 500 MB Constant Pressure Chart

tation areas; and areas of icing, turbulence, and thunderstorms. Constant pressure charts are also used in computing minimum flight paths.

Constant Pressure Prognostic Charts

Prognostic (forecast) constant pressure charts are prepared by NMC, Weather Centrals and Forecast Centers, and transmitted to field weather stations by facsimile. The forecast position and orientation of the contour (height) lines are entered on the appropriate prognostic chart. Figure 17–13 shows a 700-mb prognostic chart which was prepared from the 700-mb chart shown in Figure 17–8.

Figure 17–10. 300 MB Constant Pressure Chart