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Interpretation of Weather OVER THE PACIFIC

REPORT No. 9230-TR105-29

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INTERPRETATION OF WEATHER OVER THE PACIFIC

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REPORT No. 640 JUNE 1944

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HEADQUARTERS ARMY AIR FORCES

PREPARED BY THE WEATHER DIVISION
HEADQUARTERS ARMY AIR FORCES

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THE GENERAL CIRCULATION

The general air circulation over the Pacific is, as in other areas, completely determined by the large-scale distribution of atmospheric pressure over the oceans and surrounding continents. A study of the general circulation of the Pacific area thus becomes, first of all, a study of the distribution of pressure within the region.

Air flows from regions of high pressure to regions of low pressure, curving to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The degree of curvature is greatest at the highest latitudes and decreases to zero at the Equator. This means that at the Equator air flows directly from high pressure to low pressure with the direction of flow exactly at right angles to the isobars. At higher latitudes, the flow has a large component of motion around the high-pressure cell, with the wind tending more nearly to parallel the isobars.

A cursory glance at any series of seasonal charts of pressure over the oceans reveals that persistent cells of high pressure exist in the zone between latitudes 25° and 40° in both hemispheres. Zones of lower pressure appear at or near the Equator and between latitudes 45° and 60°. These zones do not, however, remain stationary throughout the year, but shift northward and southward within the latitude ranges given above. This north-south motion is indirectly associated with the seasonal differences in the solar heating of the earth's surface, which acts in such a manner that the zones follow the seasonal migration of the sun. In each hemisphere, therefore, all zones reach their most poleward extension during the summer months and are nearest the Equator during the winter. In addition to these semipermanent regions of high pressure over the oceans, there are high-pressure cells over the continents in both hemispheres during this season, produced by the winter cooling of all extensive land surfaces.

AIR MASS CHARACTERISTICS

The regions of high pressure from which the principal air flow originates may be termed the source regions for the air masses that move over the Pacific. It is generally within such regions that the air mass first appears at the surface after sinking from aloft. In fact, it is this piling up and sinking of air masses that produces the anticyclonic cells in the first place. Air at the source region will have the characteristics of the place of origin because of the weak circulation within these areas and the relatively long period of time during which the air masses remain in or near the source. For example, during the winter months, interior Siberia is cold and dry, with the result that the winter anticyclone over this region sends out cold, dry air over the North Pacific. The anticyclone to the east of the Hawaiian Islands, on the other hand, sends out air which is relatively warm and moist in the lower layers, and hence characteristic of the warm-water surface over which it has lain.

The initial characteristics of the air masses at their sources will be retained as long as the air stream follows a course over regions which are similar to the source. A rapid transformation of the air mass will occur if the course is over a surface which presents radically different characteristics with respect to temperature and moisture. The rate of transformation depends upon the degree of difference in temperature and moisture, the speed of air flow, and the amount of turbulence in the lower layers. Discussion of the transformation process is facilitated if the following three classes of conditions are considered:

(1) *Warm air moves over a colder surface.* In this case, the surface layer of air will undergo rapid transformation but, because of the stability produced by this surface cooling, the effects will not extend to very great heights, and the air mass at higher levels will retain the characteristics it possessed at a corresponding height over the source region. When tropical maritime air from one of the North Pacific high-pressure cells moves northward over increasingly colder water, the lower layers of the air mass very quickly take on polar characteristics, while the air at higher levels will still retain most of its original tropical characteristics.

(2) *Cold air moves over a warmer surface.* In such a situation, the surface layer of air will undergo less rapid transformation, but the effects will extend to much higher levels because of the turbulent and convective exchange of heat and moisture. When cold, dry continental air from the Siberian *high* flows out over the warm ocean waters of the northwestern North Pacific in winter, the rapid heating and evaporation quickly transform the cold, dry air mass to a warm, moist one up to very high levels. The complete transformation from a true continental air mass to a true maritime air mass sometimes takes place in less than 24 hours. Any further modification over the ocean will take place at a progressively slower rate, as the temperature and moisture differences become less.

(3) *Warm, dry air moves over a warm, moist surface.* In this case, the air mass picks up moisture very rapidly, but because of the small amount of heating at the surface the effects are felt to only a limited height. Under such conditions, a moderately shallow layer of unstable air is apt to exist at the surface with a stable inversion layer above, which prevents the distribution of moisture to high levels. When relatively dry, tropical (superior) air, originally from high levels, flows southward toward the Equator from one of the North Pacific high-pressure cells, the lower layer picks up moisture very rapidly but will pick up relatively little heat, since it was originally a warm mass at its source. As these air masses approach the Equator, they become relatively moist in the lower layers but remain dry above 6,000 to 8,000 feet.

CAUSES OF WEATHER

In the absence of an atmospheric circulation, each region on earth would possess a climate which would depend solely upon the amount of solar heat received and upon the nature of the underlying surface, i. e., whether the surface was land or water. Such a climate is approached most nearly at a source region within one of the semipermanent high-pressure cells. The study of the weather phenomena of any region then reduces to a consideration of the modifications of this fictitious or "solar" climate brought about by air flow. The weather characteristics of a particular month in a given locality are governed by: (1) the intensity of the air stream flowing over that particular region; (2) the origin of the air mass within the stream; (3) its previous history before arriving over the region; (4) the effects of local topography upon the several meteorological processes, and (5) the nearness of the region to one of the zones of atmospheric convergence.

ZONES OF CONVERGENCE AND DIVERGENCE

Over the oceans, bad weather, consisting of widespread cloudiness, precipitation, high surface winds, and turbulence, is essentially a phenomenon associated with rising air currents. As such, bad weather zones are generally absent in high-pressure areas which are, as described, regions of descending air (regions of divergence). When two air streams converge, conditions favorable for rising and lifting of air masses exist, and bad weather zones are the result. Convergence takes place where two or more air currents resulting from divergence within different high-pressure cells meet in a region of low pressure. Three such regions, favorable for widespread convergence, are the low-pressure zone near the Equator and the zones in each hemisphere on the poleward sides of the Pacific anticyclones. Other zones of convergence develop from time to time between the individual cells that make up the zones of high pressure in lower midlatitudes.

THE INTERTROPICAL FRONT

The most persistent zone of convergence over the Pacific is that of the Intertropical Front (sometimes called Equatorial Front) where the air streams of the two hemispheres meet in the equatorial region of low pressure. The latter region is sometimes referred to as the belt of doldrums. Weather conditions along the front change from day to day according to the nature of the air streams which converge into the frontal zone and the angle at which they meet. It is not a sharp front-like discontinuity in most cases, but a zone which may vary in width from 50 to 400 miles. At its worst, it is an area of solid cumulonimbus clouds rising to 40,000 feet or more, with thick layers of altostratus extending outward at several levels (see fig. 1). Ceilings and visibilities are often lowered to near zero in

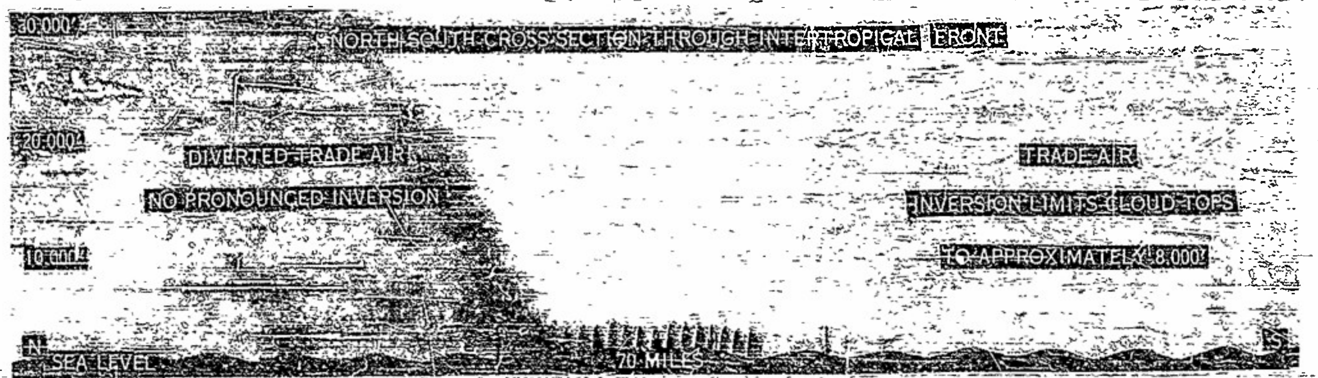


FIGURE 1

heavy rain. Under such conditions, turbulence is very severe, with heavy icing in clouds above 16,000 feet. At its best, the Intertropical Front may be merely an area of broken to overcast altostratus clouds with swelling cumulus clouds below (see fig. 2).

The air from the winter hemisphere, having had a longer trajectory over warm water, is relatively moister than the trade air of the summer hemisphere with which it is in juxtaposition at the front. By the time the diverted trade air from the winter hemisphere has crossed the Equator, the previously existing inversion has been completely destroyed, and the air mass (now called equatorial air) is moist and unstable throughout a great depth. The density and vertical extent of the cumulus clouds in the frontal zone are thus determined by the previous history of the air mass as well as the degree of convergence. Convection is strong in cumulonimbus clouds, especially if their tops are above 14,000 feet, a level which approximates the minimum freezing height in the Tropics.

In the illustration of the Intertropical Front (fig. 1) note the characteristic flattening of the cumulus clouds on the trade (poleward) side of the front, where the trade inversion (dynamically formed by subsidence in the subtropical anticyclone) limits the vertical development of the cumulus. Contrast this with the variable tops of the clouds in the equatorial air on the equatorward side of the front, where there is no subsidence inversion.

The temperature difference between air masses along the Intertropical Front is usually slight, a fact which accounts, in part, for the absence of a sharp discontinuity at the front. An exception is found in the eastern part of the Pacific in the vicinity of the Galapagos Islands where the temperature gradient across the front is frequently large. Southern Hemisphere air which crosses the Equator in this region is forced to pass over the very cold ocean waters off the northwestern coasts of South America before leaving the equatorial zone. As a result, the air in this northerly-flowing stream is rendered very stable in the surface layers and is considerably colder than the Pacific air to the north of the Equator.

Just as the anticyclones that govern the circulation move northward and southward with the sun during the course of the year, so must the Intertropical Front undergo a similar motion. Thus, in each hemisphere, the front attains its greatest poleward extension during the summer season and is nearest the Equator during the transition seasons of spring and autumn. The only exception is in the central part of the Pacific, where the Intertropical Front remains north of the Equator throughout the entire year. The seasonal migration of the front is small in the central Pacific because of the small seasonal differences in temperature and pressure in this most completely maritime region. Near the continents, however, where the effects of the great seasonal differences in temperatures and pressure come into play, the Intertropical Front varies in position within wide limits.

The 12 flow charts on succeeding pages illustrate the basic air flow over the Pacific during all months and show how the Intertropical Front moves during the seasons. It must be emphasized that these are mean charts and that the pressure distribution which produces the bad weather zones will vary from year to year, causing the seasons to be advanced or retarded. However, the basic progression of wind systems and fronts is normally a gradual process with day-to-day changes rarely over 100 miles.

The technique of flying through the Intertropical Front depends, to some extent, upon the type of aircraft. Thus, planes with service ceilings of 16,000 feet or higher rarely have difficulty in topping the clouds along the front. Other planes must weave among tops of cumulonimbus clouds at 12,000 feet or lower, and, failing to find intervals where they can traverse the area in clear air or in cloud with tops below 14,000 feet, must descend to near the surface and fly through rain squalls.

The density and vertical extent of the cumulus clouds in the frontal zone may vary considerably. Most of the time, a scattered row of cumulonimbus with considerable attendant middle and high clouds typifies the front, but there are times when cumulonimbus clouds are so close together that it is not possible to make a transit of the front without penetrating clouds. It is safe to fly in clouds whose tops can positively be judged to be lower than 14,000 to 16,000 feet. Light-to-moderate turbulence and hail may be encountered, but strong, deep drafts are not likely. The principal danger lies in entering a cloud whose top is lower than 14,000 feet and then unintentionally getting into the convective column of a cumulonimbus, whose top may reach 20,000 feet or higher. When approaching the frontal zone, it is dangerous to fly blind in thick clouds when tops cannot be ascertained. Flying at night in these regions, particularly in the neighborhood of large islands, should usually be avoided for two reasons. First, at night it is difficult to see isolated deep clouds in the path of flight. Second, there is a marked increase in cloud amount and turbulence over the ocean during nocturnal hours. This effect is most noticeable in the vicinity of islands.

The pilot should determine the orientation of the Intertropical Front at the point where he plans to cross and direct his flight at right angles, so as to spend the least possible amount of time within the bad weather zone.

AUXILIARY BAD WEATHER ZONES IN THE TROPICS

In addition to the Intertropical Front, there are several minor discontinuities in the air streams of the trade masses (tropical air). These are often drawn on synoptic charts as weak, cold fronts, since the weather associated with them is of the type characteristic of weak, cold fronts at higher latitudes. The region between two cells of the semipermanent anti-cyclones which characterize the pressure field in the trade air stream is known as a trough or col More simply, it is a localized region of convergence. In such a region, there is no subsidence inversion, and the cumulus clouds can build to greater heights than elsewhere

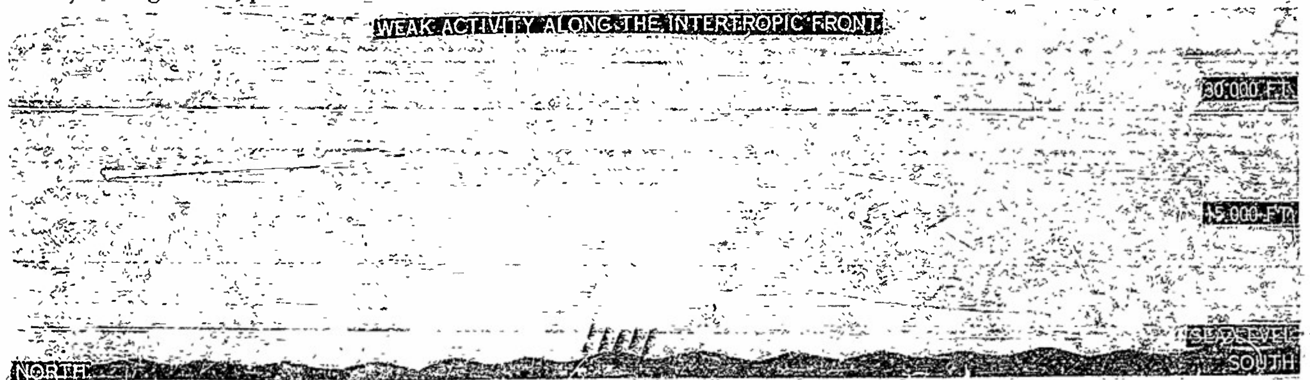


FIGURE 2

in the trade wind belt. The frontal area consists of a broad zone of heavy cumulus and an occasional cumulonimbus, with patches of medium cloud blown out in sheets at levels between 3,000 and 12,000 feet. The icing level is in the vicinity of 12,000 to 14,000 feet in the Southern Hemisphere auxiliary frontal zone, but lower (at approximately 10,000 feet) in the front lying northeast-southwest across the Guam-Japan track during the period from October through March.

These auxiliary frontal zones are ordinarily weak and will rarely present any serious problem to the pilot. These zones, however, offer a favorable field for genesis of weaker tropical storms and, when they form, the front tends to sharpen considerably and may be worse than the Intertropical Front. At such times, low-level flight becomes necessary.

Recent evidence points to the existence of rather complicated frontal structures in the eastern Pacific resulting from the effects of the cold ocean waters off the northwestern coasts of South America previously mentioned. During the Northern Hemisphere winter months, the structure of the Intertropical Front is similar to that described in the preceding section. During the northern summer, however, when the Intertropical Front is farthest north, an auxiliary bad weather zone appears to form in the region just north of the Equator but well to the south of the true Intertropical Front. This subequatorial bad weather zone in the eastern Pacific forms as the result of heating of the relatively cold Southern Hemisphere trade air as it moves northward away from the influence of the upwelling cold water south of the Equator. As the air is heated from below, the inversion, which originally formed in the air mass as the result of the surface cooling over the cold water mass, lifts from levels of 3,000 to 4,000 feet in the vicinity of the Equator and the Galapagos Islands to 6,000 to 7,000 feet at about 5° N. latitude.

At approximately 5° N., the northerly-flowing current changes direction from south-southeast to southwest and west-southwest because of the deflective force of the earth's rotation and the reorientation of isobars resulting from the deep "heat" *low* over northwestern South America. A slight decrease in wind speed results from the change in wind direction. Thus, there is a "piling up" of the Southern Hemisphere trade air that is being rapidly heated from below, the inversion is destroyed, and cumulonimbus clouds with rain showers form. Therefore, on the surface weather chart, there will appear to be two zones of bad weather, one along the Intertropical Front and the other at about latitude 5° N.

WAVES IN THE EASTERLIES

Until recently it has been assumed that the easterly flow of air on the equatorial sides of the Pacific anticyclones was remarkably uniform from day to day and remained undisturbed except for an occasional tropical cyclone. However, recent detailed synoptic analyses over the tropical Pacific have indicated the existence of wave-like perturbations, which move from east to west in the deep easterly air currents of these regions. At the present time, the nature and characteristics of these waves are only imperfectly known and will be discussed only briefly in this study.

The easterly waves or troughs are usually attended by northeast wind (southeast in the Southern Hemisphere), falling pressure, and, if the wave is moving more slowly than the air stream in which it lies, excellent weather prevailing ahead of the wave crest. In the rear portion of the waves, southeasterly winds (northeasterly in the Southern Hemisphere), rising pressure, convergence, and showery weather occur. The passage of the axis of the wave is accompanied by a lifting of the trade inversion, and thus these waves govern, to some extent, the depth of the moist layer of equatorial air.

In the typical wave, the depth of the moist layer ahead of the wave crest may reach a minimum of 5,000 feet. Under these conditions, exceptionally fine weather prevails. The depth of the moist layer increases rapidly near the trough line and often attains a maximum of 30,000 feet near the zone of most intense convergence. In the latter area, well-developed squall lines and rows of cumulonimbi are found. The weaker waves are often difficult to locate on the surface weather chart, since the convergence accompanying them may not be sufficient to produce bad weather zones over the open ocean. However, they usually cause an increase in cloudiness over island areas.

If the wave disturbance is moving more rapidly than the air stream within which it lies, convergence and showery conditions may precede the passage of the wave crest.

Unless an easterly wave is undergoing a rapid change in intensity, its rate of movement will remain fairly uniform, the direction of movement being about normal to the trough line and parallel to the steering current in which it lies. Waves of this kind occur on the average of about two per week during the season of their most frequent occurrence, and their effects in any given locality may extend over a period of 3 or 4 days. Waves which are originally weak and hardly discernible on the weather chart may deepen rapidly over a period of 24 hours, particularly when they meet the Intertropical Front.

They occur most frequently during the summer season in either hemisphere and seldom occur during the winter months.

TROPICAL CYCLONES

A phenomenon closely associated with the Intertropical Front is that of the tropical cyclone, variously termed "typhoon," "hurricane," or "willy-willy," depending upon the area within which it occurs. The characteristic difference between tropical and extratropical cyclones is in the steepness of the pressure gradient associated with the former. The well-developed tropical cyclone is a whirling eddy with a diameter of 50 to 400 miles, which is accompanied by winds as high as 150 knots toward the central (calm) center. South of the Equator, the wind spirals inward and upward in a clockwise direction around the center of lowest pressure. North of the Equator, the rotation is the reverse, and the winds spiral in a counter-clockwise direction.

Tropical storms never form nearer than 5° from the Equator, which indicates that the horizontal component of the Coriolis (deflective) force is an important factor in their development. They form only over the open sea, where large amounts of energy are available in the moist air and where surface frictional forces are slight. There is considerable evidence to show that they form at so-called triple points, where three air masses meet in a common zone of convergence.

A peculiarity of many tropical cyclones is the calm center, the so-called eye of the storm. When the center of a cyclone passes over a given locality, the wind which has been very violent dies down suddenly, either to an absolute calm or to a much lower velocity, and the precipitation ceases. The diameter of the eye or calm center varies from 10 to 30 miles, and after it passes over, the violent winds begin again but this time from the opposite direction.

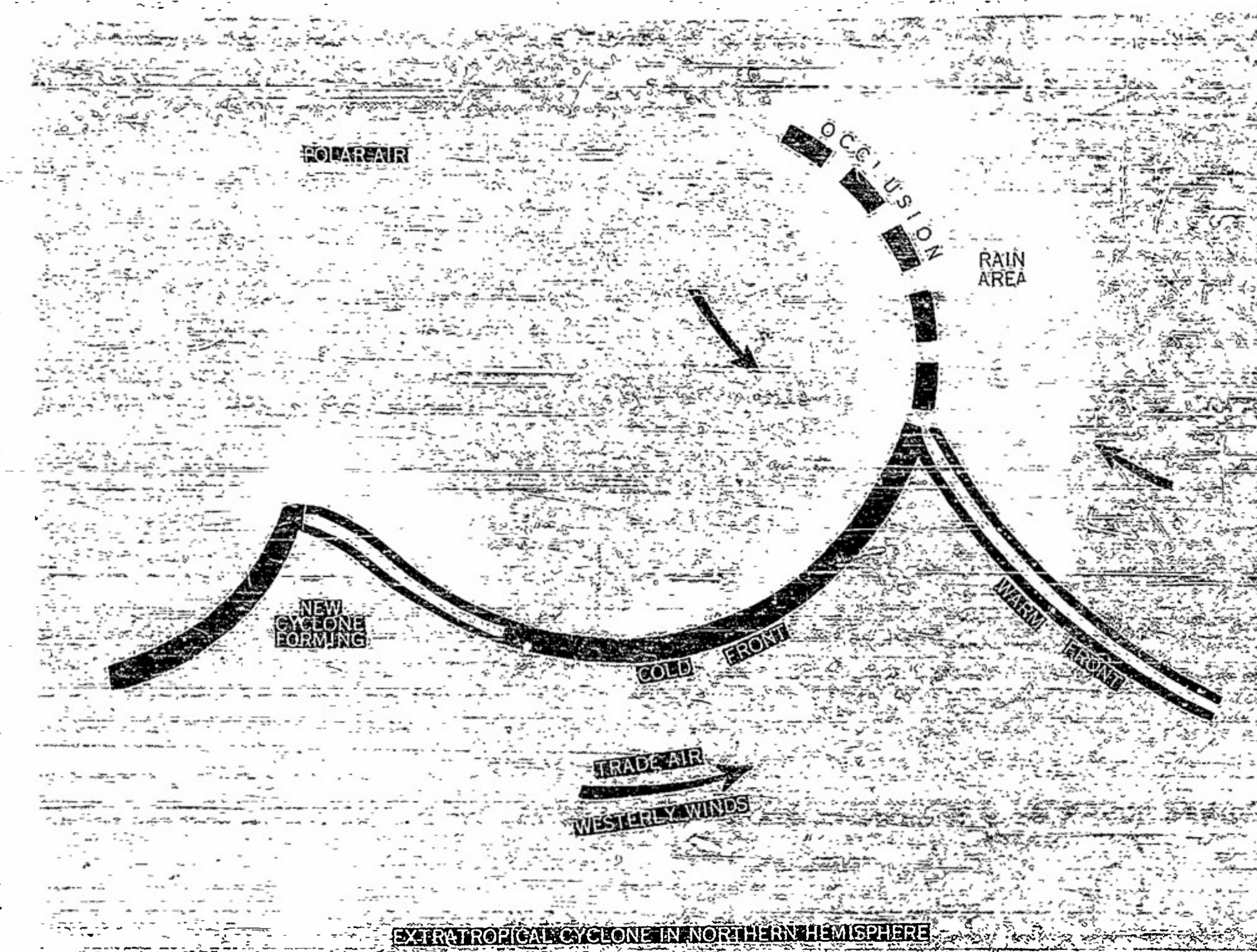
Although the tracks of individual tropical cyclones may be very irregular, they tend to describe a parabolic course after forming in the subequatorial regions. In the Northern Hemisphere, the cyclones tend to move first in a general westerly direction nearly parallel to the Equator, then northwesterly, finally curving to north or northeasterly at latitude 20° to 25°. In the Southern Hemisphere, the storms tend to move first westerly, then southwesterly away from the Equator, and finally curve to the south or southeast. When they reach higher latitudes, or move over land surfaces, their diameter increases while the intensity decreases. At higher latitudes, they often change into extratropical cyclones with well-developed frontal systems.

Generally, the storm is approximately circular, and the rain area produced in connection with it is usually rather evenly distributed about the center. Exceptions occur when the tropical cyclone moves into the higher latitudes and draws relatively dry air masses into its circulation. The region of intense winds is usually very small. At distances of only 75 to 100 miles from the center, the velocities rarely exceed 50 knots. The velocity of movement of the center is rather variable, ranging from a few miles per day in its earlier stages in the subequatorial regions to approximately 100 miles per day after it has become well developed, and increasing to 300 to 400 miles per day after recurving. This recurving of the tropical cyclone is very characteristic and is the normal result of the storm's passing into the zone of prevailing westerlies.

The frequency of tropical cyclones is small compared with that of the extratropical cyclones of higher latitudes. In none of the regions of their formation illustrated on the flow charts is the average annual number greater than 25; in some regions the yearly average is as small as two. In each hemisphere they occur principally during the summer season, when the Intertropical Front is farthest from the Equator. They, of course, do not form when the zone of convergence is within 5° of the Equator, although the outer fringes of cyclones farther north or south frequently cause westerly winds along the Equator as high as 60 knots. The regions of their formation and principal paths move northward and southward with the sun, as do the wind systems that produce the zones of convergence within which they form.

When tropical cyclones are large enough to appear on the weather map, a flight can often be made which will avoid the heaviest weather and take advantage of the best winds. In the subequatorial regions, however, their presence may not be revealed by the weather chart because of their small size when they are in the incipient stage. There is reason to believe that the tropical cyclone develops from a small, intense vortex gradually extending its influence outward from the center. Therefore, in the regions of their formation, small, incipient storms will sometimes be encountered before the synoptic chart has given any warning. It is highly important that all signs of such a possible development be understood. Such observations include: (1) Heavy cloud too high to climb over; (2) rapidly shifting winds with increasing wind velocities; (3) lightning; (4) heavy swells running counter to smaller waves; (5) westerly winds greater than 20 knots between 5° N. and 5° S., a condition which indicates cyclonic activity to the north or south; (6) cirrus and cirrostratus thickening to altostratus; (7) rain falling from altostratus; (8) turbulence in clear air.

Familiarity with the circulation in the vicinity of tropical cyclones and their normal paths is essential for safe navigation over Pacific routes in the Tropics.



EXTRATROPICAL CYCLONE IN NORTHERN HEMISPHERE

FIGURE 3

THE POLAR FRONT

The importance of convergence in producing bad-weather zones has already been discussed under the sections on convergence and the Intertropical Front. In order to obtain a picture of the geographical distribution of the principal zones of frontogenesis and the principal frontal zones, the approach has been through a consideration of wind systems and source regions for air masses. In general, it may be stated that the "source" of temperature difference is partly the normal meridional temperature gradient and partly the temperature contrasts between ocean and continents. The "agency" that creates fronts out of these sources of temperature (and moisture) differences is the deformative part of the wind field. In short, within areas of convergence where air masses with different properties are brought together, moisture and temperature gradients will be steep. It is this steepness of gradient that defines a front.

The most favorable conditions for the formation of fronts will therefore be found where the circulation is such that air from widely different sources is brought into juxtaposition by a minimum of travel. In winter, these conditions are most ideally fulfilled along the east coasts of the continents.

There are four principal types of air masses in each hemisphere, classified according to the source region, viz: arctic, polar, tropical, and equatorial. The arctic air is separated from the polar air by the Arctic Front but, over the Pacific, this front is in each hemisphere so far toward the pole (greater than latitude 55°) that it falls beyond the area covered in this study. The tropical air from the semi-permanent anticyclones of the subtropics is separated from the equatorial air masses by the diffuse Intertropical Front as has already been discussed. The one remaining, and most important, frontal system is the Polar Front which exists almost invariably between tropical and polar air masses.

In addition to these principal fronts, secondary fronts may form temporarily within the air masses when the distribution of temperature and wind is favorable for convergence. They form most frequently in polar air masses, particularly between "old" and "fresh" polar air or between polar continental and polar maritime. The secondary fronts are usually neither extensive nor long-lived, whereas the principal fronts are both extensive and more or less permanent.

As is the case with all general features associated with the general circulation over the oceans, the Polar Front moves northward and southward with the sun in such a way that in general position, it is in each hemisphere nearest the pole during the summer season and nearest the Equator during the winter months. It is true that a "mean position" for the Polar Front does not have the same degree of significance as a mean position for the Intertropical Front. Nevertheless, the general seasonal shifting of the zone within which the Polar Front is most apt to lie is evident to anyone who has had occasion seriously to analyze or inspect long series of synoptic charts for the Pacific area.

EXTRATROPICAL CYCLONES

The Polar Front, in contrast to the Intertropical Front, does not constitute a single more or less continuous band of convergence and bad weather across the North and South Pacific. It appears rather as a series of active, convergent zones which move in a general direction from west to east. These convergent zones are the migratory *lows* or travelling cyclones of midlatitudes.

It has been shown that in middle and high latitudes it is impossible for air masses with different densities (temperatures) to lie side by side continuously in equilibrium, but that waves will form along the discontinuity or front that separates the two. If the wave lengths of the disturbances are of the order of 300 to 1,800 miles, the waves are said to be "unstable," i. e., their amplitudes will increase with time. In this case, the cold air in the rear of the wave is pushed toward the Equator, where it tends to undercut the warm air, thus forming the cold front of the cyclone. A compensating poleward flow of warm air takes place in the front portion of the advancing wave, thus forming the warm front of the cyclone. The warm, light air behind the warm front tends to ride up and over the denser cold air ahead of the front. The waves therefore develop toward occlusions and a typical extratropical cyclone is the result (see figs. 3 and 4).

The formation of a cyclone along the Polar Front is first noted as a slight indentation of the front. This indentation or wave later deepens and moves along the front, rapidly at first, then progressively slower. The waves nearly always move in a direction from west to east for two reasons. In the first place, this is the prevailing direction of the wind stream in which they form. Secondly, according to wave theory, a wave-type cyclone should move in such a way that the warmer air is on the right in the Northern Hemisphere and on the left in the Southern Hemisphere. Since the warmer air is usually to the south of the Polar Front in the Northern Hemisphere, and to the north of the Polar Front in the Southern Hemisphere, the wave movement also contributes to the west-to-east motion of cyclones.

Thus, the zones of active convergence along the polar fronts in each hemisphere appear as migratory *lows* which travel from west to east, generally in the region more than 20° from the Equator. Although the variability of the form and position of these *lows* prevents their being shown on the mean air flow charts, the principal regions of formation and travel are illustrated.

In comparison with the tropical cyclone, the extratropical cyclone is exceedingly complex. There are several major differences between the two types of cyclones, the most important being the lack of symmetry of temperature, wind, pressure, cloudiness, and precipitation in the extratropical type. Other important points of variance arise from the facts that the extratropical cyclone is not so intense as the tropical, that it covers a broader area and has less torrential rains, and that, furthermore, the calm center, or "eye," is rarely observed outside the Tropics. The extratropical cyclones are most vigorous in winter, when the air mass differences and intensity of polar zones of convergence are at their maxima, whereas the tropical cyclones are characteristic of the warm season.

The weather pattern around the Pacific Polar Front storms is typified by the conventional model of the extratropical cyclone (see fig. 3). It will not be elaborated upon in this section, since detailed discussions of the structure of these formations are given in all meteorological textbooks.

The extent of the warm front precipitation area depends very largely on the structure of the warm air mass. With relatively warm, dry air on the equatorial side of the Polar Front, the precipitation and cloud area may be very small and uneven. If the overrunning warm air possesses a large amount of moisture but is fairly stable, the cloud and precipitation area will be large, with rather uniform intensity of precipitation throughout. If the warm air was initially unstable, the precipitation area may be large but have an irregular distribution.

Similarly, the intensity of weather along the cold front is determined by the temperature differences across the front and by the air mass properties of the warm air. If the warm air is moist but stable, the precipitation zone will be narrow and of moderate intensity. If the warm air was initially unstable, the bad weather zone will be more extensive and of greater intensity.

Although the average rate of movement of extratropical cyclones is about 25 knots, the speed of individual storms varies widely about this mean value. The greater the wave length or the flatter the wave, the greater its velocity. Similarly, the greater the difference in density (temperature) between the two air masses making up the front, the greater the velocity of the cyclone.

A flat wave would be one of perhaps several hundred miles in length and less than 100 miles in horizontal depth. When a wave nears the occlusion stage, it is, of course, of short length compared to its depth. This accounts for the slowing down of cyclones as they proceed toward occlusion. The greater differences in density between air masses which are found during the winter months account for the greater speed of cyclones during this season.

Frequently, during the colder months in each hemisphere, extratropical cyclones will lie across the principal air routes in midlatitudes. These storms cannot always be avoided, and during any of the colder months, it will be necessary to traverse them on some portions of the routes. The flight plan should be designed to keep the aircraft as far away from the point of occlusion as possible, for here the severest weather is found. The greatest hazards in negotiating these storms are ice and turbulence. Every effort should be made to keep out of clouds when they are above the icing level (about 6,000 feet at latitude 35° in winter).

In midwinter, it is not unusual to encounter as many as four such extratropical cyclones on one flight across the Pacific from east to west. This makes it necessary for the pilot to traverse several warm and cold fronts and possibly one or more occluded fronts. Along the cold front, it is frequently practicable to change course slightly and fly parallel to the frontal band of cumulus and cumulonimbus until a break is found between adjacent clouds. They can often be cleared at 12,000 feet through these gaps. The warm front, on the other hand, usually requires about half an hour of blind flying, but, with turbulence at a minimum in stratiform clouds, extended instrument flying is feasible as long as no ice is forming. In the portion of the storm where the cold front overtakes the warm front, a complicated structure, which is called an occlusion, results. At the point of occlusion, there is a maximum of turbulence and storminess, but farther poleward the clouds tend to stratify, and flying conditions improve, unless the cyclone is young and intensifying. Various layers of altocumulus, altostratus, and stratocumulus predominate, and flight in clear air between layers is possible. Icing levels, however, are lower in this colder air, and extended flight in even thin layers of cloud is sometimes dangerous.

Over several of the transpacific air routes, the tracks lie approximately parallel to the Polar Front but on the equatorial side. Over such routes, when it is not possible to

FIGURE 4

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deviate slightly to avoid any polar outbreaks existing on the route, it is best to change course briefly so as to traverse the front at right angles, thereby minimizing the amount of instrument flying.

On flights from east to west over the Pacific beyond the Tropics, an increasing amount of high cirrus and altostratus indicates that an extratropical cyclone lies ahead, though, perhaps, on the poleward side of the route. It indicates that a warm front will soon be reached. When the warm front has been traversed and the aircraft is in the trade (tropical) air, altocumulus clouds in bands may appear to the west or on the poleward side of the track. This indicates that there is a cold front lying parallel to the bands of altocumulus in one of these directions. This type of altocumulus, arranged in parallel bands ahead of the advancing cold front, is an extremely reliable indicator over the open Pacific and can be of appreciable assistance in determining the orientation and location of the front.

On flights from west to east over the Pacific within the Polar front zone, the route may at times intersect the looping part of the Polar front between two depressions. Although the weather along the equatorial side of the front is not generally bad, the aircraft frequently enters the cold air and suddenly arrives at the cold front from the west, without any preliminary warning such as the altocumulus bands give on the east-west trips.

In subtropical areas, weak cold fronts are sometimes encountered during the winter months, but warm fronts are extremely rare.

In negotiating one of these extratropical cyclones, the synoptic weather chart is the best guide for determining the proper way to avoid the worst of the storm.

TOPOGRAPHIC EFFECTS ON WEATHER

In previous sections, bad weather zones have been associated with the lifting of air masses that takes place within regions of convergence. Similar lifting takes place also along any natural barrier that exists across the path of the air stream. It is a matter of common observation that cloudiness and rainfall are higher on mountain slopes facing the wind than at their bases, and that areas on the lee sides of mountain ranges are often within a "rain shadow."

These results are simply an expression of the fact that the lifting of air is a cooling process, the sinking of air a heating process. Air which is originally stable resists vertical displacement and thus tends to flow around barriers rather than to rise over them. For example, the stable polar air which exists during summer in the eastern Pacific in midlatitudes does not rise over the coastal ranges of California because of the initial stability of these air masses.

Dry air which is lifted may produce no clouds or precipitation, if the height of the land barrier is considerably less than the condensation level within the dry air. On the other hand, it requires only a small amount of lifting of an initially moist, unstable air mass to produce active convection. A mountain barrier which lies directly across the path of an air stream which is unstable may produce a bad weather zone just as important, if not more important, than any of the frontal zones described in previous sections. The magnitude of the topographic effects depends upon the speed of air flow, the degree of instability of the air mass, the height and steepness of slope of the mountain barrier, and the angle at which the winds meet the barrier. The effects are greater if the air stream strikes the slope at exactly right angles than if it approaches at a smaller angle.

The horizontal distance over which the cloudiness or rainfall may increase or decrease by several hundred percent is often a matter of only a few miles. One record for an area in Java shows an increase in annual precipitation amounts from 66 inches at sea level to 166 inches at an elevation of less than 900 feet. In the Hawaiian Islands, the average annual precipitation amounts vary from as much as 400 inches on windward slopes to as little as 10 inches (or less) on several of the leeward slopes. Even small oceanic islands with rather moderate elevations will show considerable differences in cloudiness and precipitation between the windward and the leeward slopes. Such effects, however, are particularly noticeable on the larger and higher islands of the Pacific. The largest islands in the Tropics usually present persistent bad weather on their windward slopes, while, at the same time, fairly good weather will prevail on all leeward slopes.

In regions which are characterized by a seasonal reversal in wind direction, the zones of bad weather within these areas will also show a seasonal reversal depending upon the location of the windward and leeward slopes. Such effects are very important in the Japanese islands, Formosa, the Philippines, New Guinea, and the Dutch East Indies, all of which are affected by one or more of the monsoonal circulations discussed in the next section.

AIR STREAM WEATHER

The Trades

The term "trade wind" is the name applied to the steady northeast and southeast winds which represent the flow of tropical air from the North and South Pacific anticyclones toward the equatorial *low*. As has been discussed previously, these initially warm, dry air currents pick up considerable moisture in their lower layers, but the moisture does not penetrate to high levels because of the presence of an upper-level subsidence inversion.

Visibilities in the trade air are good near the surface but may be restricted in the vicinity of the trade inversion, which usually exists at levels between 6,000 and 8,000 feet. Lower clouds are usually scattered, ragged cumulus with their bases at about 2,000 feet and flattened tops at around 6,000 feet (at the base of the inversion). In the vicinity of mountainous islands, the convective instability of the air masses may be realized through local lifting, with considerable cloudiness and frequent showers on steep windward slopes. In these areas, the cloudiness and precipitation increase during afternoon hours because of local heating effects.

Near the Equator, the air masses have picked up enough additional heat and moisture to destroy the subsidence inversion. As a result, in the trade air nearer the Equator than 5° to 10° the clouds have greater vertical development and showers are more frequent. The longer the path over warm equatorial waters, the more marked is this increase in cloud height and amount.

The foregoing discussion of trade winds indicates that nearly everywhere these air streams become progressively more unstable as they approach equatorial regions. An important exception exists in the eastern tropical Pacific, where the trade air masses tend to become progressively more stable as they approach the Equator. Because of the presence of cold, upwelled ocean waters off the northwest coasts of South America, the northerly-moving trade air in this region undergoes considerable cooling at the surface. By the time the Equator is reached, a strong inversion has formed, with the base at 2,000-3,000 feet. Below the inversion, broken to overcast stratiform clouds, light rain, drizzle, and mist prevail. The air mass above this surface inversion, however, is very dry, as moisture is not carried aloft through the discontinuity. Skies above the inversion remain clear, because the still-existing trade inversion at higher levels prevents the formation of clouds and showers. This type of tropical air is peculiar to this portion of the Pacific (vicinity of the Galapagos Islands).

The Monsoon Circulations

The term "monsoon" has come to apply to any more or less steady wind which experiences a seasonal reversal in direction. During the winter season in each hemisphere, the continents become colder than the surrounding oceans and, because of the cooling and shrinking of air masses over such regions, anticyclones form. During the warmer months, the reverse is true. At this time, the continents become warmer than the surrounding oceans, the heated air masses expand, and low pressure is the result. The outflow of air from the continents at high levels during the warm season actually leads to an intensification of the oceanic anticyclones, at least in the Northern Hemisphere, where the continental differences are most marked.

The higher the latitude and the greater the mass of the continent, the greater are these seasonal effects on pressure.

Such a mechanism results in a seasonal reversal of the atmospheric circulation on the continents and over the nearby oceans. In such regions, the air flow is dominated by the continental anticyclone during the winter months, by the oceanic anticyclones during the summer months.

Northwest and Northeast Monsoon.—During the months from October to March, when the Siberian anticyclone is best developed, cold, dry air moves off the Asiatic continent in a curved path over the western Pacific. The air flow, representing the main outflow of continental air, is northwesterly in the northern portion of the area, becomes northerly at about latitude 30° N., and finally curves to northeasterly below latitude 25° N. This flow is variously termed the "Northwest Monsoon" or the "Northeast Monsoon," depending upon the portion of the track considered. For example, in the vicinity of the Japanese islands (latitudes 35° to 40° N.), it is called the Northwest Monsoon, while over the Philippines (latitudes 5° to 19° N.), it is called the Northeast Monsoon.

This air stream finally crosses the Equator where, due to the deflective force which acts to the left in the Southern Hemisphere, the current appears again as a northwest wind.

After leaving the continent, the monsoon current picks up heat and moisture very rapidly over the Japan and East China Seas and over the Kuroshio (the North Pacific counterpart of the Gulf Stream). By the time the current has become northeasterly, it is fairly moist and warm and no longer possesses its original continental characteristics. Clouds in the northwesterly stream are very scattered, occur mainly in the lower levels, and are small and compact, aligning themselves in columns with the wind. This current does, however, produce bad weather on the windward sides of the larger islands such as Hokkaido and Honshu. As was the case with the trades, the Northeast Monsoon continues to pick up moisture as it approaches the Equator, so that cloudiness is increased and isolated thunderstorms are more frequent, particularly over the land masses. By the time the current has reached the Southern Hemisphere, it is a true equatorial air mass in all respects. The Northwest Monsoon brings the rainy season to most stations in the Southern Hemisphere.

North of the Equator, in a pure Northeast Monsoon air stream, flying is relatively smooth. Ideal conditions are found at about 10,000 feet above the surface haze and lower clouds. At the Equator and southward, deep storm clouds are more frequently encountered, particularly in bad weather zones and over mountainous islands. In such clouds, turbulence will be severe, and dangerous icing will be likely above 16,000 feet.

Southeast Monsoon.—During the Southern Hemisphere winter, the Southeast Trades are particularly steady in the western Pacific, flowing toward the Asiatic summer *low* in a strong, regular stream. This flow is frequently referred to as the Southeast Monsoon. South of the Equator, the air stream retains many of its trade characteristics. Clouds are flat topped and scattered over the open ocean because of the presence of the trade inversion aloft. On the windward (southeast) sides of the larger mountainous islands, however, the clouds build up to considerable heights, particularly during the afternoon hours. Visibilities are often restricted in the lower layers because of haze and smoke.

North of Australia, in the lee of the continent, the Southeast Monsoon is dry and cloudless for several hundred miles from the coast, as the source region of the air mass in this case is the dry Australian continent itself. Because of the configuration and low-latitude position of Australia, the Australian winter anticyclone constitutes the closest approach to a source region for tropical, continental air that exists in the Pacific area.

North of the Equator, the Southeast Monsoon takes on the characteristics of true equatorial air as the trade inversion is destroyed. Cloud systems are deep, and heavy precipitation occurs on the windward sides of the higher islands. Farther north, at about the latitude of the Philippine Islands, the eastern portion of the stream along the Intertropical Front merges with the southeasterly winds of the Northern Hemisphere circulation. The latter current represents the poleward return flow of trade air on the western side of the North Pacific summer anticyclone. Along the Asiatic east coast (the China Coast in particular), this return trade current is similarly referred to as the Southeast Monsoon although, in this case, the air mass comprising the stream originates entirely within the Northern Hemisphere.

South of the Equator, the flying conditions in the Southeast Monsoon are similar to those in trade air, but attention should be called to the effects of the rugged chain of islands that includes New Guinea, the Bismarck Archipelago, the Solomons, and certain of the Dutch East Indies. These serve to interrupt the smooth airflow and introduce additional flight hazards. Turbulence is severe over these mountainous islands, particularly during afternoon hours, with cloud structures up to much greater heights than occur in uninterrupted air flow of the same character. North of the Equator, the flying conditions are similar to those in other trade air streams after they have crossed the Equator.

Southwest Monsoon.—By April, following the breakdown of the winter anticyclone over Asia, a low pressure area, which deepens with the increasing heat of summer, has become established over the continent. Meanwhile, the Australian anticyclone begins to develop, reaching its maximum intensity at the same time the *low* over Asia reaches its maximum development. The subtropical anticyclones over the South Pacific and South Indian Oceans continue to exert their influence on the circulation. The result of this pressure distribution is the most important and intense monsoon circulation of the globe—the *Southwest Monsoon* of the western North Pacific, Southeast Asia, India, and Bay of Bengal and the Arabian Sea. In popular literature, this great wind system is most frequently referred to simply as "the" monsoon.

From May to September, the Southern Hemisphere Trades stream across the Equator, curve to southwesterly, and penetrate deep into the Northern Hemisphere (this flow has been identified as far north as the Japanese islands). The source of this air flow (except for that portion which flows off the Australian Continent) is in the warm, oceanic anticyclones of the Southern Hemisphere. Thus, by the time the Equator is reached, the air masses comprising the stream are truly equatorial. Additional heat and moisture are picked up north of the Equator, rendering the air mass moist and unstable throughout an exceedingly great depth by the time it reaches the coastal areas of Asia. The great amount of energy released through the tremendous precipitation within the monsoon on the southerly slopes of the Himalayas and the western slopes of the mountain ranges of Farther India, adds to the development and maintenance of the circulation.

The effects of the Southwest Monsoon on the weather of India and Southeast Asia are well known. The effects are equally pronounced on the windward sides of all islands of the Pacific which are within this air stream. Almost continuous heavy cloudiness and rain are characteristic of slopes facing the wind.

Flying conditions in the Southwest Monsoon are similar to those described for that portion of the Northwest Monsoon which lies south of the Equator.

The Westerlies

On the poleward sides of the subtropical anticyclones lie the regions of the so-called Prevailing Westerlies. This westerly flow is not the more or less steady movement of air from semipermanent areas of high pressure to semipermanent areas of low pressure as is the case with the Trades and certain of the monsoons, but a highly irregular and intermittent flow. The belt of Westerlies is really the region of migrating cyclones and anticyclones and, as a result, the persistency of the west winds is much smaller than the persistency of the other air streams described. Poleward from the regions of the Westerlies, beyond latitudes 65° to 70°, winds with an easterly component again prevail.

The Westerlies are somewhat better developed in the Southern Hemisphere than in the Northern Hemisphere because of the complicating effects of the continents in the latter.

The flow of air in the region of the Westerlies is not everywhere symmetrical along the parallels of latitude. The flow is partly poleward, partly equatorward, as demanded by the necessity for maintaining a meridional circulation over the earth. When the pressure drop from the subtropical anticyclonic belt to the circumpolar belt of low pressure is great, the speed of the westerly flow is intensified. In this case, a "high zonal index" situation is said to exist; the individual anticyclonic cells are better developed but are fewer in number. When the pressure gradient between subtropics and circumpolar low pressure belt is relatively weak, a "low zonal index" situation is said to exist. In this case, the individual anticyclonic cells are less well developed and greater in number, and considerable interzonal flow at the surface exists. As a consequence, the westerly flow is weak.

The region of the Westerlies is essentially a region of changeable weather, where anticyclonic and cyclonic conditions alternate at irregular intervals of from 1 to 25 days. The principal bad weather zones occur, of course, in connection with the extratropical cyclones along the Polar Front, which have been described in previous sections. There are, however, additional areas of persistent cloudiness and fog associated entirely with sea surface conditions and air flow. Wherever fairly warm, moist air is forced to flow over much colder ocean waters, fog and low stratus result from the surface cooling of the air masses comprising the flow. Such conditions may occur either in regions of divergence or convergence and in the absence of lifting. This type of situation is found at high latitudes in the North Pacific (and to a lesser extent in the South Pacific) and, in the warmer months, along the west coast of South and North America. Stable conditions, with widespread low inversion stratus and fog, also occur over the cold ocean currents along the northern Asiatic coasts in summer but, in this case, the phenomenon is more closely associated with the monsoonal circulation than with that of the Westerlies.

Although the surface cloud and fog offer features unfavorable for certain types of air operations (such as the taking of drift measurements), excellent flying conditions usually prevail above the surface inversion layer. The surface layer of thick weather is usually very shallow (most frequently only a few hundred to several thousand feet in depth) and can generally be flown over without difficulty by all types of aircraft.

UPPER WINDS OVER THE PACIFIC

Because of the scanty network of upper air observing stations over the Pacific, the small-scale features of the circulation aloft are only imperfectly known at the present time. Generalizations about the large-scale features can be made, however, by considering the pressure distribution aloft at various levels.

A glance at upper air pressure and air stream charts shows that, outside of the monsoon flows, the general upper air circulation at lower levels in the equatorial Pacific is easterly in character. In the regions of the Trades, there is a marked shifting from easterly winds in the lower layers to westerly winds (the so-called Antitrades) at higher levels. The elevation at which this shift takes place varies with latitude and season as well as from day to day. In each hemisphere, during the colder months, the shift to westerly flow normally occurs at about 8,000 to 10,000 feet, but it occurs at about twice that height in summer. In the vicinity of the Equator, the easterly flow is deep and fairly constant. In the bad weather zones, when they are some distance from the Equator, the lower level of the westerlies aloft drops, sometimes even to the surface. In the eastern part of the Pacific, the westerly winds frequently continue as a northwesterly current across the Equator from the Northern to the Southern Hemisphere. In the northern summer, this flow partly compensates for the northward transport of air by the several monsoon circulations in the western Pacific.

When the *Northeast Monsoon* is active during the Northern Hemisphere winter, there is a southwesterly flow aloft out of China over the Pacific. Along the China Coast, this flow exists at levels above 4,000–5,000 feet, but over the open ocean, the level rises to 8,000 feet. Other monsoon streams are deep and the upper winds, except at the very highest levels, approximately follow the surface air streams.

At high levels in the atmosphere (above 12,000 feet), the individual anticyclonic cells over the Pacific tend to disappear, with the result that the pressure distribution is more nearly zonal in character (particularly in the Southern Hemisphere). At these levels, the pressure decreases steadily from near the Equator toward the poles. The result of such a pressure distribution is westerly winds throughout all higher levels except, perhaps, in the immediate vicinity of the Equator, where easterly winds prevail at some of the higher elevations.

During the warm season in each hemisphere, the continental summer low pressure areas at the surface are replaced by high pressure aloft because of the vertical transport of air into higher levels. Thus during this season the anticyclonic cells are displaced at high levels from the oceans to the continents. This results in a tendency toward a northerly flow aloft along the eastern sides of the continents and a southerly flow along the western sides. This tendency, of course, is merely superimposed upon the general west-east circulation at these levels and is effective only in the lower midlatitudes.

During the winter months in each hemisphere, the surface anticyclones over the continents are replaced by low pressure aloft at fairly low levels because of the vertical "sinking" of air toward the surface. For example, the intense surface anticyclone over Asia has ceased to exist at an elevation of only 6,000 feet. This distribution of pressure results in a tendency toward southerly winds on the eastern sides of the continents (as over the Northeast Monsoon current), and northerly winds on the western sides of the continents.

At higher latitudes, the westerly flow at the surface continues up through all higher elevations, but with greater persistency. At intermediate levels, however, the westerly flow of air is highly irregular because of the effects of the migratory cyclones and anticyclones that pass through the area.

AIR FLOW AND WEATHER ZONES OVER THE PACIFIC

JANUARY

During January the Intertropical Front west of longitude 165° W. lies entirely within the Southern Hemisphere. The anticyclone over Siberia reaches its maximum development during this month with the result that the Northeast and Northwest Monsoon systems are at their maximum intensity. The Northeast Trades of the eastern North Pacific cross the Equator as diverted trades west of 165° W. It is midsummer in Australia with the "thermal" low-pressure area over the western desert region well developed. Auxiliary bad weather zones can be noted between the Northeast Trades and the Northwest Monsoon; between the Southeast Trades and the high-pressure areas east of New Zealand and west of South America; and in northern Australia between the Southeast Trades and the air streams from the west (sometimes called the West Monsoon).

The polar front cyclones in the North Pacific reach their southernmost extension during this month, occasionally occurring as far south as Formosa in the western Pacific. In the Southern Hemisphere, the extratropical cyclones do not penetrate farther north than latitude 35° S.

Gale winds are most frequent during this month northeast of Australia, where they may be expected on about 10 percent of all days. Gales are frequent during this month in the northern North Pacific, also, but January is the month of least frequent occurrence at high latitudes in the Southern Hemisphere. Tropical cyclones occur frequently in the Australian area but are rare in the Northern Hemisphere.

This month presents the maximum rainfall and cloudiness along the United States west coast, where precipitation amounts range from 3 to 15 inches and average cloudiness from 55 to 80 percent. Also, these elements reach their maximum frequency at many stations in the Dutch East Indies that face the Northwest Monsoon of the Southern Hemisphere. It is the rainiest month on the eastern slopes of New Caledonia, the northern slopes of New Britain, and some of the western South Pacific Islands, notably, Samoa and Tahiti, where the mean precipitation for January ranges from 8 to 20 inches.

Although January is the cloudiest month at a number of stations (on the west side of the Japanese islands) which face the Northwest Monsoon, rainfall amounts are low. At the same time, it is a clear month for east coast stations. For example, the mean cloudiness for Kanazawa and Akita on the west coast is between 80 and 90 percent, but for Tokyo and other stations on the east coast, the values range between 40 and 60 percent.

January is the driest and clearest month on the southwest slopes of the Philippines which are protected from the Northeast Monsoon (average rainfall—1 to 2 inches) and on the southwest slopes of some of the Dutch East Indies islands. This is the dry and clear season also in the New Zealand area and in the eastern South Pacific between latitudes 10° S. and 40° S.

FEBRUARY

By February, the Intertropical Front has penetrated its deepest into the Southern Hemisphere, occasionally moving in over northern Australia. Tropical cyclones are frequent along the east and west coasts of Australia, over the South Pacific east of Australia, and, occasionally, in the region east of the Philippines. Auxiliary bad weather zones exist over the South Pacific east and north of the Fiji Islands, over the North Pacific between the Marianas and the Philippines, and in the Northeast Trades between the Hawaiian Islands and Wake.

The polar front cyclones in the Southern Hemisphere begin to penetrate farther northward, in the eastern South Pacific occasionally reaching as far as the Juan Fernandez Islands.

February is the rainiest month at stations in the South Pacific in the vicinity of the Intertropical Front and the South Pacific auxiliary bad weather zone east of the Fiji Islands (mean rainfall during this month at Makcta is 8.8 inches). It is still the rainy season in northern Australia, along the eastern sides of the Philippines, and on the northern slopes of some of the Dutch East Indies (rainfall is at a maximum during this month on the north coast of Ceram—up to 17 inches).

The dry Northwest Monsoon season continues over most of the rest of the northwest Pacific, with precipitation amounts between 1 and 3 inches. Exceptions are some stations on the western slopes of the Japanese islands, where amounts run as high as 8 inches.

In the eastern Pacific, precipitation and cloudiness continue to be high north of latitude 35° N., but the dry season continues in the southeastern South Pacific.


JANUARY
NORTH WEST
MONSOON
HIGH
NORTH EAST
CYCLONES
FREQUENT
SOUTH EAST TRADES
LOW
AUSTRALIA
LOW
HURRICANES
FREQUENT
SOUTH EAST TRADES
SOUTH EAST TRADES
HIGH
HIGH
HIGH
HIGH


FEBRUARY
HIGH
AFGHANISTAN
NORTH WEST MONSOON
HIGH
MONSOON
NORTH WEST MONSOON
SOUTH EAST TRADES
LOW
AUSTRALIA
SOUTH EAST TRADES
SOUTH EAST TRADES
HIGH
HIGH
AXIS OF HIGHS
HIGH

MARCH

In March, the Intertropical Front over the western South Pacific begins to retreat northward, and the Southeast Trades become stronger over Australia as the summer thermal *low* begins to weaken. The bad weather zone over Australia is similarly displaced westward by the increased intensity of this flow. The Siberian winter anticyclone becomes considerably weaker than during February. The Northeast Trades, however, continue to move across the Equator west of the 160th meridian.

The polar-front cyclones in both hemispheres follow approximately the same tracks as they do in February, continuing to move south of the 20th parallel in the Northern Hemisphere, and nowhere moving nearer the Equator than the 30th parallel in the Southern Hemisphere.

Tropical cyclones continue to occur on the east and west coasts of Australia and now form also over the Arafura and Coral Seas.

Precipitation and cloudiness begin to decrease rapidly in the northeastern North Pacific, while they begin their winter increase in the corresponding region in the eastern South Pacific. In the western North Pacific, cloudiness and rainfall increase during this month along the east coasts of the Japanese islands, but decrease on the east coasts of the Philippines as the Northeast Monsoon begins to weaken.

In the western South Pacific, the period of maximum rainfall is reached during March at Rarotonga (12 inches), in the Fijis (14 to 17 inches), and along the extreme northeast coast of Australia (where the average March precipitation ranges from 9 to 17 inches).

APRIL

In April, the Intertropical Front continues its retreat northward throughout its entire length, although it still remains south of the Equator in the western portion. The greatest change from the previous month is the cessation of the Northwest Monsoon in the western North Pacific and its replacement by the trade circulation. The Northeast Trades continue to blow across the Equator between longitudes 180° and 140° E.

The polar front cyclones of the Southern Hemisphere begin moving northward over Australia, with their effects occasionally extending as far as Brisbane on the east coast. The polar front cyclones in the North Pacific do not extend nearer the Equator than the 30th parallel, except in the far western portion, where weak cold fronts occasionally extend down as far as Formosa.

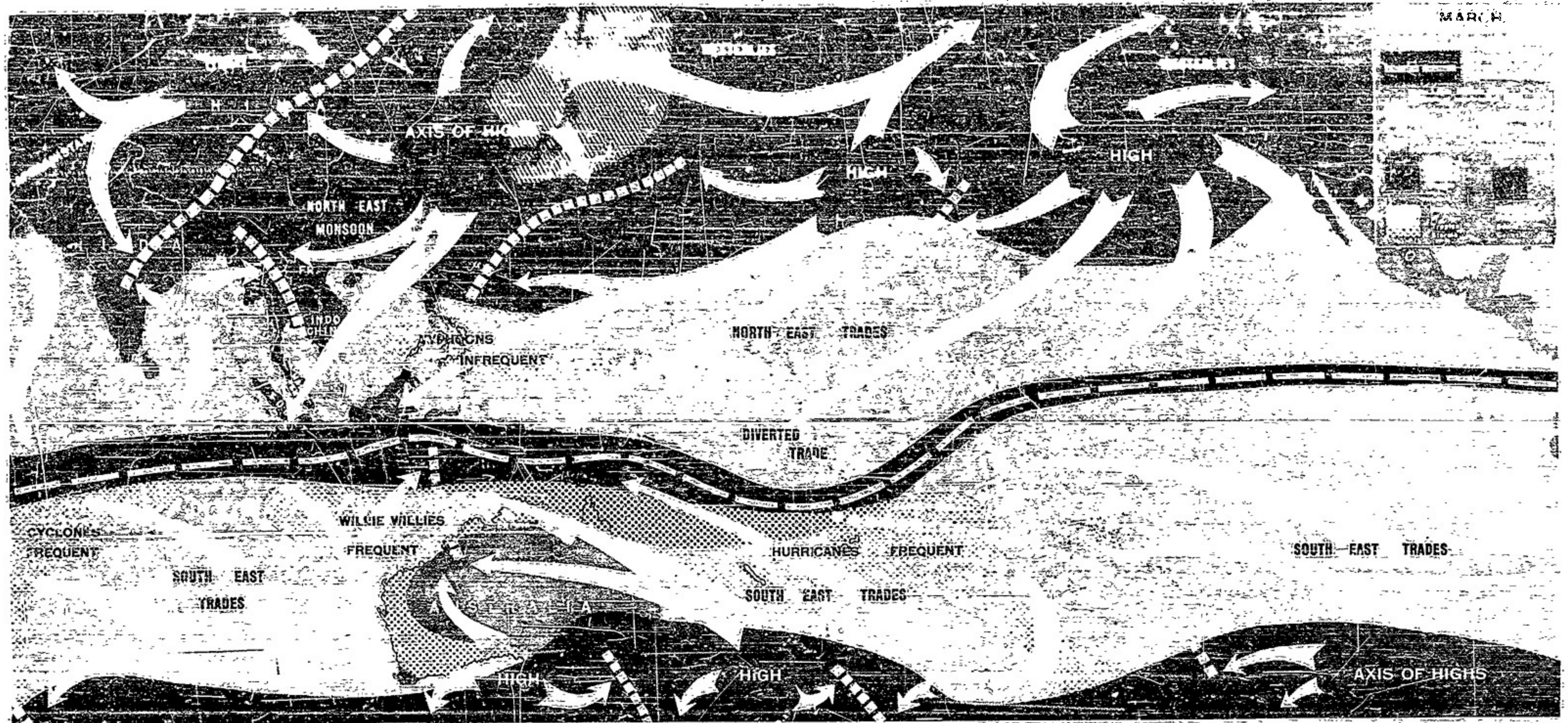
Because of the equatorial position of the Intertropical Front during April, tropical cyclones are infrequent in either the Northern or Southern Hemisphere.

Precipitation and cloudiness decrease slowly during April in the northeastern North Pacific but continue to increase in the corresponding latitudes in the eastern South Pacific, as the polar front cyclones extend their effects northward. This is the month of maximum precipitation at the Equator in the vicinity of the Galapagos Islands and along the northwest coasts of South America.

Precipitation is at a maximum during April at nearly all stations in Borneo, since this is the month during which the Intertropical Front begins, as it moves northward, to pass over the island. Representative rainfall amounts are 17 inches at Puruktjau, 19 inches at Poetoessibau, 12 inches at Amuntai, and 8 inches at Samarinda. Elsewhere over the Dutch East Indies, the rainfall and cloud amounts generally show a decrease over March.

Precipitation is at a maximum during April at Fanning Island (13.5 inches) and at Midway (5 inches). Elsewhere over the tropical Pacific east of the 170° E. meridian, rainfall decreases during April. In the New Zealand and southeastern Australia regions, precipitation and cloudiness continue to increase toward their winter maximum.

In the western North Pacific, cloudiness and rainfall on the east coasts of the Japanese islands show an increase over March, with amounts ranging between 5 and 10 inches. On the west coasts of the Philippines, however, April is the month of least precipitation, with the average amounts ranging from 1 to 3 inches.


MARCH
AXIS OF HIGH
NORTH EAST
MONSOON
HIGH
HIGH
TYPHOONS
INFREQUENT
NORTH EAST TRADES
DIVERTED
TRADE
CYCLONES
FREQUENT
WILLIE WILLIES
FREQUENT
SOUTH EAST
TRADES
HURRICANES FREQUENT
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SOUTH EAST TRADES
HIGH
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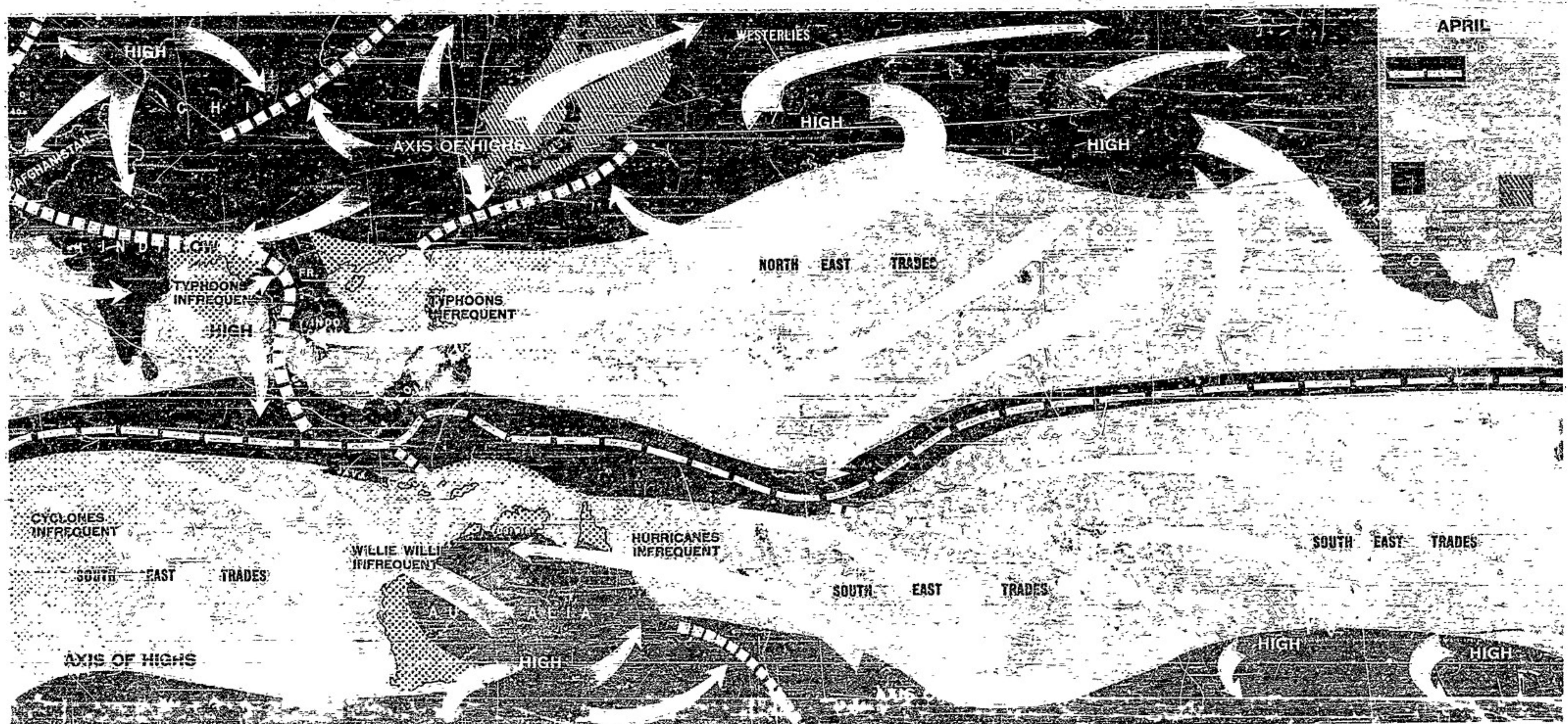
AXIS OF HIGHS


APRIL
WESTERLIES
HIGH
AXIS OF HIGHS
HIGH
HIGH
AFGHANISTAN
LOW
TYPHOONS
INFREQUENT
HIGH
TYPHOONS
INFREQUENT
NORTH EAST TRADES
CYCLONES
INFREQUENT
SOUTH EAST TRADES
WILLIE WILLIES
INFREQUENT
HURRICANES
INFREQUENT
SOUTH EAST TRADES
SOUTH EAST TRADES
AXIS OF HIGHS
HIGH
HIGH
HIGH

MAY

In May, the thermal *low* which existed over Australia during the summer has been replaced by a weak anticyclone. Meanwhile, over Asia, the winter anticyclone has completely disappeared, and low pressure begins to take its place. As a result, the Southeast Trade stream is intensified in the western Pacific and begins to penetrate into the Northern Hemisphere as the Southwest Monsoon. The Intertropical Front is now entirely in the Northern Hemisphere except between longitudes 160° W. and 160° E. Auxiliary bad weather zones exist in the Southeast Trade wind system near Easter Island and along the Pitcairn-Ellice Island axis. In the Northern Hemisphere, an additional auxiliary convergent zone exists between Midway and the Hawaiian Islands. Tropical cyclones (typhoons) become frequent in the area northeast of the Philippines but become infrequent south of the Equator.

The polar front cyclones in the Southern Hemisphere continue to advance northward and occasionally affect some of the southernmost tropical Pacific islands. In the Northern Hemisphere, extratropical cyclones become infrequent south of the 30th parallel.

Precipitation and cloudiness continue to decrease in the eastern North Pacific, where precipitation amounts average between 0.5 and 4 inches. The summer stratus régime begins along the southern and central California coasts, but cloud amounts still remain less than during midwinter. May is the driest and clearest month along the southern coast of Lower California (average rainfall at La Paz -0 inches, average cloudiness 25 percent). In the eastern South Pacific, precipitation increases and is at a maximum at isolated Chilean stations during this month (Traiguen—8 inches). Cloudiness is at a maximum during May at Frutillar (86 percent) and Valparaiso (50 percent).

Precipitation and cloudiness increase over all portions of Southeast Asia affected by the Southwest Monsoon. They reach a maximum during this month over the southern portion of the Philippines (Davao precipitation—10 inches), the Banda Islands (15 inches), the southwest coast of New Guinea (Fakfak—13 inches), and the southeast portion of Celebes (Kendari—8 inches). Rainfall is at a maximum during this month also over portions of the Marshall Islands (Jaluit—16.5 inches). In the southern South Pacific, cloudiness and precipitation continue to increase toward the winter maxima.

JUNE

During June, the Intertropical Front lies entirely in the Northern Hemisphere. The North Pacific anticyclone meanwhile has increased in intensity, but the low pressure over Asia has become deeper. The Southwest Monsoon now covers almost the whole of Farther India, the South China Sea, and the southeastern portion of the Philippines. The Australian winter anticyclone continues to strengthen, sending out dry continental air over parts of the Dutch East Indies. Auxiliary bad weather zones exist between New Zealand and the Fijis, along the Pitcairn-Ellice Island axis, between Easter Island and the South American coast, and in the North Pacific midway between the Hawaiian Islands and the Kuriles. Tropical cyclones become more frequent in the North Pacific east of the Philippines and south of the Japanese islands.

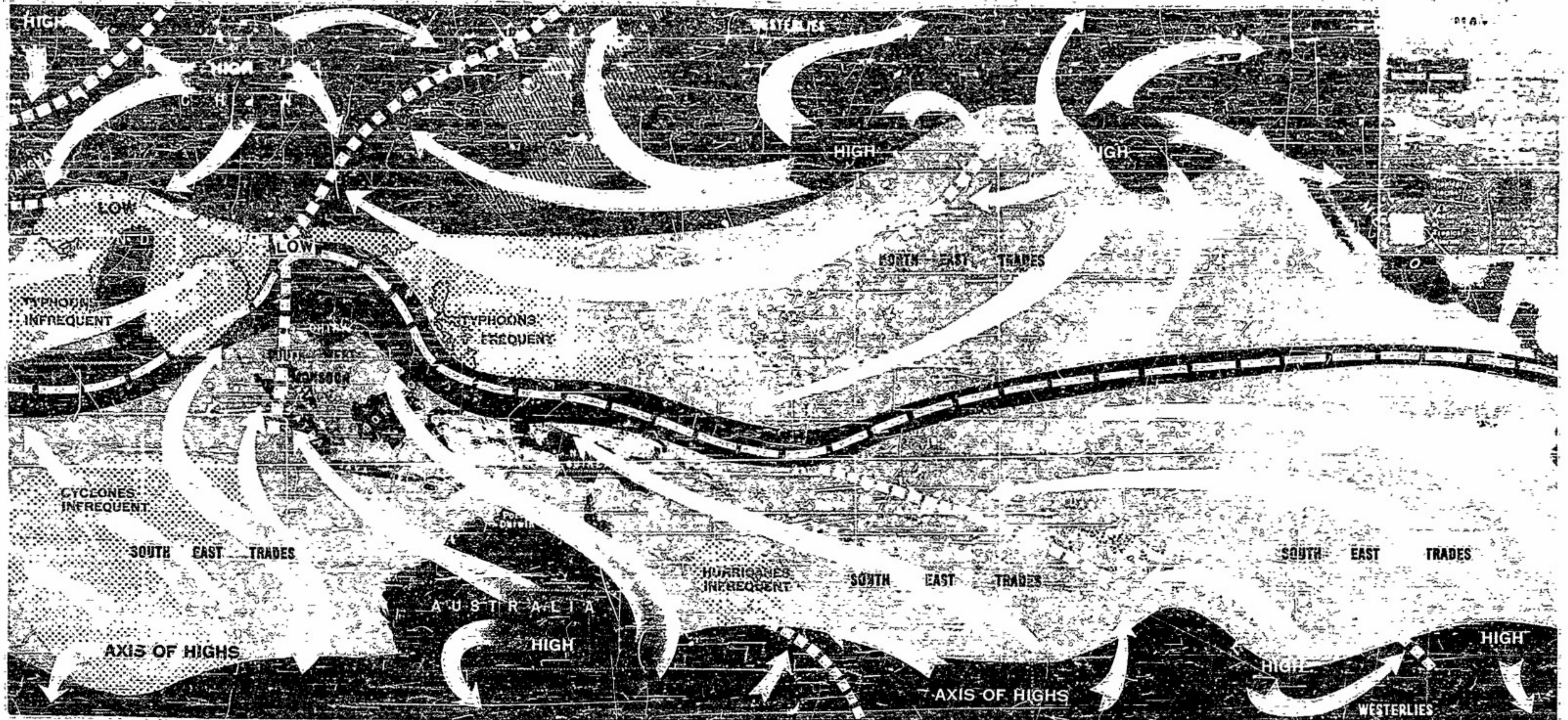
June is the month with the greatest number of gales in the South Pacific at the higher latitudes. Elsewhere over the North Pacific and the tropical South Pacific, winds of gale force are comparatively rare.

The polar front cyclones in the Southern Hemisphere occasionally extend their influence as far north as the 20th parallel during this month. In the Northern Hemisphere, however, they seldom occur south of latitude 35° N.

June is one of the driest months in the eastern North Pacific north of the 30th parallel, and in the central North Pacific (Honolulu—1 inch). It is the clearest month along the central California coast (average June cloudiness at San Francisco—30 percent). It is, however, the wettest month along portions of the Mexican and Central American coasts (average June precipitation at Tapachula—18 inches). In the Southern Hemisphere, June is the rainiest and cloudiest month along most of the South American coast between latitudes 30° S. and 45° S. and also over the southeastern South Pacific in general. Representative figures for precipitation are 6.5 inches over the Juan Fernandez Islands, 9 inches at Easter Island, 8 inches at San Fernando, and 14 inches at Punta Arenas.

Over the northwest Pacific, June is the wettest month in southern Japan (Kagoshima—17 inches) and along the Asiatic east coast between latitudes 20° N. and 35° N. Representative precipitation values for this region along the China coast are 10 inches at Nanning, 16 inches at Hong Kong, 10.5 inches at Swatow, 10.5 inches at Wenchow, and 7.5 inches at Shanghai. This rainy period (often referred to in China and Japan as the period of the "Bai-U" or "Plum Rains") is associated with the Polar Front which often exists in a quasi-stationary position over China and Japan during June.

In the western South Pacific, June is one of the dry months in the Dutch East Indies, which are now partially under the control of dry continental air from the Australian anticyclone. It is the driest month in portions of the Solomons (Tulagi—7 inches) and New Britain (Rabaul—3 inches). Nevertheless, June is one of the rainy months in the portions of the South Pacific under the influence of the Polar Front system.



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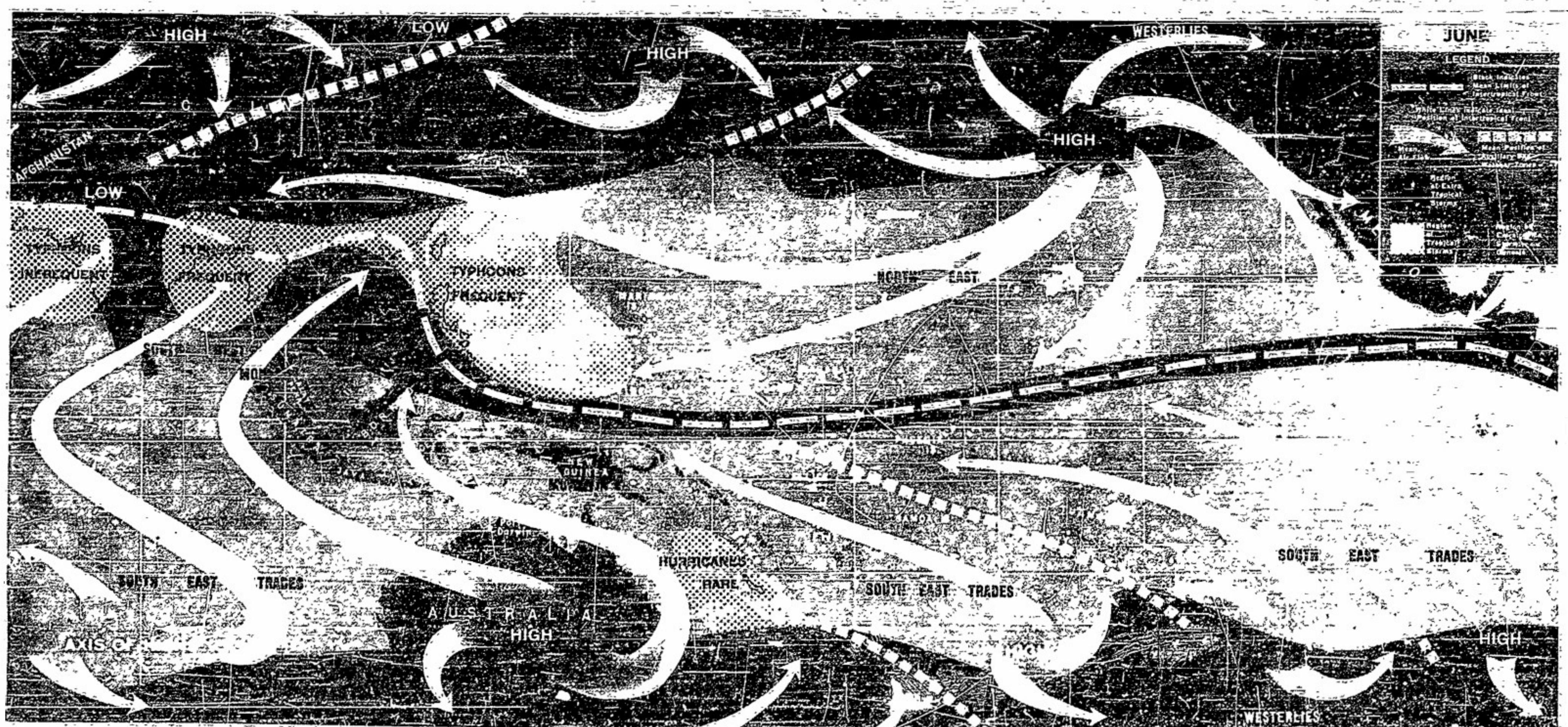

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JULY

July is the month when the Southwest Monsoon attains its greatest development, sometimes extending as far north as the Japanese islands. East of the Philippines, the Southeast Monsoon also becomes its strongest, as both the North Pacific summer anticyclone and the Asiatic thermal *low* attain their greatest intensities. Meanwhile, the Australian winter anticyclone achieves its greatest development, causing a strong outflow of dry continental air over the Arafura and Timor Seas. Auxiliary bad weather zones exist in the South Pacific along the Pitcairn-Gilbert Island axis and between New Zealand and the Fijis.

Tropical storms become frequent in the western North Pacific and occasionally extend their influence as far north as the Japanese islands. They also occur infrequently in the eastern North Pacific in the vicinity of the Revillagigedo Islands. They do not occur in the Southern Hemisphere during this month.

Polar front cyclones in the Southern Hemisphere occasionally extend as far north as the Loyalty Islands, New Caledonia, and Pitcairn. They are relatively rare in the North Pacific south of latitude 40° N., except in the western portion.

July is the driest month in the part of the eastern North Pacific between latitudes 30° N. and 50° N., with rainfall amounts ranging from 0 to 2 inches at coastal stations and over the ocean. In the eastern South Pacific between latitudes 20° S. and 45° S., rainfall and cloudiness decrease slowly from their June maxima.

This month presents the maximum rainfall amounts in portions of the Philippines (Manila—17 inches) and at an occasional station on the west coast of the Japanese islands (Okayama—6.5 inches). However, it is the driest month at many stations in Borneo and elsewhere in the East Indies, which are located on northeast slopes and therefore protected from the Southwest Monsoon. Rainfall during July is at a minimum for the year at Kuching (5 inches), Puruktyou (8 inches), Poetoessibau (9.5 inches), and similarly exposed stations elsewhere in Borneo. It is at a minimum also at Palembang (4 inches) and Seribudolock (3 inches), both on the northeastern side of Sumatra.

July is generally the driest month over north central Australia as well as over a number of the southwestern Pacific islands, notably, the Fijis (mean precipitation at Navua—5 inches; at Suva—5 inches), Rarotonga (4 inches), and Samoa (3 inches). It is the rainiest month, however, in the western South Pacific between latitudes 25° S. and 45° S. Representative July rainfall figures are 6.5 inches for Norfolk Island and 5 inches for Aukland, New Zealand.

AUGUST

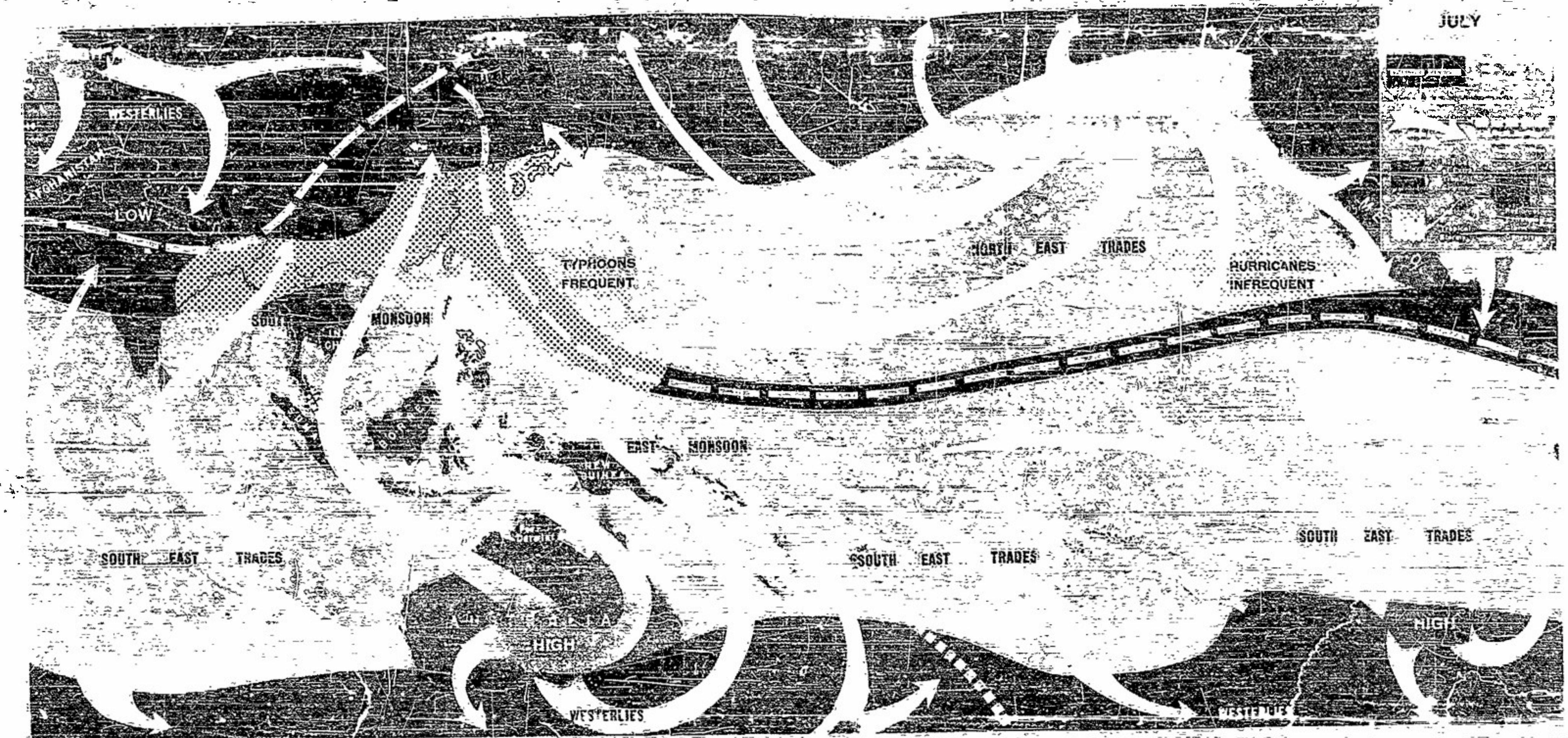
During August, the Intertropical Front begins its southward migration, except in the central Pacific, where it remains approximately stationary. The low pressure area over Asia begins to weaken, and the Southwest Monsoon withdraws from northern China. Tropical cyclones are frequent during this month in the North Pacific south of the Japanese islands, north of the Philippines, and as far east as the Marianas. They also occur infrequently along the west coast of Mexico between Acapulco and the northern border. One or two have extended their effects as far north as southern California during this month.

Polar front cyclones in the North Pacific begin to occur farther southward than they do in July, sometimes affecting Midway Island at the northwestern end of the Hawaiian chain. In the Southern Hemisphere, the extratropical cyclones follow approximately the same paths as they do in July.

August, also, is a dry month along the west coast of the United States and in the northeastern North Pacific, although in the far north, precipitation increases slightly over that of July. The wet season continues along the Mexican west coast (Tapachula—11 inches). In the eastern South Pacific, rainfall decreases rapidly south of the 20th parallel but increases northward. It is the cloudiest month along the southern coast of Peru (Mollendo—85 to 90 percent) and the north coast of Chile (Iquique—85 percent), since it is in this month that the South American west coast stratus regime reaches its maximum development.

August is the clearest month along the south and west coasts of Honshu in the Japanese islands (Sakai—60 percent, Kanazawa—60 percent, Akita—65 percent), but it is the rainiest month to the northward, in the vicinity of the Okhotsk Sea. Representative rainfall figures in the latter area are 3.5 inches at Bolsheretsk, 3 inches at Nikolaevsk, and 6 inches at Sofiski Priisk. It is the cloudiest month along portions of the northeastern coasts of the Philippines (Baguio—90 percent, Manila—80 percent).

The dry season continues over most of the East Indies south of latitude 5° N., and August is the driest month in the vicinity of Ceram (Wahai—3.5 inches, Banda—4 inches), parts of Celebes (Pangkadiene—1 inch), southeastern Borneo (Amuntai—2.5 inches), the north coast of Java (Cheribon—1 inch, Kendari—1 inch), and on Flores (Ende—1 inch). It is also the driest month along the central east coast of Australia (Bundaberg—2 inches average August precipitation), and over several of the South Pacific islands, notably, the Society Islands (Papeete—2 inches) and the Marquesas (Atuana—3 inches). August is, however, the wettest month at several of the northwestern tropical Pacific islands, namely, Guam (15.5 inches) and Wake Island (6 inches).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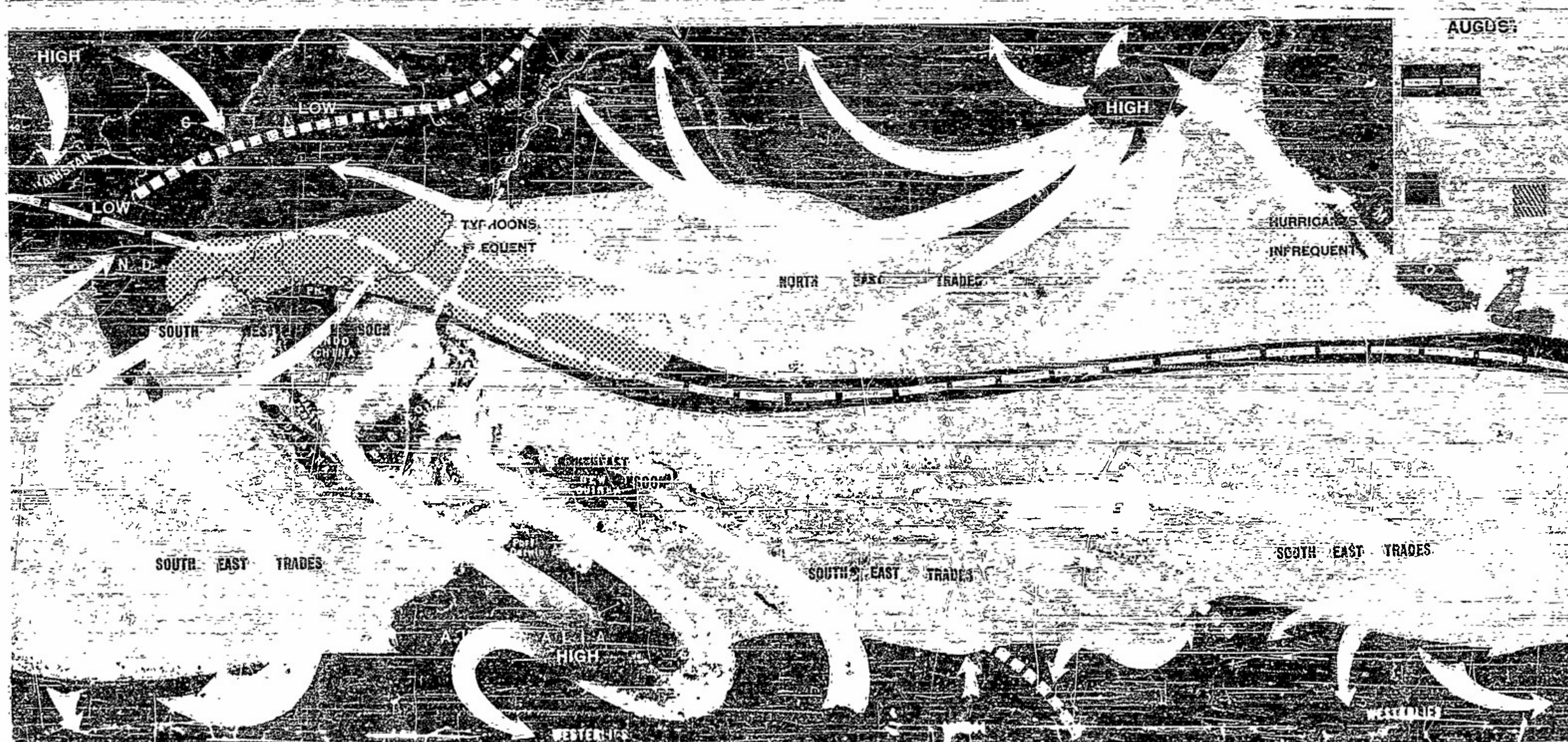
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SEPTEMBER

By September, the Asiatic summer *low* has completely disappeared and is replaced by a weak anticyclone. The Northwest Monsoon begins in the north as a result of this pressure distribution, although the Southwest Monsoon is still in existence over most of Southeast Asia as far north as Luzon and the South China Sea. The Intertropical Front continues its movement southward, although at a very slow rate except in the far western portion. Anticyclonic conditions still prevail over Australia, and dry continental air continues to flow out of the interior over the Arafura and Timor Seas. Auxiliary bad weather zones exist in the Southeast Trades along the Cook-Caroline Islands axis and between New Zealand and the Fijis. There is also a small secondary zone of convergence between Easter Island and the Juan Fernandez Islands. In the Northern Hemisphere, an important zone of convergence begins to develop during September between the trade wind system and the Northwest Monsoon air over the western Pacific.

Tropical cyclones occur frequently in the western North Pacific south of Japan and north of the Intertropical Front. They also occur infrequently in the region just east of the Hawaiian Islands and along the Mexican and Lower California coasts north of the Revillagigedo Islands, occasionally reaching the southern California coastal region as weak disturbances. (An exception occurred in September 1939, when a well-developed hurricane reached as far north as the Los Angeles area.)

Polar front cyclones in both the Northern and Southern Hemispheres follow approximately the same paths as they do in August.

September is one of the dry months in the western North Pacific north of latitude 30° and is the clearest month along portions of the Washington coast (Tatoosh Island—60 percent average cloudiness). It is still the wet season along the Mexican west coast, however, and rainfall amounts at some coastal stations run as high as 18 inches. Cloudiness remains high along the west coast of South America between the 10th and 20th parallels, with average cloudiness for the month ranging between 80 and 90 percent. It is also the cloudiest month in the vicinity of Easter Island (60 to 70 percent).

September is the rainiest month at most Japanese east coast stations (Kochi—16 inches, Tokyo—9 inches, Ishinomaki—7 inches, Hakodate—7 inches) as well as along portions of the Indo-China coast (Dalat—12 inches). It is, however, the driest month over many portions of the Dutch East Indies, notably, Timor Laut (Saumlakki—1 inch), Sandalwood Island (Waingapu—less than 0.5 inch), northeastern Celebes (Gorontalo—2 inches), and over portions of Java (Ragadjampi—3 inches). It is also the driest month in extreme northeastern Australia (Cooktown—0.5 inch, Cape York—less than 0.5 inch), as well as in parts of the northern Solomons (Kieta—8 inches) and at Ocean Island (4 inches).

OCTOBER

During October the Intertropical Front continues its southerly movement but still remains entirely within the Northern Hemisphere. The Asiatic anticyclone increases in intensity, with the result that the Northwest Monsoon circulation increases in strength and persistency. The Northeast Monsoon begins over the Yellow and South China Seas. Meanwhile, the Australian winter anticyclone has become very weak, although the Southeast Monsoon continues with decreased intensity. The Southwest Monsoon has withdrawn entirely from China, and during this month exists only over the southern portion of the South China Sea, Mindanao, the southwestern portion of Indo-China, and the Malay States. Auxiliary bad weather zones in the Southern Hemisphere exist over the northern portion of the Tasman Sea, along the Pitcairn-Bismarck axis, and between Easter Island and Pitcairn. In the Northern Hemisphere, an additional auxiliary convergent zone exists between the trades and the Northwest and Northeast Monsoons.

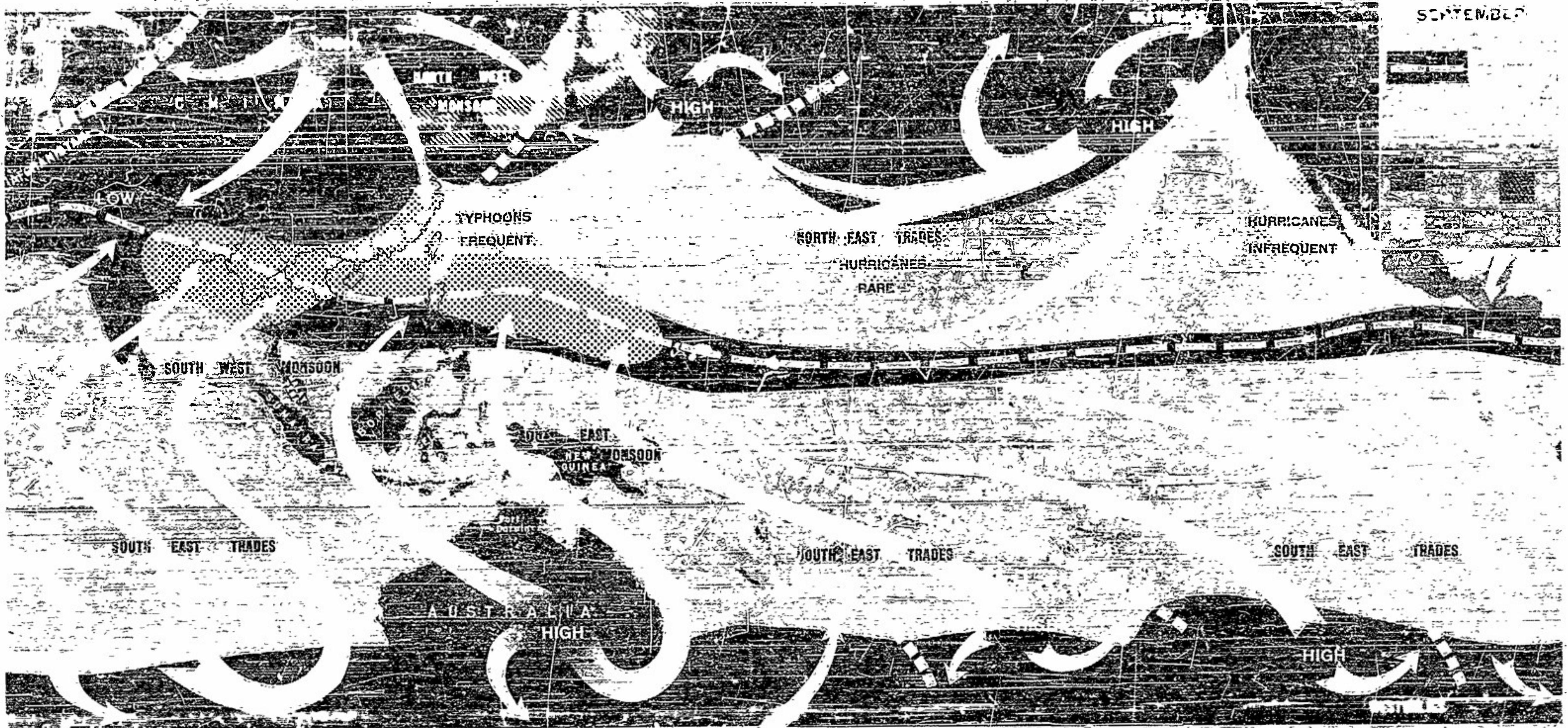
Tropical cyclones occur frequently during October in the far western Pacific south of latitude 25° N. and north of the Intertropical Front. They occur less frequently in similar latitudes along the Mexican west coast, in the area around Wake Island, and, in the Southern Hemisphere, over the Coral, Arafura, and Timor Seas.

Polar front cyclones in the Northern Hemisphere extend their effects southward during October, occasionally occurring as far south as the Hawaiian Islands. In the Southern Hemisphere, the extratropical cyclones seldom occur north of the 30th parallel except in the vicinity of Pitcairn Island.

In the northeastern North Pacific, precipitation and cloudiness increase rapidly over that of September, as extratropical cyclones become more frequent. It is the cloudiest month along parts of the southern coast of Alaska (Juneau—80 to 90 percent). At corresponding latitudes in the eastern South Pacific, rainfall and cloudiness decrease as the Southern Hemisphere polar front cyclones become less frequent. It is the driest month at Easter Island (average October rainfall—1.9 inches).

In the northwestern North Pacific, precipitation and cloudiness decrease generally over the Japanese islands and over the Asiatic east coast as far south as the 20th parallel. It is, however, the rainiest month over the Komandorskie Islands (Medny Island—3 inches) and over portions of the Aleutians (Dutch Harbor—7.5 inches). It is also the wettest month over parts of Indo-China (Hué—26 inches, Phnom-Penh—10 inches) and over portions of the Philippines (Cebu—8 inches).

Rainfall and cloudiness begin to increase over most of the Dutch East Indies during October, as the dry Southeast Monsoon from Australia weakens in intensity, although it is still the dry season here as well as over northern Australia. October is the driest month in New Caledonia (Noumea—2 inches, Pouébo—2.5 inches) and over portions of the southeastern coast of Australia (Port Macquarie—3.5 inches). It is the clearest month in the vicinity of Malden Island (average cloudiness for October—10 to 15 percent).


SEPTEMBER
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NOVEMBER

During November, the Intertropical Front continues its southward movement and the western portion of it is now in the Southern Hemisphere. The Southwest Monsoon has by now completely disappeared and is replaced entirely by the Northwest and Northeast Monsoon circulations north of the Equator. A weak anticyclone still exists in the far southern coast of Australia, but a low pressure area begins to form in the extreme northeast during this month. However, an outflow of dry continental air over the Arafura and Timor Seas still continues. Auxiliary zones of convergence exist in the Southeast Trade stream along the Society Islands-Solomon Islands axis to the northeast of New Zealand, and one exists in the eastern South Pacific southwest of Easter Island. In the Northern Hemisphere, an important auxiliary bad weather zone exists between the trade circulation and the Northwest and Northeast Monsoon streams. The Siberian anticyclone continues its development, but a small, weak high pressure area also forms over the southern Japanese islands, resulting in the formation of a secondary zone of convergence along the Asiatic east coast.

Tropical cyclones are still frequent in the Philippines, Mariana Islands, and South China Sea regions.

Polar front cyclones in the Northern Hemisphere extend their influence still farther south during November and become more frequent and intense throughout the entire belt of Westerlies. In the Southern Hemisphere, such storms seldom occur north of the 30th parallel.

Precipitation and cloudiness both increase rapidly in the eastern North Pacific north of latitude 25° N., and November is the wettest month along portions of the coast of British Columbia (average November rainfall is 7.5 inches at Bella Coola). It is also the cloudiest month along most of the Washington coast (Tatoosh Island—80 percent average cloud cover). South of the 20th parallel, however, cloudiness and precipitation decrease generally except over the central Pacific in the vicinity of the Hawaiian Islands, where some stations report the maximum rainfall amounts during November. Examples of the latter are Hakalau (22.5 inches), Honomu (24.5 inches), and Tantalus (15 inches). It is the driest month at Midway (2 inches) and Fanning Island (3 inches).

In the eastern South Pacific, cloudiness and precipitation decrease generally toward the summer minima. November is the clearest month along parts of the Chilean coast, as, for example, at Refresco, where the average cloudiness is between 5 and 10 percent.

Rainfall continues to decrease over the east coasts of the Japanese islands as well as over the entire Asiatic coast and the Philippines down to the 10th parallel. Precipitation increases, however, over most of the East Indies and northern Australia as the summer wet season is approached.

DECEMBER

During December, the Intertropical Front west of longitude 170° W. lies entirely within the Southern Hemisphere. The anticyclone over Siberia has become well developed, with a resulting intensification of the Asiatic monsoonal circulation. The Northwest Monsoon now penetrates the Southern Hemisphere over the Java and Arafura Seas. The Northeast Trades of the eastern North Pacific cross the Equator as diverted trades west of 170° W. The thermal summer *low* has developed over northwestern Australia, causing a westerly flow (sometimes called the West Monsoon) along the northern coast of Western Australia and Northern Territory. Auxiliary zones of convergence in the Southern Hemisphere exist between the Tuamotus and the Fijis, over eastern Australia, and over the region northeast of New Zealand; in the Northern Hemisphere, in the region west of the Hawaiian Islands and between the trade circulation and the Northwest and Northeast Monsoons.

Tropical cyclones occur infrequently in the Philippine region and in the area around the Fiji Islands. The polar front cyclones in the Northern Hemisphere occur farther south than in November except in the central North Pacific, where they appear to take a more northerly course. In the Southern Hemisphere, extratropical cyclones do not occur farther north than latitude 30° S.

Winds of gale force become relatively infrequent at higher latitudes in the South Pacific, but December is the month of their most frequent occurrence in the northern North Pacific. Winds of force 7 or higher occur on an average of 35 percent of the days during this month in the region southeast of the Kamchatka Peninsula.

In the northeastern North Pacific, December is the rainiest month along the Oregon and Washington coasts. Representative rainfall figures for the month are 8.5 inches at Northhead, 13.5 inches at Aberdeen, and 6.5 inches at Portland. It is also the [illegible] month over many parts of the Hawaiian Islands; for example, Honolulu has 4 inches, Wahiawa 15 inches, Eke 25.5 inches, and Molokai 5 inches. It is, however, a dry-season month along the west coast of Mexico south of latitude 20° N.

In the eastern South Pacific, rainfall and cloudiness increase along the South American coast between latitudes 0° S. and 15° S., but precipitation continues to decrease elsewhere over the area.

Cloudiness and precipitation continue to decrease along the west coast of Japan and Asia south to latitude 10° N. December is the driest month at Hong Kong (1 inch), Shanghai (1.5 inches), Tokyo (2 inches), Nanning (1.5 inches), and similarly located stations. Nevertheless, December is the rainiest month over some portions of western Japan facing the Northwest Monsoon, for example, at Kanazawa where the mean December precipitation is 14 inches. It is a wet month over some of the Dutch East Indies and Malaya, presenting the maximum rainfall over parts of Sumatra (Bireuën—10 inches, Seribudolock—9 inches, and Palembang—18 inches). This month is also the cloudiest at some stations along the east coast of Indo China, for example, in the vicinity of Nha-Trang, where the average for December is between 75 and 80 percent. This is the clearest month for most east coast Japanese stations (Sakai—80 percent, Tokyo—40 percent, Nagasaki—65 percent); for most of Korea (Fusan—30 percent, Jinsen—45 percent); and for the Ryukyu Islands (Miyako—45 percent).


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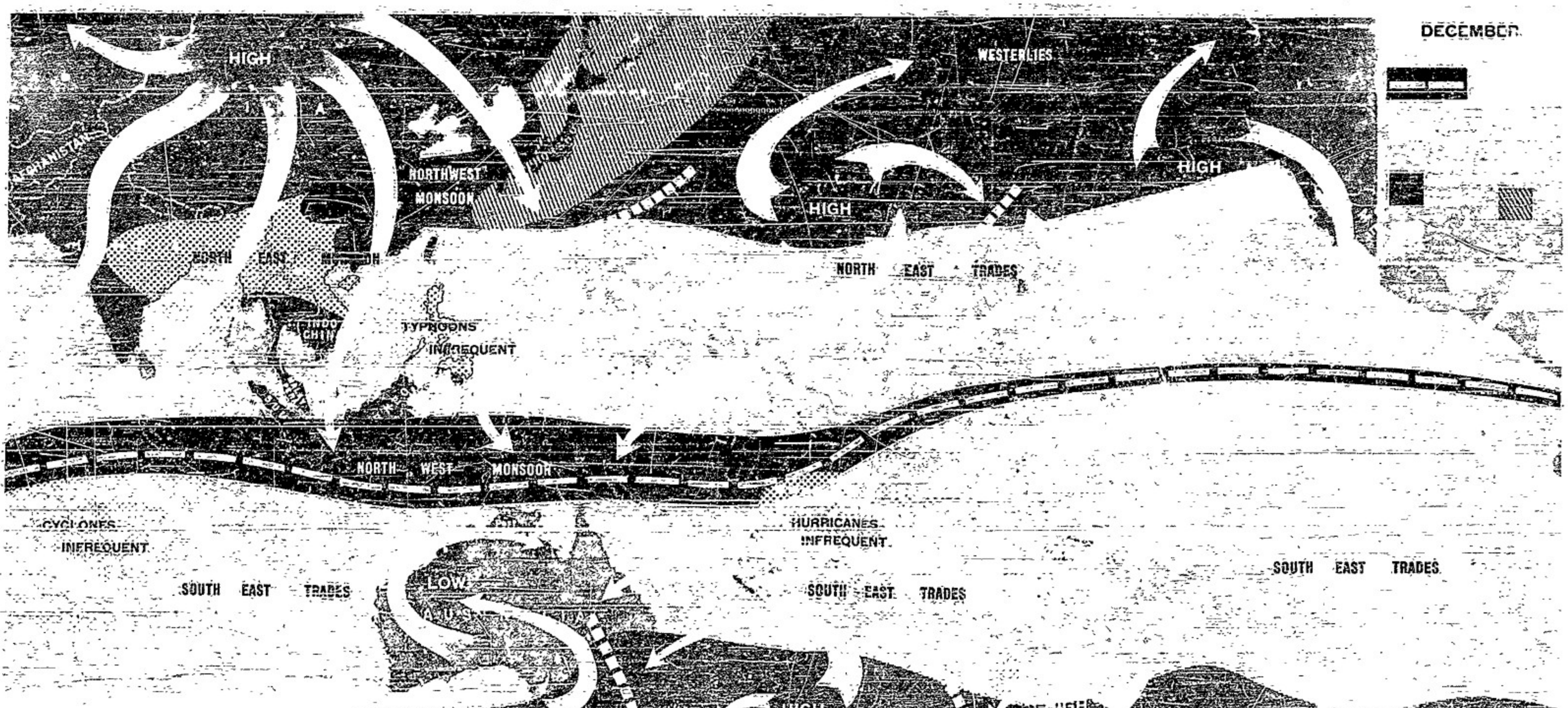
DECEMBER
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HURRICANES INFREQUENT
SOUTH EAST TRADES
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LOW
HIGH

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