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MARINE METEOROLOGY

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FOREWORD

The present textbook, entitled Marine Meteorology, was prepared for the regular course trainees of the Training Department, to meet the needs of the new curriculum which was introduced in December 1978. This textbook constitutes one of the volumes in the Oceanography and Meteorology Series, the others being Fisheries Oceanography, published in September 1978, and Oceanographic Observation Methods, which will be published in the near future. The author hopes that this series of textbooks will prove useful, not only to the trainees but also to all those interested in these subjects.

Finally, the author wishes to express his thanks to Miss B. Mountfield for her helpful suggestions and comments during compilation of the text, as well as to Mrs. Kanchana Rodchareon for her devoted assistance in the preparation of the draft.

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March 1979

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MARINE METEOROLOGY

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1. ATMOSPHERE AND ITS VARIATIONS

1.1. Atmosphere

The air surrounding the earth is called the atmosphere. It follows the rotation of the earth in a general west to east direction and at a speed of 376 m/sec. The state of the atmosphere is always changing. The atmosphere consists mainly of a mixture of nitrogen and oxygen; it also contains argon, carbon dioxide, hydrogen, neon, helium, etc. The components of the atmosphere, with the exception of water vapour, are shown in Table 1.1. The content of water vapour in the atmosphere is different at different times and in different localities, but it may reach almost 4% at the highest and fall to zero in the polar areas in winter. On an average, the content of water vapour is 0.2% in winter and 2% in summer. Vertical convection takes place in the atmosphere up to a height of about 5 km; therefore, the proportion of the constituents is almost constant within this range. However,

Table 1.1 Composition of the Atmosphere

Gasses	Nitrogen	Oxygen	Argon	Carbon dioxide	Hydrogen	Neon	Helium
Proportion (%)	78.08	20.49	0.94	0.03	0.01	0.0012	0.0004
Density ($\times 10^{-5}$)	13.92	15.94	19.82	22.01	1.00	9.91	1.97

heavy oxygen gradually decreases with an increase in altitude, whereas light gases such as hydrogen and helium increase with altitude. Roughly speaking, at a height of about 50 km the atmosphere contains mainly nitrogen and at a height of 100 km mainly hydrogen.

In the atmosphere, an innumerable number of fine particles of earth and sand, soot, bacteria and other fine dusts of organic and inorganic matters are suspended, and most of these particles become the cores of water vapour condensation. Therefore, these particles, together with the water vapour, become the causes of meteorological phenomena such as rain, snow, fog and thunderstorms. In coastal areas and over the ocean, minute particles of salt in suspension, produced from the spray of waves, become condensation cores of fog.

We are living at the lowest level of the atmosphere; the uppermost limit of the atmosphere has not yet been clearly determined. Meteorological phenomena such as clouds, fog, rain and winds usually occur in the troposphere, which extends to about 12 km above the earth. In the troposphere, temperature decreases with increasing altitude at a rate of about $6^{o}C$ per 1 km. The layer above the troposphere is called the stratosphere, and the temperature there is almost constant, usually around $-55^{o}C$. The boundary between the troposphere and the stratosphere is called the tropopause. The tropopause is highest near the equator, i.e., nearly 17 km, and the height decreases with increasing latitude; it is 8 to 10 km at about latitudes 60^{o} to 90^{o}. In Japan, this height is about 15 km in summer and 9 km in winter.

In the stratosphere, nacreous clouds appearing in higher latitudes occur at a height of 20 to 30 km and the ozone maximum layer is as high as 20 to 25 km. It is evident from the unusual propagation of sound waves that a high temperature layer exists at a height of about 50 km. The layer in which twilight occurs is about 63 km in height. On summer nights in higher latitudes, luminous clouds have been observed to move from east to west with a speed of about 80 m/sec at a height of about 80 km. The ionosphere or the Kennely-Heaviside layer consists of an E-layer at a height between 100 and 150 km, and a F-layer up to 400 km. Radio waves can be transmitted by reflecting from these layers. The height of the luminous layers is estimated to be 200 to 300 km and coincides with that of the ionosphere. The height of falling stars is 200 to 300 km, and the density of the air at those heights becomes negligible. It is considered, from the height of aurora (63 to 1,100 km but generally around 110 km), that the atmosphere certainly exists as high as 700 to 800 km.

1.2 Air Temperature

Atmospheric temperature or air temperature has an influence not only on living and health conditions, on working efficiency at fishing grounds or when loading articles on board, but also on the activity of marine organisms such as seaweed culture, through the effect of water temperature.

Air temperature at a height of 1.5 m is taken as the standard air temperature. This height is closely related to our daily life, the activity of animals and the growth of crops. Air temperature is measured by means of a mercury thermometer. As a unit of temperature the Celsius scale ($^{\circ}C$) is generally used; the temperature of melting ice is taken to be $0^{\circ}C$ and that of boiling water $100^{\circ}C$, the interval between $0^{\circ}C$ and $100^{\circ}C$ is graduated in a hundred equi-intervals. In the Fahrenheit scale ($^{\circ}F$), the freezing and boiling points are taken to be 32° and $212^{\circ}F$, respectively and the interval between these points is graduated in 180 equi-intervals. The formula for converting the Fahrenheit scale into the Celsius scale is as follows:

$$C = (F - 32) \times \frac{5}{9}$$

When measuring temperature, correction for instrumental error should be made for each temperature reading.

Our sense of feeling heat or cold depends not only on the high or low air temperature, but also on winds, sunshine and humidity, and temperature by bodily sensation is determined by the above factors. Air temperature is constantly changing with changes in the weather such as insolation and conditions on the surface of the earth.

Solar radiation first warms the surface of the earth and the heat from the earth's surface then warms the air. Therefore, the air temperature is highest at the surface and usually decreases with increasing height. The rate of decrease in temperature is about $0.6^{\circ}C$ for every 100 m of elevation. However, a phenomenon called inversion of air temperature sometimes occurs; the temperature is higher at the top of a mountain than at the foot. In an area where the sun rays project to the ground almost at a right angle, the quantity of heat received in a unit area is more than that in the area where the rays of the sun projects to the surface obliquely. Therefore, the equatorial area has a higher temperature than the polar areas; temperatures are higher in summer than in winter, they are also higher around noon than in the early morning or in the evening.

With respect to diurnal variations, the temperature is lowest around sunrise, increases gradually and reaches its highest point around 2.00 pm. Diurnal range is the difference between the maximum and minimum temperatures during one day; it is large in inland areas and slight on the ocean. In other words, the ocean warms and cools at a slower rate than the land surface. If we consider the annual variations in temperature, it will be seen that the maximum and minimum air temperatures usually occur about one month earlier than those of water temperatures. The season when the maximum and minimum temperatures occur depends greatly on latitude. In the equatorial area, the maximum temperature occurs around the vernal and autumnal equinoxes and the minimum around the summer and winter solstices. In the tropical areas, the maximum occurs around May and the minimum around November. In the cold areas, the situation is similar to that in the tropical zone, but the range is much greater.

Generally speaking, temperature variation is slight over the ocean, compared with the continental climate, in which temperature variation is considerable. Abundant water vapour on the ocean is one of the causes of the mild oceanic climate. As regards temperature distribution, it will be found that isothermal lines are almost parallel to latitude, but in some places the distribution pattern is greatly affected by the oceans, in particular by the existing warm and cold currents.

1.3. Atmospheric Pressure

Since we are living at the lowest level of the atmosphere, the pressure produced by the atmosphere's own weight constantly acts on us. This pressure is called the atmospheric pressure and causes variations in the weather. If the pressure decreases, the weather breaks. Therefore, changes in atmospheric pressure are a very important means by which mariners can forecast the weather.

In meteorology, pressure is expressed as the force acting on an area of 1 cm^2; when one million dynes of force act on the surface of 1 cm^2, the pressure is termed 1 bar. 1/1,000 bar is referred to as 1 millibar (mb) and used as the unit of atmospheric pressure. Another system has customarily been used in meteorology: the pressure acting on the base of 1 mm of a mercury column at 0°C and under the standard gravity; it is called the 1 mm of mercury column pressure. 760 mm of mercury column pressure is defined as 1 atmosphere. Therefore, 1 atmosphere is identical to

Mass of mercury		Acceleration of gravity		Height of mercury column		
13.5951	x	980.665	x	76	=	1,013,250 dynes,

which are almost equal to 1,013 mb. Denoting the numerical values in pressure given in mm and mb unit systems by P and P' respectively, the relation between P and P' is given by $P' = (4/3)P$ or $P = (3/4)P'$ and is shown in Table 1.2. 1,000 mb correspond to 750 mm of a mercury column.

Table 1.2 Comparison between pressures in mm and mb

P (mm)	770	765	760	755	750	745	740	735	730	725	720
P'(mb)	1027	1020	1013	1007	1000	993	987	980	973	967	960

Atmospheric pressure varies with the time of day, season and location. Diurnal variation of pressure comprises the semi-diurnal and diurnal cycles. The maximum pressure occurs between 8.00 and 9.00 am and between 9.00 and 10.00 pm; the minimum pressure between 4.00 and 5.00 am and 3.00 and 4.00 pm. The difference between the maximum and the minimum is very slight. As for seasonal variations, in continental areas the miximum and the minimum pressures occur in winter and summer respectively, while in oceanic climate areas the maximum and the minimum pressures occur in summer and winter respectively (Figs. 1.1 and 1.2).

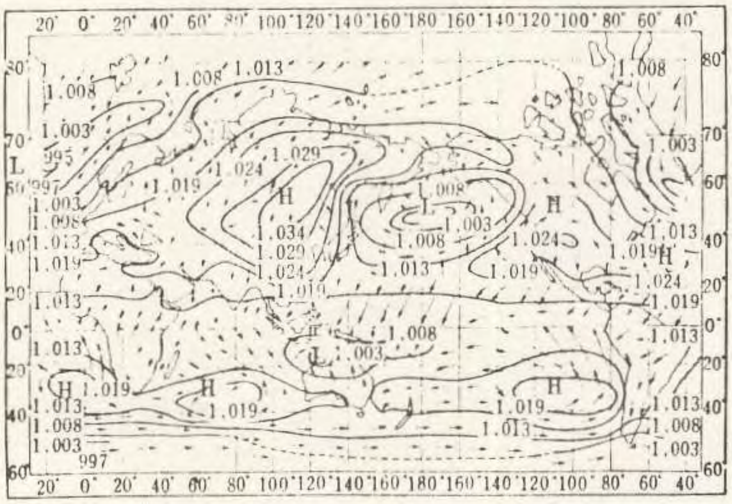


Fig. 1.1 Distribution Pattern of Atmospheric Pressure and Wind in Winter

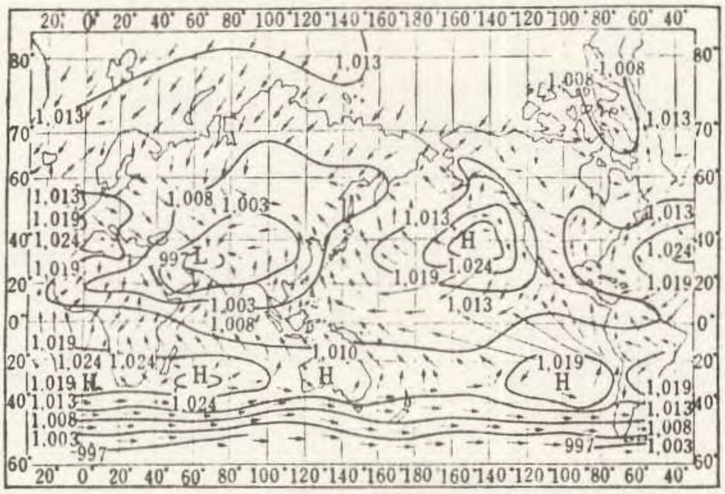


Fig. 1.2 Distribution Pattern of Atmospheric Pressure and Wind in Summer

In tropical areas and in the summer in temperate areas, diurnal variation in atmospheric pressure is very regular. Occurrence of a disturbance in the regular variation of pressure is a sign of breaking weather. Pressure distribution is shown by isobars, and their distribution pattern indicates the location of high and low pressures, wind direction and velocity. Variation in atmospheric pressure responds to many factors; apart from variations due to latitude, the distribution pattern of land and sea, and the diurnal variation, the atmospheric pressure also varies under the effect of moving low and high pressures.

1.4. Water Vapour in the Atmosphere

1.4.1. Humidity

A certain amount of water vapour is always contained in the air; the more humid the air, the more water vapour it contains. The quantity of water vapour in grams contained in 1 m^3 of air is called the absolute humidity. Whether the air is dry or humid depends also on the temperature so that the dryness of air is not always expressed in terms of the absolute humidity. The quantity of water vapour which can be contained in a definite volume of air is limited, and the limit is dependent on the temperature. For example, the maximum quantity of water vapour contained in 1 m^3 of air at 10°C is 9.33 g and that at 30°C is 30.04 g. Suppose that 9 g of water vapour is contained in 1m^3 of air, then the humidity at 10°C becomes 96%, showing a extremely humid state, while that at 30°C is 30%, showing a considerably dry state.

To show the dryness of air, the ratio of the quantity of water vapour actually contained in 1 m^3 of air to the maximum quantity of water vapour that can be contained at that temperature is used; this ratio is called humidity, or more correctly, relative humidity, and is given in percentages. Water vapour in air at 100% humidity has reached its maximum and represents a saturated state. The difference between the maximum quantity in 1 m^3 of air at a certain temperature and the quantity actually contained at that temperature is called the saturation deficit. When water vapour is saturated at a certain temperature and if the temperature decreases for any reason, the maximum quantity of water vapour the air can contain naturally decreases. Consequently, the surplus quantity is condensed to become water droplets (very fine water drops), forming clouds, fog, rain, etc.

Humidity varies with a change in weather, and is different at different times and in different localities. Generally speaking, throughout a day, humidity is at its maximum at the time of the lowest temperature and at its minimum at the time of the highest temperature. By season, humidity over land areas reaches its maximum in winter and its minimum in summer, while, over the ocean, it reaches its minimum in winter and its maximum in summer. Humidity influence our perception of heat together with temperature and wind velocity, and is closely related to health and working efficiency.

1.4.2. Evaporation

The water vapour contained in the atmosphere is produced through evaporation from the surface of the earth, the ocean, ice, snow, etc., evaporation from the ocean surface being the most important contributor. Evaporation from oceans takes place mainly in tropical and temperate areas and it plays an important role in precipitation on land. The rate of evaporation depends on the following factors:

1) The higher the surface temperature of land or waters compared with air temperature, the larger the quantity of water vapour evaporating from the surface in unit time. Therefore, evaporation is prevalent in tropical areas and more so in daytime than at night-time. In temperate areas,

evaporation from the sea's surface is greatest in winter.

2) When the air is drier, more evaporation occurs.

3) Evaporation increases in proportion to the force of the wind.

4) Evaporation occurs in inverse proportion to atmospheric pressure.

In the seas adjacent to Japan, evaporation is prevalent in the Kuroshio and Tsushima Warm Current regions and is not so considerable in the regions of the Oyashio and North Korea Currents; it reaches its maximum in winter and its minimum in summer.

1.4.3. Precipitation

Water vapour in the atmosphere is condensed to form water droplets or ice crystals. Those water droplets or ice crystals that cannot be suspended in the atmosphere and fall to the ground are called precipitation. Water droplets, forming clouds, are further condensed to form rain drops, while those droplets that are frozen are called, depending on their shape, sleet, snow, hail or snow pellets.

The formation of rain drops, like that of clouds, is due to the condensation of water vapour by adiabatic cooling. A rain drop within the range of 0.1 to 1.0 mm is made of

1,000 to 1,000,000 droplets, each of which is 10^{-2} mm in diameter. It is a necessary condition, for rain fall, not only that there should be clouds, but also that water droplets should be formed continuously and abundantly. When the temperature in a cloud is less than $0^{\circ}C$ and supercooled water droplets and ice crystals co-exist in the cloud, evaporated water from these droplets changes into ice crystals and this process makes the ice crystals larger and increases their number. When these ice crystals become so large that they cannot be suspended in the air by the existing ascending current, they fall down into other clouds, which are situated in the lower layers and consist of water droplets only; then the ice crystals, changing into water droplets and growing into rain drops, fall to the ground. The process of rain fall is considered to take place as described above (Fig. 1.3).

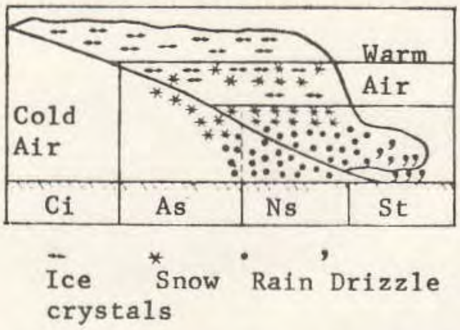


Fig. 1.3 Structure of Rain Clouds

The origin of rainfall can be classified as follows:

1. Rainfall due to low pressure. When a low pressure is formed, adiabatic expansion occurs owing to an ascending current caused by the existing low pressure. If this ascending current contains a large amount of water vapour, there occurs abundant condensation and, as a consequence, rain drops are produced.

2. Rainfall due to topography. When an air mass containing water vapour approaches a high mountain ridge, an ascending current of air occurs along the slope of the mountain. Consequently, adiabatic expansion occurs and the air is cooled to produce heavy rainfall or snowfall.

The abundance of precipitations is measured by the amount recorded in mm of rain (after melting, for snow and ice), collected in a given locality as it reaches the ground. As regards their distribution, precipitations are most abundant in the doldrums or the equatorial calm belt between 10^{o}N and 10^{o}S. Moving towards the poles from this rain belt, rainfall is still relatively abundant in the trade wind zone, reaches the minimum in the temperate calm zone, increases slightly in the westerly prevailing wind zone, and decreases again in the polar regions. The main cause of such a distribution pattern of precipitations is due to the atmospheric circulation. When there is a cold ocean current near land, the air above the waters is cooled and cannot retain as much water vapour as before, and fog is produced. Even though the air mass, containing the fog thus produced, drifts towards the land, precipitations do not occur by warming. On the other hand, rain falls abundantly in a coastal area near a warm current.

1.5. Clouds

A cloud is a mass of very small water droplets or ice crystals floating in the air and located relatively high up in the atmosphere. When the mass of water droplets is situated near the ground, it is called fog, and when it is not as dense as fog but merely veils a distant view it is called mist. A cloud is composed of very small water droplets whose size ranges from 0.01 to 0.1 mm in diameter. These droplets, which are produced continuously, fall down at a slow speed of about 40 m/hr and disappear at a certain height; consequently, the mass of water droplets, or cloud, appears to be floating at much the same height in the air.

There are various types of cloud differing in appearance, these difference being due to the height at which they float, the cause of formation and their shape. Clouds are classified into ten internationally accepted common types, as shown in Table 1.3.

Table 1.3 The ten types of cloud formation

Category	Mean Height	Kind		
High Clouds (C_H)	6,000 m - Tropopause	1.	Cirrus	(Ci)
		2.	Cirrocumulus	(Cc)
		3.	Cirrostratus	(Cs)
Middle Clouds (C_M)	2,000 - 6,000 m	4.	Altocumulus	(Ac)
		5.	Altostratus	(As)
Low Clouds (C_L)	Near Ground - 2,000 m	6.	Stratocumulus	(Sc)
		7.	Stratus	(St)
		8.	Nimbostratus	(Ns)
Vertically-developed Clouds	500 - 6,000 m	9.	Cumulus	(Cu)
		10.	Cumulonimbus	(Cb)

A brief description of the foregoing cloud types is given below to facilitate their identification.

1. Cirrus (Ci). Cirrus clouds are the highest of all clouds, usually forming above 9,000 m. They are detached, delicate, white cloud units appearing in all seasons. They are often feathery, fiber-like, or tufted in appearance, and sometimes take a shape known as "mare's tail". Owing to their appearing at great heights where prevailing temperatures are low, cirrus clouds are composed of small ice crystals or needles and not droplets of water.

2. Cirrocumulus (Cc). These clouds take the form of small, white, flaky-looking globular masses covering small or large portions of the sky; they have no shading. The delicate groups of cirrocumuli are often rippled in appearance, or they may be arranged in bands across the sky. It is this banded arrangement of the delicate white cirrocumulus packs that has resulted in the appellation "mackerel sky" where this type of cloud is present. They are the least common of the cloud types, often forming from the degeneration of original cirrus or cirrostratus clouds with which they must be associated. Being at the heights equivalent to the other high clouds, they are also usually formed of ice crystals. The individual cloudlets are less than one degree across.

3. Cirrostratus (Cs). These clouds take the typical form of a thin whitish veil or sheet, often covering all or a good portion of the sky. They may be very thin, giving the sky a slight milky-white or veiled appearance, or they may form a definite white sheet. Cirrostratus clouds are responsible for the haloes often occurring around the sun or moon. In fact, the presence of such features usually indicates the presence of cirrostratus. The very thin appearance of these clouds indicates the great height at which they commonly occur, which is the same as for cirrus. Hence these, too, are formed of ice spicules or needles.

4. Altocumulus (Ac). These clouds form elliptical units occurring individually or in groups. When in groups, altocumuli may form as disorderly, and more or less closely grouped, masses or in definite bands, with clear sky alternating. Altocumuli may have grey shading on their undersurface. Individual altocumulus clouds

are frequently elongated, elliptical or lenticular units distinguishable from the cumulus (to be studied later) by their height and absence of vertical doming. The wavy or parallel bands of altocumulus, mentioned above, are particular characteristics of this cloud type. The formations known as "sheep clouds" or "woolpack clouds" are examples of high globular altocumulus groups.

5. Altostratus (As). Altostratus clouds are uniform bluish or greyish-white cloud sheets, covering all or large portions of the sky and sometimes occurring in uniform broad bands. The sun may be totally obscured or may shine through weakly giving the sky a watery appearance. The typical watery sunlight is characteristics of altostratus. Very frequently there is a complete or nearly complete absence of shadow associated with this weak sunlight, for the general illumination of the clouds is sufficient to offset the shadows cast by the weakened sunlight. Just how thick these clouds are depends on the height at which they form. If very high, they may grade into cirrostratus. The lower they form, the heavier and denser they become. Altostrati yield a large degree of precipitation. particularly in the middle and high latitudes, being composed of both water and ice particles.

6. Stratocumulus (Sc). These clouds form large, heavy rolls or elongated globular masses arranged in long, grey parallel bands that usually cover all or most of the sky. They grade in appearance from definite cloud rolls that are close together to a more or less continuous sheet broken into irregular parallel bands. They often form from the flattening of cumulus clouds which may be arranged in bands, or may develop as a continuation of altocumuli occurring at

low latitudes. In the latter case, the stratocumuli will appear darker, lower, and heavier than the related altocumuli.

7. Stratus (St). This is a uniform grey cloud sheet or layer. Stratus clouds have no particular form or structure and usually cover the sky completely. The uniform cloud sheet may sometimes be partly broken into elongated patches. The stratus sheet is normally thicker and darker than the higher altostratus which may be overlying. It is often difficult or impossible to distinguish low stratus formations from high fog, for an almost continuous graduation exists. Thus, warm, humid air, flowing across cooler regions, may yield very thick advection fogs. During the day, much of the lower portion of the fog may evaporate and leave a high fog or stratus above the ground. Stratus clouds frequently become broken and wind-blown, to form more or less shapeless ragged patches which are then called fractostrati or scud clouds.

8. Nimbostratus (Ns). Nimbostrati are thick, dark grey, shapeless cloud sheets with irregular broken clouds beneath and surrounding them. They are the common associates of steady precipitation, whether rain or snow. Nimbostrati have a poorly defined "wet" undersurface in contrast to the "dry" undersurface of stratus clouds, and frequently are underlain by ragged fractostrati with which they may merge.

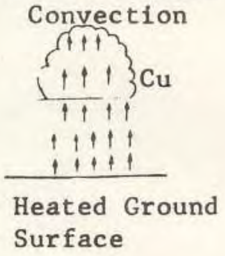
9. Cumulus (Cu). Cumulus clouds are the majestic, billowing, white clouds so prominent in summertime. However, they may occur at any season. These clouds are typically flat-based, with a pronounced vertical thickness which extends upward as a domed or

turreted mass resembling a cauliflower. Cumuli are for the most part fair-weather clouds. Frequently after a storm has passed, a continuous train of small flat cumuli, with a relatively small vertical doming, will float across the sky. If the flat bases of these clouds join each other, they form a nearly plane surface - the dew point level. Irregular wind-torn patches of cumuli, formed by wind action on large cumulus clouds, are called fractocumuli.

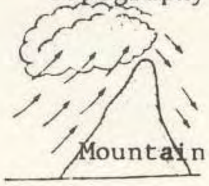
10. Cumulonimbus (Cb). Cumulonimbi arise from cumuli that have developed into tremendous towering clouds with a vertical range, from base to top, of 3 to 8 km. When grown to this height, such clouds are the forerunner of thunderstorms, the cloud itself being called a thunderhead. Such clouds are marked by the turrets which are ever changing in form and shape as the cloud builds up higher and higher. In the well-developed thunderhead or cumulonimbus, the top becomes flattened and drawn out in the direction of motion, resulting in an anvilshaped head.

There are variations of the above ten cloud forms called fumuli, lenticulars, cumuliformi, mammati, undulati, radiati, etc. From a different viewpoint, clouds can be classified into (1) cumulus-like clouds, developed vertically, (2) wavy clouds, arranged like ridges, and (3) stratified clouds. Their formation as well as their appearance are different. Considering the formation of clouds, cumulus-like clouds are formed by either heat convection resulting from a heated surface or ascending currents along slopes due to topography or front. There are a variety of causes for the formation of wavy clouds, but most of them are produced by an ascending motion along a gently sloped frontal surface. Wavy or ridge-like clouds are formed along the boundary surface between cold and warm air masses. Stratified cloud is a huge mass of clou produced along a warm frontal surface, and covers a wide area. Generally speaking, the main reason of precipitation resulting fro the condensation of water vapour in the air is the adiabatic cooli or adiabatic expansion of air due to an ascending motion (Figs. 1. a - h).

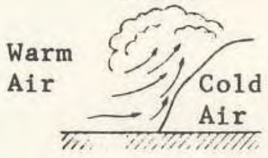
(a) Due to Heat Convection



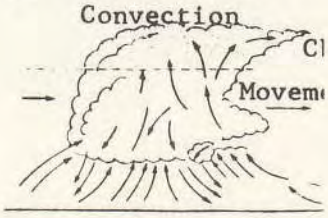
(b) Due to Topography



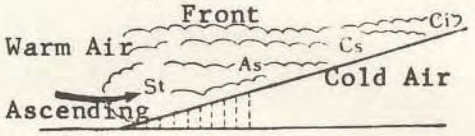
(c) Due to Front



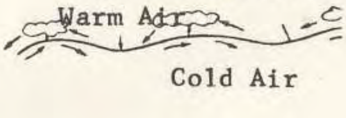
(d) Due to Heat Convection



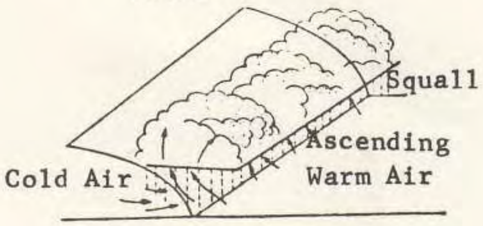
(e) Due to Warm Front



(f) Due to Wave Moti on Frontal Surfa



(g) Due to Cold Front



(h) Due to Typhoon

Figs. 1.4 (a)- (h) Generation of Clouds

The amount of cloudiness is either stated in terms of the number of tenths of the sky obscured by clouds or described in words. The use of specific decimal fractions to indicate cloud coverage will of course give a more specific indication of this amount. The decimal point is usually omitted when using the numerical system. Thus 7 indicates that seven-tenths of the sky is covered.

When indicating cloud conditions, two sets of descriptive terms are often used. These are given in the following table.

Table 1.4 States of the Sky

Designation		Amount of Cloudiness
Clear	Clear	Less than 1
Scattered	Partly cloudy	1 to 5
Broken	Cloudy	6 to 9
Overcast	Overcast	More than 9

1.6. Fog

Fog is formed by the condensation of water vapour in the lower layer of the atmosphere. The various types of fog are classified, according to the manner in which they are formed, as follows:

1. Frontal fog. Formed by the evaporation from rainfall near a front.

2. Steam fog. Formed by cold winds blowing from either the Arctic Sea or a continent across a warm sea surface.

3. Radiation fog. Formed by cooling of the air near the ground, when the earth is cooled considerably on clear nights with very slight wind. Frequently occurs in a basin with very slight wind. Harbours, especially those surrounded by hills, are often shrouded in radiation fog during the night and early morning. As the sun comes up over the horizon the fog disappears.

4. Advection fog. Formed by cooling of the warm moist air blowing across a cold sea surface or a cold ground surface. Observed often in cold current regions in summer. Steam fog is one type of advection fog. When a slight wind of 2 to 3 m/sec blows continuously from a warm sea, dense advection fog occurs.

5. Upslope fog. Formed by adiabatic cooling due to an ascending current along the slope of a mountain. Sometimes the fog is so dense that it does not lift even during daytime.

Fogs are usually classified according to their effect on visibility. This classification is given in Table 1.5.

Table 1.5 Visibility

Scale	Designation	Visibility
		Objects not visible at
0	Dense fog	50 m
1	Thick fog	200 m
2	Fog	500 m
3	Moderate fog	1 km (1/2 n. mile)
4	Thin fog or Mist	2 km (1 n. mile)
5	Visibility poor	4 km (2 n. miles)
6	Visibility moderate	10 km (5 n. miles)
7	Visibility good	20 km (10 n. miles)
8	Visibility excellent	50 km (30 n. miles)
9	Visibility exceptional	Objects visible more than 50 km (30 n. miles)

Fog occurring over the sea is called sea fog. When sea fog occurs, it may happen that even the bow of a ship cannot be seen from the navigation bridge. Shipwrecks caused by collision or stranding result mostly from very poor visibility due to sea fog. The height of sea fog is usually not more than 100 m; when the fog is low, the mast of a ship can sometimes be seen emerging above the fog. Some fogs, however, reach up to a height of about 400 m. The height of occurring fog is closely related to the inversion layer of temperature. Most of the sea fogs are advection fogs which occur by the mixing of a warm humid air, transported across a cold sea surface, with the cold air associated with the cold surface beneath. However, some of them are steam fogs formed by cold winds from the continent blowing across the warm sea surface.

Condensation nuclei are essential to the occurrence of fog. A number of condensation nuclei are always present in the atmosphere: these are hygroscopic salts such as NaCl, $MgSO_4$, $CaSO_4$, H_2SO_4, HNO_3, $CaCl_2$, etc., which produce water droplets when the humidity exceeds 100%.

1.7. Wind

1.7.1. Wind

Wind is defined as air moving horizontally clo to the earth's surface. It results from differences of pressure in the atmosphere.

Wind can be determined by its direction and velocity. Wind direction is the direction from which wind blows; if wind blows from the North, the wind direction is referred to as north. On the sea, wind direction is expressed in terms of 32 cardinal points (Fig. 1.5). For the measurement of wind direction,

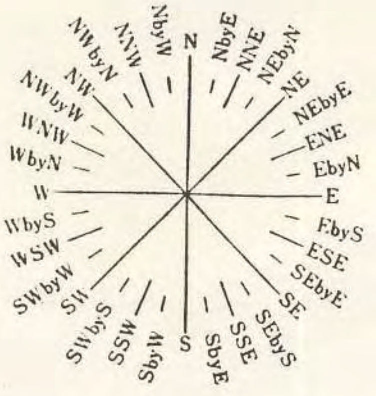


Fig. 1.5 Wind Direction

a wind vane is commonly used. For an approximate measurement, however, wind direction can be determined even from the direction of a fluttering flag or pennant, of trailing smoke, or of wind-wave. Wind direction at a high altitude can be judged from the direction of a moving cloud.

Wind velocity is expressed in m/sec and usually the average velocity, obtained from the recordings over a 10-minute period, is used. Sometimes the units of km/hr or miles/hr can be used to indicate wind velocity. An anemometer is most commonly used to measure velocity; the instrument consists essentially of three or more hemispherical cups extending on horizontal arms from a vertical shaft on a spindle. The higher the wind velocity, the faster the cups will rotate the movable spindle. By means of a magnet-generator arrangement, or a gear system with proper electrical contacts, this spinning motion is translated to show the wind speed on remote instruments. This equipment may indicate the instantaneous velocity by means of dials or buzzers, or it may record instantaneous or average velocities for reference purposes. The propeller-type anemometer combines speed and direction transmitters in a single unit for general purposes.

In the early part of the nineteenth century, Admiral Beaufort of the Royal Navy developed the well-known scale of wind velocity that bears his name. The modern Beaufort system employs a series of numbers from 0 to 17, each number standing for a wind velocity between certain limits in knots. Table 1.6 shows the relationship between the Beaufort scale and the force in knots, including an additional reference to wave height, and Table 1.7 gives the criteria for determining the Beaufort wind force.

Table 1.6 Beaufort Scale and Wind Velocity

Beaufort Scale	Designation	Wave Height(m)	Wind Velocity in Knots
0	Calm	-	1
1	Light air	0.1 (0.1)	1-3
2	Light breeze	0.2 (0.3)	4-6
3	Gentle breeze	0.6 (1)	7-10
4	Moderate breeze	1 (1.5)	11-16
5	Fresh breeze	2 (2.5)	17-21
6	Strong breeze	3 (4)	22-27
7	Moderate gale	4 (5.5)	28-33
8	Fresh gale	5.5 (7.5)	34-40
9	Strong gale	7 (10)	41-47
10	Whole gale	9 (12.5)	48-55
11	Storm	11.5(16)	56-63
12	Hurricane	14 (-)	64-71
13	Hurricane		72-80
14	Hurricane		81-89
15	Hurricane		90-99
16	Hurricane		100-108
17	Hurricane		109-118

Note: Figures in parentheses in the column "wave height" indicate the highest values.

Table 1.7 Criteria for determining Beaufort Wind Force

Beaufort Force	Specification for Use at Sea
0	Sea like mirror
1	Ripples with scaly appearance; no foam crests
2	Small wavelets, crests of glassy appearance and not breaking
3	Large wavelets with crests beginning to break, scattered whitecaps
4	Small waves growing larger, numerous whitecaps
5	Moderate waves with greater length, many whitecaps with some spray
6	Larger waves, whitecaps very numerous, more spray
7	Sea tends to heap up, streaks of foam blown from breaking waves
8	Fairly high waves of greater length, well-marked streaks of foam
9	High waves with sea beginning to roll, dense streaks of foam with spray blown higher into air - may cut visibility
10	Very high waves with overhanging crests, sea is white with foam, heavy rolling and reduced visibility
11	Waves exceptionally high, sea covered with foam, visibility further reduced
12-17	Sea completely covered with spray, air filled with foam, greatly reducing visibility

The wind observed on board a running vessel is the apparent wind; it combines the natural wind and the wind produced by the ship's movement. From the data on the apparent wind and on the ship's course and speed, the direction and speed of the true wind can be obtained vectorially as shown in Fig. 1.6.

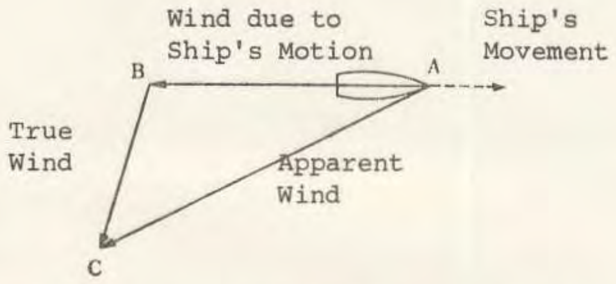


Fig. 1.6 True Wind and Apparent Wind observed aboard a moving Ship

For the measurement of wind direction and velocity in the upper layers, pilot balloons are utilized. When inflated properly, they have a known rate of ascent. Observations on a balloon are then made at one minute intervals with a theodolite, which measures the angular horizontal drift of the balloon and also its angle of elevation. Since the drift of a balloon is equal to the wind speed at a particular elevation, it is a simple matter to compute these values from the observed data. A lantern attached to a pilot balloon provides for nocturnal observations. A modern method is radiotracking, by which a large-sized balloon with a radio transmitter is tracked by means of a radio direction finder.

Winds occur because of differences in atmospheric pressure. The greater the pressure difference existing over a certain distance, the stronger the occurring wind: e.g., the wind is stronger when the pressure difference is 2 mb per 100 km than when it is 1 mb per 100 km. Accordingly, the division of the pressure difference between two isobars, one of which is passing through a certain point, by the shortest distance between these isobars is taken as a measure of the wind-producing force and is referred to as the pressure gradient at that point.

Winds blow from a high-pressure zone towards a low-pressure zone, just as water flows from a higher point towards a lower point. Owing to the effect of the earth's rotation, however, actual winds do not blow straight along the direction of the pressure gradient. Wind direction deflects to the right hand side in the northern hemisphere. Actual winds usually blow from a high-pressure zone towards a low-pressure zone, forming an angle of 25° to 35° with the isobars. In the northern hemisphere, when an observer is standing with his back against the wind, the low pressure will be located along a direction of 20° to 30° deviated forwards from that of his laterally outstretched left arm. In the southern hemisphere, the low pressure is along a direction of 20° to 30° deviated forwards from that of the right arm. The high pressure is along a direction towards the right behind the observer if he is in the northern hemisphere. This illustrates the law known as Buys Ballot's Law, which is useful for detecting the center of a low-pressure and avoiding it.

1.7.2. Monsoon

There exists a wind, over the land and sea, which reverses its direction approximately every six months: in winter it blows from the continent towards the ocean, and in summer from the ocean towards the continent. The wind blows almost constantly over a wide area and for a certain period, and it changes its direction approximately every six months. This wind system is referred to as monsoon.

1. Monsoon in winter. In winter, the continent is cooled and this, in turn, produces high pressure over the continent, while over the ocean the temperature is relatively high and the pressure is low. In consequence, a wind system, blowing from the continent towards the ocean, develops near the surface. The wind direction deviates to the right hand side in the course of movement in the northern hemisphere, because of the earth's rotation. The north wind prevails in the Far East region covering the Kamchatka peninsula and the Sea of Okhotsk, the northeast wind over Taiwan, the South China Sea, Indo-China and the Malay peninsula, the northwest wind around the mainland of Japan, and the north wind over the area from Okinawa to Central China. The wind is strongest in the area adjacent to Japan; its force is usually 4 to 7 and reaches 8 in the peak monsoon season during December and January. Over the ocean it sometimes reaches force 11.

In particular around the Kurile and the Aleutian Islands in the North Pacific Ocean, the Siberian High and the Aleutian Low develop considerably after passing over Japan. Consequently, the pressure gradient becomes steep and a strong monsoon blows over the area. In the area covering the Bay of Bengal, the Arabian Sea and the Indian Ocean, the northeast monsoon, which blows from the continent towards and over the ocean, prevails in the winter season. This winter monsoon, however, is rather weak over the land area of India, because this area is sheltered by the Himalayas. During this season in Australia, in the southern hemisphere, the climate is mild and winds blow from the South Pacific and the South Indian Oceans towards the inland area.

2. Monsoon in summer. The continent in summer, as opposed to the winter, is heated considerably and the pressure there lowers, while the temperature of the air above the ocean is relatively low. Therefore, the wind near the surface blows from the ocean towards the continent. In the upper air, however, an antimonsoon belows from the ocean towards the continent in winter and from the continent towards the ocean in summer: the boundary between the monsoon and the antimonsoon is several kilometers high, and this height is regarded as the upper limit of the monsoon.

The area adjacent to Japan is governed by the Ogasawara High and the southeast monsoon develops there. The wind force is usually rather weak even in the peak season of July to August. On the other hand, in the South China Sea and the Indian Ocean, the southwest monsoon in summer develops considerably as compared with the northeast monsoon in winter. With the development of the Indian Ocean High in the summer season, the southwest monsoon brings a season of abundant rains into India and Burma. In summer, a low pressure develops in the inland area of India, and a steep pressure gradient is produced between this inland area and the area off the Arabian Sea and the Bay of Bengal, where the Indian Ocean High prevails. Thus, a strong southwest monsoon of wind force 5 to 8 blows over the area, causing high waves and continuous rough sea conditions, and abundant precipitation on land. The intermonsoon seasons occur about April and October, and there is no distinct wind during these seasons.

Monsoons exist in Australia, Africa, and North and South America, but these are not so marked as in the Far East and the Indian regions.

1.7.3. Sea and land breezes

In the coastal areas of the tropical region, all year round, and during summer in the temperate region, a sea breeze always blows from the sea towards and over the land from around 10.00 am, if the weather is fine. This breeze lasts until about sunset, and ceases to blow after sunset; it is followed by what is known as the evening calm. In the night-time, the land breeze blows from the land towards and over the sea and it ceases about sunrise; the windless period that follows is referred to as the morning calm. These breezes are called the sea and land breezes. On a fine day in the temperate zone, these breezes always develop but they never do so in bad weather. Disturbances in the breezes can be regarded as the forerunner of a change in weather such as a typhoon.

The wind force of the sea and land breezes is that of a gentle breeze (3 to 5 m/sec). The range of the sea breeze extends from 7 to 10 km offshore to 20 to 30 km inland, but sometimes it may reach a total of 70 km. The range of the land breeze is usually 7 to 10 km but sometimes it reaches 15 km. Generally the wind direction of these breezes forms a right angle in relation to the coastline. The sea breeze is about 1 m/sec in speed at the beginning, but increases its speed gradually and reaches a maximum of 4 to 7 m/sec. The land breeze is generally not as strong as the sea breeze.

These sea and land breezes result from the fact that the land heats and cools more quickly than the sea. In daytime, the pressure over the land is lower than that over the sea and this state reverses at night-time. Around sunrise and sunset, there is no pressure difference over land and sea, and the breezes cease. When there is a sea breeze or a land breeze, an anti-breeze occurs in the upper air and, thus, convection occurs (Fig. 1.7).

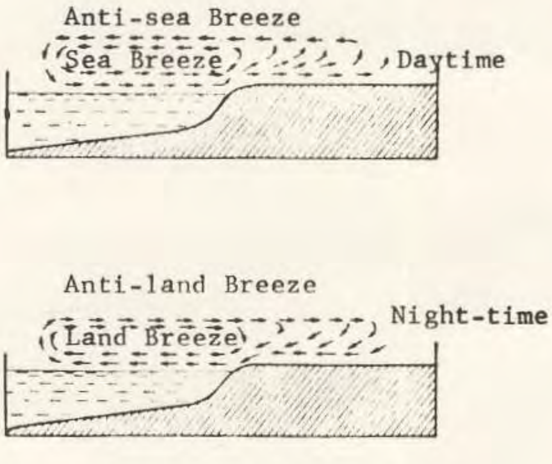


Fig. 1.7 Sea and Land Breezes

A relatively important navigational aid results from this daily heating coupled with the sea breeze. As the warm sea air reaches an island whose land area has been heated during the daytime, it partakes of the convectional air motion over the island and rises. The ascending air produces adiabatic cooling and forms cumulus clouds as it cools to dew point. Such clouds are daily characteristics of these small islands and can be seen from a great distance when the land beneath is completely invisible. They are sometimes called atoll clouds owing to their prevalence over the coral atolls in tropical waters. Brief and heavy showers may develop if the heating is sufficient to cause towering cumulonimbus clouds to form from the original cumuli. Breezes, similar to the sea and land breezes, occur above a great lake; these are called lake breezes.

Mountain and valley breezes exist in mountain areas, or areas with a marked topographic relief. During daytime heating, valley areas become relatively overheated. Consequently, the warmed air rises up the sides of the valley or mountain during the periods of sunshine. These breezes may be weak or strong, depending on the nature of the topography. Such air movements, originating at the valley floor, are called valley breezes. During the night in the same areas, the air on the mountain sides which is in contact with the cooling slopes, cools faster than the surrounding air or that in the sheltered valley below. Hence the air along the slopes settles downwards, being more pronounced on nights when good radiation weather prevails and permits rapid cooling of the mountain sides and consequently of the adjacent air. Again, local topography may favour the development of rather strong nocturnal mountain breezes.

Both valley and mountain breezes are sometimes slowed down considerably by the effect of adiabatic cooling in a rising valley breeze, and adiabatic heating in the case of a settling mountain breeze.

The air which strikes a mountain range is forced to rise up along the slopes of the mountain; thus clouds are formed there by adiabatic cooling of the air, and precipitation occurs as a result. The air, however, descending the leeward slopes of the mountain to the floor of an adjacent valley or plain after crossing the mountaintop, warms adiabatically at the rate of $1^{\circ}C$ per 100 m of descent. Thus if the wind descends the side of a mountain several hundred meters high, it will be considerably warmer and hence drier than the air prevailing in that area. In the winter and early spring such warm dry winds are responsible for rapid melting of the snow, and thus clear the soil for spring farming. In Europe the name foehn is applied to this wind, while in the United States and Canada along the eastern or lee slopes of the Rockies, the Indian name chinook is used. These foehn winds sometimes occur in summer along the coasts of Japan, facing the Japan Sea; during this season, the southeast monsoon prevails around Japan, and if a low depression passes over the Japan Sea, this monsoon becomes strong enough to cross the high mountain range, running along the mainland of Japan. In some coastal areas facing the Japan Sea, the temperature sometimes exceeds $40^{\circ}C$ owing to this foehn phenomenon.

The foehn may originate from winds that ascend the windward slopes and descend the leeward slopes of a mountain range. If the air in ascending cools sufficiently to reach dew point, further rising will cause cooling according to the reduced moist adiabatic rate. But on descending the lee slopes, the dry air now warms only according to the dry rate and may reach a much higher temperature than the air at the same level on the approach side.

1.7.4. Squall

Squall is a wind that starts to blow suddenly and violently, or, in other words, a wind whose force increases in a short time. Squall line or wind-shift line refers to winds that occur simultaneously along a line and proceed together forming a line; a squall line is characterized by such meteorological phenomena as a sudden and rapid change in wind direction, heavy rain, hail or snow, an abrupt decrease in temperature, a sudden increase in humidity and atmospheric pressure, etc.

A cold front is accompanied by dense roll clouds, a strong ascending current, thunder and lightning, a sudden rise of the atmospheric pressure (the pressure may increase several millimeters in a few minutes), and an abrupt change in wind velocity, etc. When a cold air mass intrudes beneath a warm air mass and, in consequence, the warm air mass is forced upwards, rain clouds (nimbus clouds) occur and the wind velocity may exceed 20 m/sec. The greater the temperature difference between the cold and warm air masses, the more violent is the squall that ensues.

Radar gives the observer up-to-the-minute information on clouds, precipitation, and storm movement as well as providing a means of detecting otherwise undetected storms. An active cold front is commonly characterized by a band of well-developed thunderstorms and is identified on the radarscope by a linear pattern of strong cloud echoes. The clouds are very bright, with a rounded and solid appearance. A qualitative estimate of the structure and activity of the front can be made from the intensity of the cloud echoes, the spacing between the bright areas, the area covered by the individual clouds, the vertical extent of the clouds, and the velocity of the cloud line as measured on the radarscope. Weak cold fronts are usually much less well defined and may be missed entirely by radar if convective activity is low.

Squall lines are generally narrower than frontal zones but are otherwise much the same in appearance and in convective activity. They commonly precede cold fronts, so that their proper identification by radar and other sources may provide a means of forecasting the cold front to follow.

Squalls in winter are generally accompanied by cold fronts. The wind direction of a squall line is almost at a right angle to the isobars, but it may be affected by topography. In a mountainous region, the wind deviates, taking a direction almost parallel to a mountain range or a valley. The wind associated with a line of discontinuity (front) is relatively conservative so that squall forecasting is possible.

The northwest monsoon begins to prevail around Japan in late autumn or early winter, and if a line of discontinuity (a cold front) passes over the area, a violent squall exceeding 15 m/sec in wind force blows from the west and lasts for several minutes to several hours. Small fishing vessels are frequently wrecked owing to such a squall. Some squalls are accompanied by warm fronts.

1.8. General Circulation of the Atmosphere

The motion of air results from temperature differences. In the equatorial region the temperature is high and the pressure is low, while in the polar regions the temperature is low and the pressure is high. Therefore, cold and heavy air from the polar regions flows in the lower near-surface layers of the atmosphere towards the equatorial region, and in the upper layers a wind system exists from the equatorial region towards the polar regions. This large-scale circulation of air is called the general circulation of the atmosphere (Fig. 1.8).

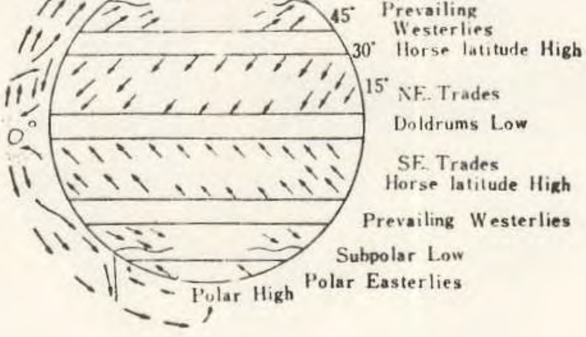


Fig. 1.8 Wind System and General Circulation of the Atmosphere

Since, however, the earth is spherical and consequently the parallel of latitude becomes narrower with the movement from the equator towards the poles, so the air-flow from the equator to the poles is similar to the flow from a wider space into a narrower space. As a natural consequence, the tendency to accumulate air increases with the approach to the mid-latitudes. Since, moreover, the earth rotates from west to east, the air-flow from the upper layers in the equatorial region gradually deviates to the right hand side in the northern hemisphere, and finally becomes a west wind in the mid-latitudes. For this reason, two belts of mid-latitudes high (horse latitudes high) are formed in the near-surface layers at about 30° to 40° latitude in both hemispheres. In the near-surface layers, winds blow from these belts of high-pressure towards a belt of the equatorial low (doldrums low). In the northern hemisphere, however, the wind deviates to the right hand side owing to the earth's rotation and finally becomes a northeast wind. In the southern hemisphere, this wind deviates to the left hand side and finally becomes a southeast wind. These winds in both hemispheres blow constantly keeping their respective directions throughout the year; these are referred to as the trade winds.

Two sets of air-motion, originating in the upper layers in the equatorial region and moving towards the poles, have directions opposite to those of the trade winds and are called the anti-trade winds. In the northern hemisphere, the anti-trade wind moves towards the southeast in the upper air of the equatorial region; it changes to a southerly direction as it moves to the higher latitudes, and become the southwest- to west wind in the temperate zone. Corresponding to this wind, in the southern hemisphere, the northeast wind in the upper layers of the equatorial region, which changes its direction northward as it moves to the higher latitudes, becomes the northwest- to west wind in the temperate zone. These anti-trade winds tend to sink down when approaching the mid-latitudes and are the origins of the two belts of horse latitudes high.

The northeast trade wind occurs between the tropic of Cancer and the equator, and the southeast trade wind between the tropic of Capricorn and the equator. In the equatorial region where these two winds meet, the wind direction is indefinite and the area is mostly calm; the region is called the equatorial calm zone (doldrums). An ascending current is active in the region and frequent rainfalls, accompanied by squalls, occur.

In the North Pacific Ocean, the northeast trade wind prevails in a wide area extending from 10° to 40°N, and from 140°E to 120° W, except in waters neighbouring the Asiatic Continent and the North American Continent. This northeast trades region shifts to the north in summer and to the south in winter. In the central part of the trades region, the wind direction is almost constant; its speed is around 6 to 8 m/sec on an average. In the area adjacent to the Asiatic Continent, however, this trade wind is affected by the prevailing monsoon. In the South Pacific Ocean, the southeast trade wind prevails between 5° and 20°S and east of 160°E; its direction ranges from southeast to east. In the area adjacent to Australia, however, this wind is sometimes affected by the prevailing monsoon.

Part of the anti-trade wind passes through the upper layers of the horse latitudes high, proceeds into the higher latitudes, and produces the prevailing westerlies together with the west wind, which originates from the horse latitudes high and blows in the near-surface layers. In the polar regions cold air is accumulated to produce the polar highs. The easterly winds blowing from the polar highs are called the circumpolar winds. The boundary between the circumpolar wind and the prevailing westerlies is referred to as the polar front. Along the polar front highs and lows, which frequently pass through the higher latitudes, are produced. The warm air mass originating in the equatorial region and the cold air mass from the poles come in contact at the polar front region.

The prevailing westerlies are strongest at about 40° to 50° latitude in both hemispheres. The area in the vicinity of 40° S is called the roaring forties where violent storms occur nearly all the time. Whale catcher fleets bound for the Antarctic Sea always suffer from the rough sea usually for as long as a week when passing through the area. The prevailing wind direction is between northwest and west, and the force is 5 to 6 on an average. The area always has rough sea conditions and the waves are high, but more so in winter than in summer.

1.9 Air Masses

1.9.1. Air masses

An air mass is a large, horizontally homogeneous body of air within the atmosphere as a whole. Its uniformity is principally one of temperature and humidity. In size, air masses cover hundreds of thousands of square kilometers; vertically, they extend upward for hundreds or thousands of meters. There is no difficulty in perceiving uniform ocean currents within the main ocean body. Ocean water is visible: the Kuroshio Current or the Gulf Stream are readily apparent from their movement, colour, temperature, seaweed content, etc. Uniform bodies of air, or air masses, are not so obvious, but their presence is adequately shown by meteorological observations, in particular as regards their temperature and humidity. Air masses are identified and their motion traced through instrumental rather than visual observation. Their presence is often also felt very noticeably by our senses. We are all aware of the oppressively hot, sticky, summer heat waves. We are also aware of the dramatic end of such a hot-weather spell, when, following a violent thunderstorm, a wave of cool, dry air is experienced for several days. A large, hot, humid air body responsible for the heat wave has simply been replaced by a cool, dry air mass with the consequent relief for the heat sufferers.

The study of air mass characteristics and behaviour is known as air mass analysis. A primary weather concern is to determine the conditions within the air mass, its direction of movement, and the changes in its properties as it moves. The resulting properties of this moving air mass are the weather conditions that are experienced along its line of motion.

Although air masses and their boundaries (fronts) are physically inseparable and are intimately related to the structure of cyclones, it is easier to consider them separately and then combine the information as in the following chapters.

Air masses derive their original properties from the surface over which they form. The temperature and humidity characteristics of an air mass are determined directly by the nature of the surface beneath. In considering the relatively large volume of air masses and the poor powers of heat conduction that air possesses, it is apparent that such uniform bodies will not form very rapidly. A large volume of air must remain stagnant or circulate for some time over a particular portion of the earth, in order gradually to acquire its distinctive temperature and humidity characteristics.

Air masses develop more commonly in some regions than in others, the areas of formation being known as source regions. We may note, for example, that the common source regions of air masses affecting the weather around Japan are the Siberian Continent, the Sea of Okhotsk, the area in the vicinity of the Ogasawara Islands, the area of the Yangtze River of China and the equatorial area in the North Pacific Ocean. It will be noticed that the source regions tend to bound the belt of prevailing westerlies. One set of source regions exists along the northern boundary in the vicinity of the subpolar low-pressure circle, while the other set exists along and to the south of the horse latitudes. The basic difference between the air originating in the northern source regions and that in the southern source regions is therefore one of temperature. A second difference is that of humidity.

Cold northern air masses are called polar air masses, while the warm air bodies originating in low latitudes are called tropical air masses. Then, depending on whether they form over land or water, the air masses will be dry or humid, respectively. Dry polar air of continental origin is known as polar continental air, and when of oceanic origin, polar maritime air. Similarly, tropical air is known as tropical continental and tropical maritime air. Arctic and equatorial air masses form in the far north and in equatorial regions, respectively. Table 1.8 summarizes the basic information concerning the six principal air masses.

Table 1.8 Classification of Air Masses

Name and Symbol of Mass	Place of Origin	Properties
Arctic Air Mass (A)	Polar region	Low temperatures, low specific but high summer relative humidity, the coldest of the winter air masses
Polar Continental Air Mass (Pc)	Subpolar continental areas	Low temperatures (increasing with southward movement), low humidity, remaining constant
Polar Maritime Air Mass (Pm)	Subpolar and arctic oceanic areas	Low temperatures, increasing with movement, high humidity
Tropical Continental Air Mass (Tc)	Subtropical high-pressure land areas	High temperatures, low moisture content
Tropical Maritime Air Mass (Tm)	Southern borders of oceanic subtropical, high-pressure areas	Moderately high temperatures; high relative and specific humidity
Equatorial Air Mass (E)	Equatorial and tropical seas	High temperatures and humidity

1.9.2. Air masses in Asia and their variations

Air masses in Asia consist of the Siberian air mass (Pc), the Sea of Okhotsk air mass (Pm), the Ogasawara air mass (Tm), the Yangtze River air mass (Tc) and the equatorial air mass (E) (Fig. 1.9).

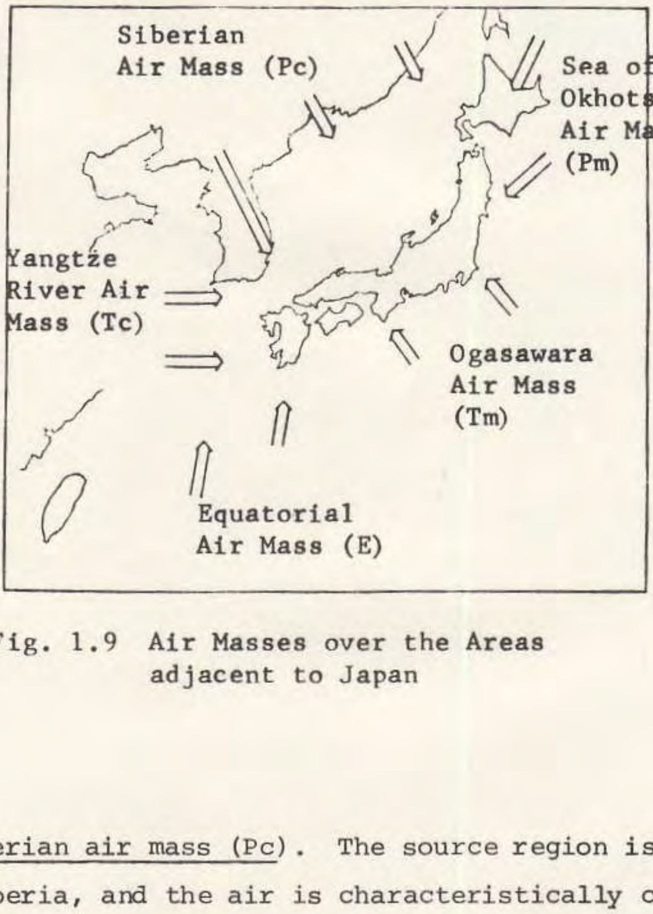


Fig. 1.9 Air Masses over the Areas adjacent to Japan

1. Siberian air mass (Pc). The source region is near Lake Baikal in Siberia, and the air is characteristically cold and dry. During most of the summer season this cold air body is rather restricted, but it begins to develop from about August to October and reaches its peak about January.

In winter, the great polar air mass of Asiatic origin overflows to the south and east. The air moving southward travels with the northeast Indian monsoon, spreading cold air over the Indian Ocean and reaching as far as the South Pacific Ocean. The air travelling eastward continues into the North Pacific Ocean, where it plays a dominant role in shaping the weather not only of the Pacific, but of western North America as well.

When in the source region, this polar continental air is very stable and clear, since the cold surface beneath prevents convection. The temperature in such air often increases with an increase in altitude, yielding an inversion. This results essentially from the pronounced cooling of the surface air. After leaving the source region, the nature and amount of modification depend on the underlying surface conditions. Winter continental polar air undergoes little change while crossing over cold land surfaces. Upon reaching warmer land areas, local surface heating causes the formation of cumulus clouds which may become heavy and join to form stratocumulus.

When this air of winter origin advances over sea surfaces, arctic sea smoke or steam fog may form in the low levels of the air masses, if the water is warm. With the evaporation of sea water into it, the dry polar continental air mass undergoes modification to polar maritime air. Over cold water surfaces this air remains stable but tends to develop clouds of the stratus type, yielding drizzle and light rain. Fog may occur with or without the formation of the stratus sheet. Over warmer ocean waters, convectional-type clouds tend to form, with associated showers.

When the Siberian air mass is prevalent, the area around Japan is covered with a pressure distribution pattern high in the west and low in the east; the pressure gradient becomes steep and a strong northwest monsoon blows over the area. This monsoon transports cold, moist air to the Japan Sea coasts and produces cloudy weather with heavy snowfall, while along the Pacific side of Japan the weather is clear and dry; this condition lasts as long as the monsoon continues to blow.

The northwest monsoon, on moving southward, changes to the north wind in the vicinity of Okinawa and to the northeast wind in that of Taiwan. This monsoon, when travelling further southward, produces continuous rainfall in parts of southeast Asia and the Philippines.

2. Ogasawara air mass (Tm). The Ogasawara air mass or the North Pacific air mass originates in the subtropical high-pressure zones of the North Pacific Ocean. The weather there is mostly calm and clear. As marine tropical air moves outward from its source, with either the westerlies or trade wind circulation, its properties are modified. When this air moves with the westerlies, cold water surfaces are encountered. The uniform chilling of the air mass tends to produce fog and stratus clouds and occasionally light rain. With the retreat of the polar air mass in summer, the tropical maritime air extends farther northward than in winter. The northward

surge of warm, humid air, upon melting cold ice-carrying Arctic Ocean currents, is responsible for the prevalent summer fogs of the North Pacific Ocean. In moving equatorward with the trades, maritime tropical air becomes warmer and more humid. For the most part, clear skies with scattered cumulus clouds prevail in this air in the poleward portion of the trade wind belt. The closer the approach to the doldrums, the greater is the tendency for the formation of convection-type clouds, with associated thunderstorms.

Around July, the Asiatic continent is heated by strong sunshine and a low-pressure is produced above the continent. On the other hand, a high-pressure develops over the North Pacific Ocean and the seas southeast of Japan are covered by this high-pressure. Thus, the Ogasawara air mass is formed, with its center near the Ogasawara Islands in the North Pacific Ocean. Since this air mass is formed over the tropical ocean in summer, the air is characteristically warm and humid.

In summer, eastern Asia is under the influence of the Ogasawara air mass, and consequently the climate of eastern Asia is governed by this air mass. As it moves towards the north, it becomes more stable because its lower layer is chilled, when passing over the cold sea surfaces. Since this air mass contains much moisture, heavy rainfall occurs if it encounters a prevalent front or low depression. After passing over the Japan Sea and as this air mass approaches the east coast of Siberia, dense sea fogs are produced over the cold current region along the coasts of North Korea. When this air mass moves westward and approaches Kyushu and

Shikoku, it becomes unstable after passing across the Kuroshio current region, and produces fogs or topographical rainfall in that region.

3. Sea of Okhotsk air mass (Pm). The source region is the area from the Sea of Okhotsk to the northern seas off the Sanriku district of Japan. This air mass develops mainly in the rainy season of the area between June and July. Polar maritime air is for the most part polar continental air that has remained over the sea surface a sufficient length of time to absorb relatively large quantities of moisture. Since the air mass ultimately move eastward, owing to rotational forces, the eastern sections of the oceans are characteristically overlain by polar maritime air. The western portions of the oceans may be influenced by polar continental air or polar continental air having acquired maritime characteristics. When moving over warmer surfaces, whether water or land, this air mass tends to yield cumulus-type clouds and associated showers, as a result of convection. When crossing colder surfaces, stratus clouds, fog, and often drizzle may result.

The Sea of Okhotsk air mass is cold and humid, and brings very bad weather to the mainland of Japan. With the decline of the northwest monsoon in early summer, this air mass develops with its center around the cold Sea of Okhotsk with melting ices and the seas off the Kuriles. The air mass moves to the south associated with the northeast wind and approaches the central area of the mainland of Japan, and this contributes towards producing the rainy season over Japan, with the cyclones moving eastward on a stationary front (Baiu front) along the southwest coasts of Japan. Generally speaking, when this air mass is prevalent, heavy rainfalls occur. When the air mass is weak, there is no marked rainy season.

4. Yangtze River air mass (Tc). The source region is in the area of the Yangtze River in mainland China. This air mass often occurs in spring and autumn. The air is dry and clear, and moves eastward as migratory anticyclones. After this air mass has passed, the weather breaks and rainfall frequently occurs.

Continental tropical air, being dry and warm, has a high moisture capacity and a low relative humidity and will therefore absorb moisture rapidly when travelling over water areas. It is thus rapidly modified to tropical maritime air.

1.10. Line of Discontinuity (Front)

The weather properties, such as temperature and humidity, within an air mass are relatively uniform, but, when air masses of different temperatures meet in the course of their movement, a short transition in weather conditions (temperature, humidity, pressure, wind, etc.) occurs across their boundaries. If one were travelling northward in a warm or tropical air mass, a slight but steady temperature decrease would be encountered. Then on crossing into the cold polar air to the north a sudden sharp drop in temperature would be experienced. The uniform slow change in weather conditions gives way to an abrupt discontinuous change in leaving an air-mass boundary. This has led to the term line of discontinuity being applied to the boundary of an air mass. The term front is synonymous with the term line of discontinuity and has virtually replaced it. More specifically, fronts are the boundaries of, or separations between, air masses.

It should be remembered that air masses have a large vertical as well as horizontal extent. The surface separating adjacent air masses vertically is known as a frontal surface. The ground front is therefore the line formed by the intersection of the frontal surface with the ground. These three-dimensional aspects should always be considered and kept in mind when dealing with air masses and fronts. Most of the weather charts and maps that will be encountered, either in this text or elsewhere, will show the horizontal distribution of air masses, fronts, isobars, etc. However, the vertical extension of the sloping frontal surface should not be forgotten in viewing such charts.

Although fronts differ as to types, they have many weather properties in common. When cold and warm air masses meet, the cold air wedges beneath the warmer air, which in turn rises over the sloping upper surface of the cold mass. Fig. 1.10 shows

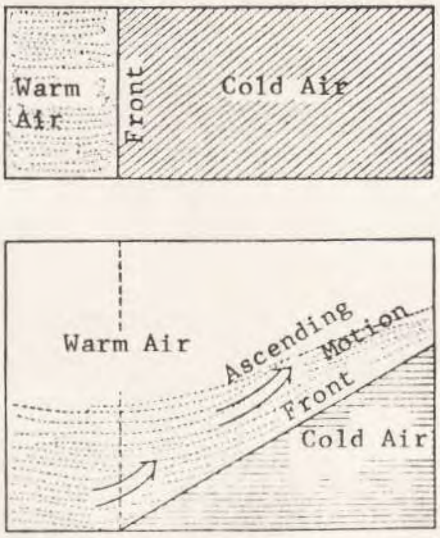


Fig. 1.10 Cross Section of Frontal Surface

a vertical cross-section through adjacent warm and cold air masses and indicates this condition. The slope of the upper surface of the cold air is actually very gentle, varying from 1:100 to 1:500 in different air masses. By slope is meant the ratio of vertical rise to horizontal distance. Thus, a slope of 1:100 indicates a vertical change of 1 unit for each 100 horizontal units; i.e., a slope of 1 km vertically over a horizontal ground distance of 100 km. Although treated as such, the frontal surface is not actually a mathematical surface. In reality, a transition zone exists between the two different air masses. The frontal transition zone may vary from several ten to several hundred meters, depending on the contrast in properties between the air masses. The greater the temperature and humidity contrast, the less is the mixing of the air bodies and the thinner is the transition zone. Owing to the gentle slope of the frontal surfaces, the transition area, even though relatively thin, will cover many kilometers when intersecting the horizontal ground surface.

In places where air-flow converges, as shown in Fig. 1.11.a, the intervals of isothermals become narrower so that the

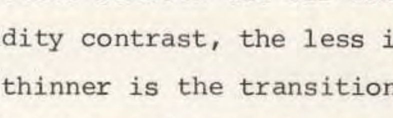


Fig. 1.11(a) Generation of Front

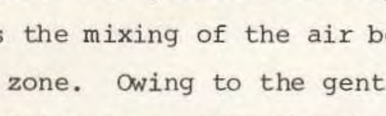


Fig. 1.11(b) Extinction of Front

degree of discontinuity becomes more marked. In places where air-flow diverges as in Fig. 1.11.b, however, the intervals of isothermals become wider and, therefore, the degree of discontinuity becomes weaker. If air masses, although originating in the same source region, travel over areas of different weather properties for a long time, they become different air masses. If they come in contact again, a front is formed between them. On the other hand, when air masses of different source regions travel to and stay in the same area for a sufficient length of time, they assume the same weather properties, being affected by the surface below, and a front between them can no longer be formed.

1.10.1. Types of fronts

When cold and warm air masses come into contact, the manner of contact is different, depending on which of the two air masses is more dominant. From such a viewpoint, fronts can be classified as follows:

Warm fronts. Warm air mass is more prevalent; front advances from the warm air mass towards the cold air mass.

Cold fronts. Cold air mass is more prevalent; front advances from the cold air mass towards the warm air mass.

Stationary fronts. Both air masses are even, front is stationary. An example is seen in the stationary front (Baiu front) occurring during the rainy season along the southwest coasts of Japan.

Occluded fronts. This type of fronts is formed by the contact of a cold front and a warm front; its structure is complex. These fronts can be divided into the warm front type occlusion and the cold front type occlusion.

Another classification of fronts can be made, on the basis of the types of air masses forming the front. This classification is as follows:

Arctic fronts. Formed by contact of the arctic and polar air masses.

Polar fronts. Formed by contact of the polar and tropical air masses.

Inter-tropical fronts (equatorial fronts). Formed by contact between the tropical air masses of the northern and southern hemispheres. These fronts play an important role in the generation of typhoons.

1.10.2. Warm fronts

If a boundary separating water and oil in a same vessel is removed suddenly, the water sinks beneath the oil because water is heavier than oil. In a similar manner, when cold and warm air masses come into contact, the cold and consequently heavier air mass tends to sink down and the warm and lighter air mass tends to ascend the cold air body.

A warm front is formed when, of the two adjacent air masses, the warm air mass is more dominant than the cold air mass. The warm front proceeds along a direction from the warm air mass towards the cold air mass. As seen in Fig. 1.12, the warm air mass is so light that it ascends above the cold air mass, rising up along the frontal surface. While it ascends, the air cools and water vapour is condensed to produce clouds within the warm air mass. Clouds thus produced are, from the lower layer to the upper layer, stratocumulus, altocumulus, cirrocumulus and cirrus, and rain or snow falls from the stratocumulus clouds. The area of precipitation extends usually about 300 km from the front towards the cold air mass. The type of rainfall depends on the nature of the two air masses, but it is generally light rain.

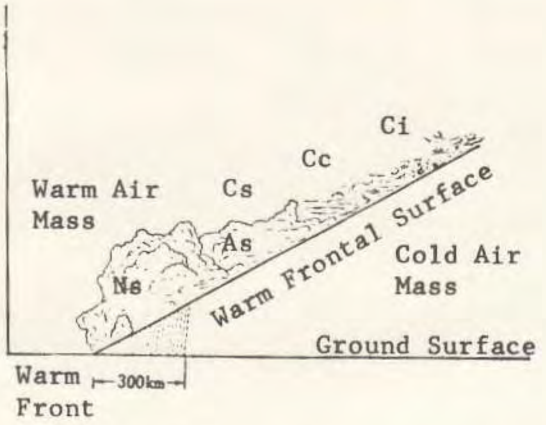


Fig. 1.12 Warm Front

With the approach of a warm front, the types of cloud change from high clouds to middle clouds, then to low clouds, and finally rainfall occurs. After a warm front has passed over, a warm air mass follows, the temperature increases and the weather settles.

1.10.3. Cold fronts

A cold front is formed when, of two adjacent air masses, the cold air mass is more dominant than the warm air mass. The cold front proceeds along a direction from the cold air mass towards the warm air mass. As shown in Fig. 1.13, the cold and heavy air mass intrudes like a wedge below the warm air mass, and the warm air mass is pushed upwards to produce cumulus and cumulonimbus. With the passage of a cold front, heavy showers or snowfalls occur, and sometimes this is accompanied with an abrupt change in meteorological conditions such as a thunderstorm, squall, wind-spout or hail-storm. In general, precipitation occurs just after the passage of a cold front.

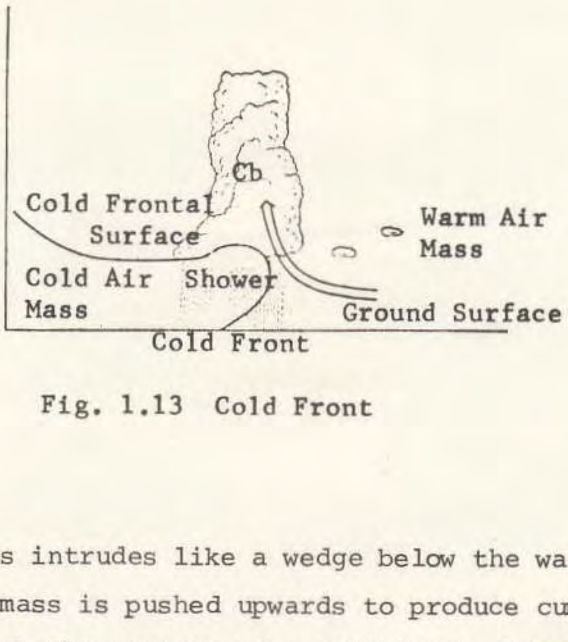


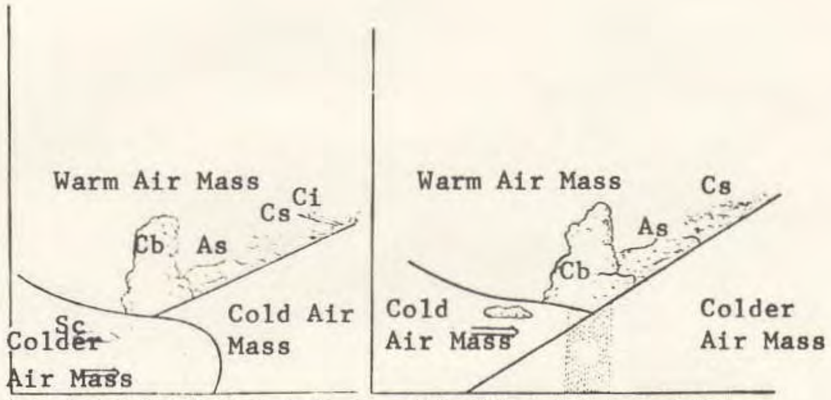
Fig. 1.13 Cold Front

When a prevalent cold front approaches, cumulus and cumulonimbus clouds emerge from the far distant horizon and form a dense cloud bank; soon all the sky is covered with black clouds, and it becomes dark. At the same time, the wind changes suddenly to a northwesterly or westerly cold wind and a heavy shower or thunderstorm, accompanied by a sudden gust of wind, occurs.

With the passage of a cold front, the atmospheric pressure increases suddenly and the temperature decreases. The travelling velocity of the cold front is usually so fast that the weather improves rapidly. Cold fronts, which accompany the approach of the Siberian air mass in winter and the cyclones in the early spring, are sometimes very dominant and the weather changes suddenly.

1.10.4. Occluded fronts

Cyclones are usually associated with cold and warm fronts. Generally speaking, the travelling velocity of cold fronts is higher than that of warm fronts. Consequently, a cold front finally catches up with a warm front. As this front advances further, one of two cases may occur, depending on the circumstances; the cold air mass, which has caught up with the warm front, pushes up the warm frontal surface and creeps down into the frontal surface, or the newly arrived cold air mass creeps up along the original warm frontal surface. The front thus formed is called the occluded front, and the former case is referred to as the cold front type occluded front and the latter as the warm front type occluded front (Figs. 1.14. a - b).



(a) Cold Occluded Front (b) Warm Occluded Front

Figs. 1.14(a)-(b) Occluded Fronts

The meteorological conditions in the area of an occluded front show a combination of weather conditions of warm and cold fronts; in the case of a cold front type occluded front, precipitation occurs mostly behind the front, and in the case of a warm front type occluded front shower-like rainfall occurs before the passage of the front.

1.10.5. Stationary fronts and Baiu front

When two evenly-balanced air masses are in contact, the front between them is almost stationary; if it moves at all, it does so in a restricted area without any definite direction. This type of front is called a stationary front. The weather conditions accompanying these fronts are similar to those of warm fronts, although the conditions depend on whether the warm air mass or the cold air mass is dominant.

In the early summer in Japan, there is a rainy season called "Baiu". This Baiu phenomenon is caused by a stationary front formed between the Sea of Okhotsk air mass and the Ogasawara air mass. This stationary front is referred to as the Baiu front (Fig. 1.15). At the time of the formation of the Baiu front, both air masses are even so that the front, extending roughly from east to the west, stays as long as one month along the southwest coasts of Japan, and rainfall occurs over a long period of time. During this period, however, the state of equilibrium between both air masses sometimes breaks and the front moves away from its original place, and consequently there occurs a temporary intermission of rainfall.

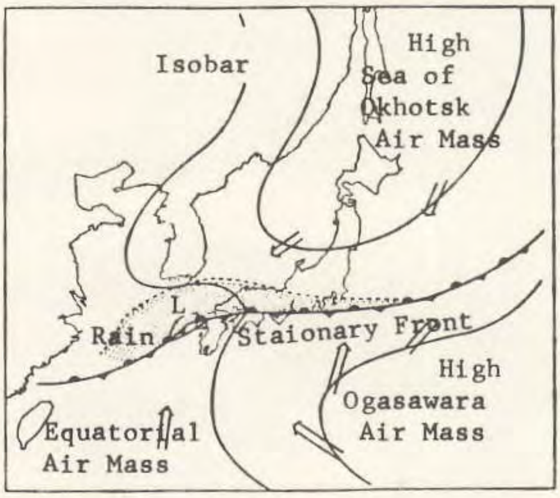


Fig. 1.15 Stationary Front

Towards the end of the rainy season, the Ogasawara air mass becomes more prevalent, thus a considerable amount of moist air reaches the neighbouring areas of Japan from the tropical ocean, and, even with the passage of a weak cyclone along the stationary front, there are heavy rainfalls and damage by flood may occur. With the increasing power of the Ogasawara air mass, the mainland of Japan is covered with this air mass and the Baiu front gradually moves towards the north; the summer season then sets in south of the front; this is called the end of Baiu.

1.10.6. Topographical fronts

These fronts are formed owing to the effects of local topography. An example is seen in the case described below. One branch of the winter Siberian air mass blows as a westerly wind along the southeast coasts of Japan, and the other branch blows as a northeast wind along the northeast coasts. The winds meet in the area off the Chiba Prefecture where they form a front (Fig. 1.16).

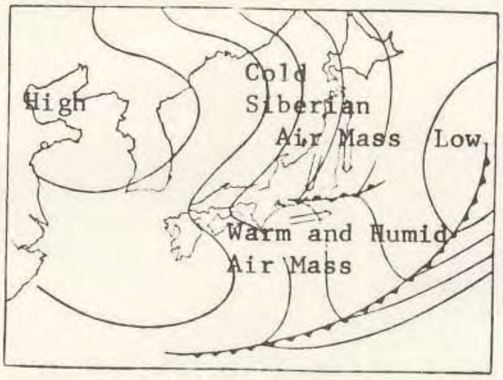


Fig. 1.16 Modifications of Siberian Air Mass

These air masses originate from the same air mass, but, once they have separated into two branches owing to the effects of topography and travel separately passing over different areas, they are modified by acquiring different properties from the underlying areas. When they meet again, their weather properties are not the same any longer, and thus a front is formed between the two air masses. In winter, along the coasts facing the Japan Sea, a topographical front is sometimes formed, with associated continuous snowfall.

Topographical fronts may also be formed merely by the diurnal variation in temperature. On clear and calm nights, the ground surfaces of inland areas cool and, in consequence, the bottom layer of the air body is modified by chilling, and becomes a cold air mass. On the other hand, the sea surface near the coast is not as cool as the inland areas, because of the difference of specific heat. Therefore, the air in coastal areas retains the properties of a warm air mass. When these air masses meet, they form a front. This type of front is sometimes formed off the Chiba Prefecture and along the southeast coasts of Japan (Fig. 1.17).

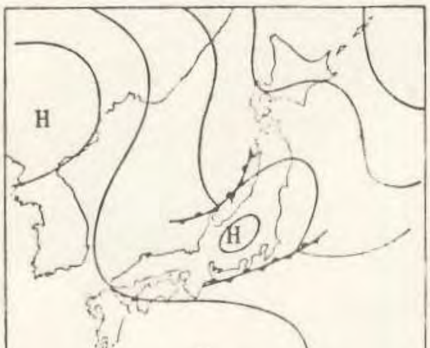


Fig. 1.17 Generation of a Topographical Front

When these fronts are prevalent, precipitation may occur. Conversely, when cold maritime air blows into an inland low depression, generated by the heated ground surfaces, a front is formed and this may cause thunderstorms.

1.11. Cyclones (Low depressions)

Cyclones result in rough weather; heavy rainfall, strong winds, etc., are caused mainly by cyclones. Atmospheric pressure on the earth differs according to the locality and the time factor. By examining the geographical distribution pattern of atmospheric pressure, we can find many places of low-pressure, where the pressure decreases with the movement from the outside towards the inside; these are called cyclones. When looking at a weather chart, we can again find cyclones whose isobar contours are almost circular, the value of pressure decreasing towards the center of the circle.

By the terms high-pressure or low-pressure, we do not mean to designate any specific value. Cyclone means a low pressure area within a higher pressure area. The atmospheric pressure at the center is called the central pressure. In the region of a cyclone, wind blows rotating from the outside (high-pressure) towards the inside (low-pressure). This rotation is counter-clockwise (contra-sole) in the northern hemisphere and clockwise (cum-sole) in the southern hemisphere (Fig. 1.18).

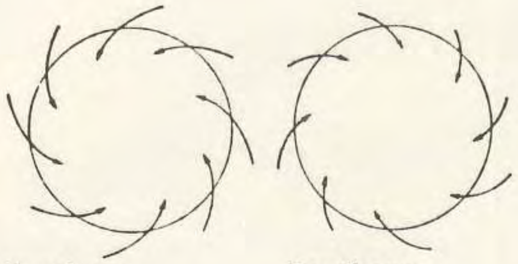


Fig. 1.18 Wind directions in Cyclones in the Northern and Southern Hemispheres

The air blowing into the center forms an ascending current and reaches the upper layers (Fig. 1.19). When the air containing much moisture ascends, the water vapour in the air is condensed to produce clouds, and this in turn produces rain- or snowfall. Therefore the weather is bad in the region of a cyclone.

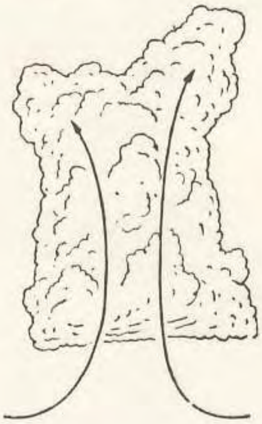


Fig. 1.19 Ascending Current and Clouds at the center of a Cyclone

1.11.1. Varieties of cyclones

Cyclones are produced in various places, and their nature and structure differ greatly depending on the source region. Thus, cyclones are classified into two main types: tropical cyclones which originate in the tropical region, and extratropical cyclones which originate in areas other than the tropical region. Tropical cyclones are generated in the warm and moist air of the equatorial region, and extratropical cyclones are formed on the boundary between a cold air-flow from the north towards the south and a warm air-flow from the south towards the north. Besides the above types, there are orographic cyclones, which include those generated by topographical effects and those produced by summer season over heating of the ground surfaces in inland areas.

Storms developed from tropical cyclones are referred to as typhoons, and those developed from extratropical cyclones are called whirlwinds. A typical example of a whirlwind is a tornado, which frequently occurs during the warm season in the central and southern regions of the United States.

1.11.2. Structure of cyclones

As already mentioned, in the area of a cyclone, the weather is bad because of the existing ascending current. However, the degree of bad weather is different in different places in the region; characteristically bad weather is seen near a front (Fig. 1.20). In the vicinity of the cold front, cumulonimbus clouds are formed, with associated showers or thunderstorms, and in the area

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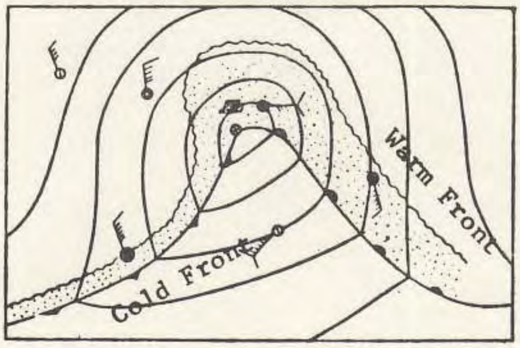


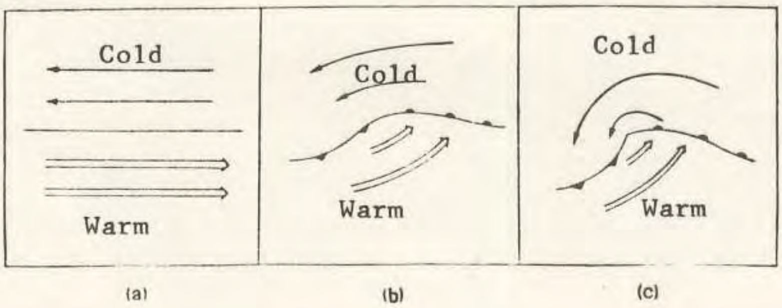
Fig. 1.20 Structure of a Cyclone

north of the warm front, continuous rainfall is seen over a wide area of up to 300 km in width. Further to the north, the sky is covered with middle and high clouds. On the other hand, towards the south of the warm front, the weather is relatively stable and warm.

1.11.3. Generation of cyclones

Although cyclones can be produced anywhere in the areas north of the mid-latitudes, the region where they are most frequent is restricted to those areas having a continent in the west and facing an ocean in the east, as on the east coasts of Asia and of North America.

There are two theories on the generation of cyclones: (1) When cold and warm air masses are in contact to form a front, and if, by any disturbance, a wavy contour is generated on the front, this wavy part of the front develops into a cyclone (wave theory), (2) If air is heated unevenly, a part of the air locally heated decreases in density to produce an ascending motion; consequently, the pressure near the ground surface lowers, and this produces an inflow of air from the outsides and finally develops into a cyclone (local heat theory). Small-sized low depressions produced in an inland area on a clear and calm day, and stationary low-pressure generated over a continent during summer are explained by the second theory, although these are restricted to particular localities. Fig. 1.21 shows the generation process of a cyclone



Figs. 1.21(a)-(c) Generation of a Cyclone

according to the wave theory model. The situation (a) shows that warm and cold air masses are in contact, forming a front between these two air masses. If, in this case, either one of the air masses becomes prevalent, a part of the front advances to form a wavy contour as in (b). In (b), the cold air mass pushes the cold front foreward and the warm air mass the warm front foreward. If the situation as in (b) continues, this unstable wave grows to a larger wave as in (c) and finally develops into a cyclone.

1.11.4. Cyclones; their sizes, development and decay

The size of a cyclone is given conveniently by the outermost isobar of a closed contour. Generally speaking, the larger the area in this outermost isobar, the lower is the central pressure and, in consequence, the stronger the wind. When the central pressure of a cyclone is decreasing, and when the scope enclosed by the isobar is becoming wider, and, moreover, when the wind force accompanying the cyclone is becoming stronger, the cyclone is said to be developing. When the situation is reversed, it is called the decay of a cyclone.

Cyclones occurring during spring to autumn are usually small-scale and do not develop fully, while those during autumn through winter to early spring often develop considerably. Some of the cyclones, generated in an area west of Japan, pass over Japan 24 hours after generation, developing rapidly, and arrive close to the Bering Sea within about four days, where they reach their peak. The central pressure of the cyclones often falls as low as about 950 mb. Cyclones, which have developed rapidly, have a wind velocity which may reach 20 to 25 m/sec, and some of them develop into storms with winds exceeding 30 m/sec: such cyclones are the cause of shipwrecks of fishing vessels in the northern North Pacific.

The reasons why cyclones develop and decline have not yet been fully ascertained; however, some of the general principles and empirical laws on cyclones may be summarized as follows:

1. The greater the temperature difference of cold and warm air masses on both sides of a front, and the more moist the warm air mass, the larger is the cyclone that develops. With the greater density difference between the air masses, the motion of air becomes more active. In this case, the warm air cools owing to an ascending motion and the water vapour contained in the air is condensed to produce clouds. The resultant heat discharged serves to develop a cyclone. In winter, if the temperature rises considerably in daytime, there will often be rough weather on the following day.

2. Generally speaking, cyclones become weaker after reaching land, and develop again if they move out of a land area towards an ocean. They tend to develop especially in the vicinity of a boundary separating different water masses.

3. With the development of the surrounding high-pressure, cyclones tend to develop.

4. When the pressure gradient becomes steeper as the center of a cyclone is approached, and when the diameter of an equi-valued isobar increases, a cyclone develops.

5. Conversely, if the pressure gradient becomes gentler as the center of a cyclone is approached, and if the center divides into two, the cyclone decays. If the wind force of the outer region is stronger than at the center, the cyclone generally declines.

6. According to the wave theory of cyclones, occluded cyclones decline. Since the cold front, extending from the center of a cyclone, generally travels faster than the warm front, the cold front finally catches up with the warm front to produce an occluded front along this part of the front: this situation is referred to as the occlusion of a cyclone. With the development of occlusion, the warm air mass rises from the ground surfaces and the air-body is pushed up to the upper layers. Thus, near the ground surface only the cold air mass remains. In such situations, the energy supporting a cyclone decreases and, thus, the cyclone rapidly decays because of friction and other effects.

1.11.5. Cyclones in the areas adjacent to Japan

Since Japan and neighbouring areas are located in the mid-latitudes, they are often covered by the polar front belt, which is formed by the contact of cold and warm air masses. With the southward movement of the arctic air mass, the northern part of Japan is affected by the arctic front. In summer, the equatorial air mass frequently approaches Japan, with associated heavy rainfall. Since, moreover, this region is located at a boundary between a continent and an ocean, and consequently, the continental and maritime air masses are in contact over the region, Japan and neighbouring areas provide favourable conditions for the generation of cyclones. The cyclones, produced in the region, generally advance towards the northeast or the east developing in the course of their movement. Fig. 1.22 shows the

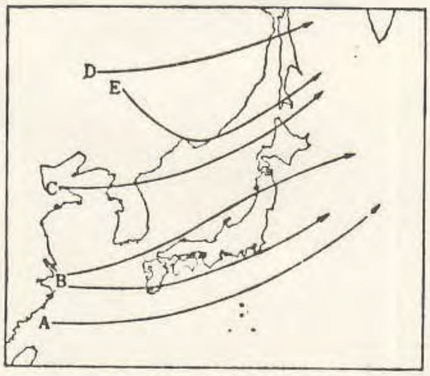


Fig. 1.22 Trajectories of Cyclones over the Areas adjacent to Japan

migratory routes of the cyclones. In the figure, route A is that of winter cyclones, which develop mostly into storms. An instance of such a cyclone is worth mentioning: a cyclone was generated on the East China Sea and was about 1,020 mb at the beginning, arrived near Kyushu 24 hours after generation, developing up to 1,000 mb. Thereafter, the cyclone passed over the area and proceeded towards the seas east of Japan, with a rapid decrease in its central pressure.

When the cyclone moved to the seas off the Kuriles and then to the Aleutian waters, it developed to about 900 mb. The area of storm, with cyclones such as the above, is surprisingly wide and its radius may reach as much as 2,000 km. During winter in these regions, such cyclones cause continuous rough sea conditions over a long period.

In spring and autumn, most of the cyclones travel along routes B or C. Cyclones along route B follow the migratory anticyclones and affect the weather over the mainland of Japan. These cyclones follow two routes as shown in Fig.1.22. One advances along the south coasts of Japan and the other passes over the Japan Sea. Sometimes, a cyclone, on approaching Japan, divides into two and each branch travels separately. Cyclones following route C proceed eastward from North China, crossing over Korea and then the Japan Sea. This type of cyclone develops considerably while passing over the Japan Sea, especially in the early spring, and sometimes the whole mainland of Japan is affected by the storm. In such situations, southern Japan is covered with a warm air mass and the weather is relatively bad. When a cold front passes over, occasional showers occur. However, a strong southerly or southwesterly wind blows, which may reach 25 m/sec.

Cyclones of route D originate in Europe or western Asia and do not have a great effect on the weather in Japan. Some cyclones take route E, and sometimes develop in a similar manner to those of route C in the early spring.

1.12. Typhoons

As already mentioned, cyclones produced over the tropical seas are of a quite different nature compared with those produced in the temperate zone. These are called tropical cyclones and they do not comprise a front. Their source region is between 5° and 25°N; they are very seldom generated near the equator. A small number of cyclones are produced in the area north of 25°N, but they are very weak.

In the northern hemisphere, the source regions of tropical cyclones are limited; they are the southwestern part of the North Pacific, especially the seas east of the Philippines, from the Mariana to Caroline waters, the Bay of Bengal in the Indian Ocean, the Carribean Sea and the waters around the West Indies in the North Atlantic Ocean. In the southern hemisphere, the source regions are the waters northeast to northwest of Australia, and the waters east of Africa.

Of the tropical cyclones generated in the North Pacific, the more violent are called typhoons. These typhoons are produced all the year round, and there may be as many as 20 to 30 in a year. In winter, however, they are seldom produced and never approach the vicinity of Japan. The season when typhoons are most frequently generated is from July to October; there may be as many as three to four a month during this season, and some of them approach Japan, with associated heavy storms.

1.12.1 Structure of a typhoon

Near its center, a typhoon is almost round in shape. In the case of small-scale typhoons the diameter may be about 80 km, while it may be as much as 2,000 km in the case of large-scale ones. However, the diameter of most typhoons is generally between 500 and 1,200 km. Inside a typhoon, the pressure decreases rapidly towards the center, and, in consequence, the wind and rainfall there become more violent. In places of strong wind and rain, near the center, the wind velocity is more than 30 m/sec, and sometimes exceeds 90 m/sec.

While over the sea, typhoons are accompanied with violent winds and rain. Once they reach land, however, they decay rapidly due to friction with the ground surfaces and the wind velocity seldom exceeds 50 m/sec. The strongest wind region is not at the center, but is located in an area 10 to 30 km distant from the center. Inside a circle of 20 to 60 km in diameter, the wind becomes weaker with the movement towards the center. At the center, the air is almost calm and the sky is clear: this area is called the eye of the typhoon. This phenomenon is clearly observed on the sea, while on land it is not so easily discernible. In a typhoon, the wind generally blows with pulsations, and is accompanied by heavy showers.

The structure of typhoons differs, depending on the areas and the seasons of generation. Those produced in the low-latitudes during summer have almost circular isobars, and the region of rainfall and clouds is nearly circular. The wind velocity is strongest in a belt-like area around the eye, and decreases considerably with the movement towards the outside. The temperature inside a typhoon is nearly constant, with only a slight increase towards the center.

The weather conditions accompanying a typhoon are almost symmetrical in relation to the center. Therefore, the variations of weather conditions at a fixed point depend on the geographical relation between that point and the typhoon's path. For example, suppose that a typhoon is moving towards the north. If it passes over an area west of a given point, then the wind changes its direction from the east to the east-southeast, then to the southeast and increases its speed. Clouds become lower and thicker, the weather is at its roughest, the wind at its strongest, and the pressure at its lowest: this stage shows the nearest approach of the typhoon to the point. Thereafter, the wind direction changes from the south-southwest to the southwest, then to the west, and the weather improves very rapidly. In the above case, the nearer the center of a typhoon passes over the given point, the stronger the wind blows and the heavier the rain falls. On the other hand, if a typhoon passes over an area east of this point, the wind changes its direction from the east to the north, then to the north-northwest, rotating anticlockwise. The weather is roughest at the time of the north wind, and it begins to improve when the wind turns to the northwest or the west. If a typhoon passes just over the given point, the wind increases its speed keeping its original direction and heavy showers occur intermittently. The pressure decreases very rapidly. With the passage of the center of a typhoon, the wind suddenly reverses its direction. Thereafter, the weather improves owing to a process inverse to the one described above.

The structure of typhoons occurring in autumn is different from that of summer typhoons; the symmetry in relation to the center is distorted to an ellipse, usually with its major axis along a front. The direction of its major axis is almost parallel to that of movement. If we examine the distribution pattern of the wind force, we find that it is stronger in the right semicircle than in the left semicircle. Therefore, the right semicircle of a typhoon is called the dangerous semicircle and the left semicircle the navigable semicircle; this results from a combination of the general air-flow which affects the typhoon's movement with the rotating air-flow forming the typhoon.

1.12.2. Generation of a typhoon

During July to October, the Australian High develops in the southern hemisphere and the prevailing southwest wind blows into the northern hemisphere, crossing over the equator. This southwest wind comes in contact with the northeast trades, blowing from the North Pacific High, and they form the equatorial front. Typhoons are considered to be produced from the belt of the equatorial front. Many small islands, located in this belt, are heated by strong sunshine and produce local ascending currents. The air contains much moisture so that many small-scale whirlwinds are generated; these whirlwinds are thought to join and thus produce a typhoon. If, moreover, there occurs a northwesterly or northerly air-flow, which originated in the polar continental air mass and whose properties are modified in the course of movement affected by the ocean beneath, these three winds (the southwest wind from the Australian High, the northeast trades, and the northwest wind originating in polar continental air mass) join to produce a particularly strong typhoon.

1.12.3. Paths of typhoons

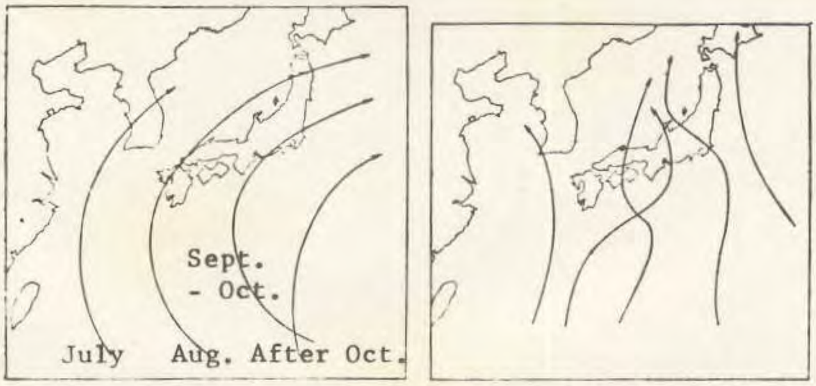
Typhoons, produced in the areas south of the Philippines, take different paths, depending on the season of generation. Those produced during the winter and spring first move towards the west-northwest at speeds of about 20 km/hr, then some of them proceed towards the South China Sea, passing over the Philippine waters, the areas of Indo-China and then become extinct. While the others change their direction towards the northeast, pass over the Ogasawara Islands or the areas east of these islands and move away towards the Aleutian waters; these typhoons never approach Japan.

During the rainy season (June to July), typhoons sometimes move directly northward. During the summer and autumn, some of them approach Japan, then change their direction to the northeast and proceed to the Kuriles waters or to the Aleutian waters.

Typhoons usually move towards the west-northwest or the northwest for about four or five days after generation, then turn to the northeast: this is called the turning of a typhoon.

Most of the turning points are between 20° and 30° N and the typhoons reach their peak when they arrive at the turning point. In the vicinity of the turning point, the central pressure is at its lowest, the wind force reaches its maximum intensity and the diameter of the typhoon is at its widest. Once these typhoons have turned their direction, they increase their migratory speed and reach 40 to 60 km/hr. Autumn typhoons, in particular, sometimes exceeds 100 km/hr in their migratory speed.

The most common trajectories of typhoons are illustrated in Fig. 1.23. a , but some typhoons take unusual paths as in Fig. 1.23. b. Since accurate prediction of a typhoon's course is of utmost importance, much research has been conducted on this subject; however, the problem has still not been fully solved. At the moment, therefore, predictions are carried out on the basis of a synoptic analysis, and some important indications for such predictions are summarized as follows:



Figs. 1.23 (a)-(b) Usual (left) and Unusual (right) Trajectories of Typhoons

1. Typhoons move, driven by the air flow in the upper layers. Information on the upper layers of the air flow can be obtained by observation and estimation; this still provides a useful means for prediction. Usually the general air flow at a height of 3,000 to 6,000 m is taken as a measure, although this height varies, depending on the scale and structure of the typhoon. As an example, Fig. 1.24 illustrates the general air flow pattern at a height of 6,000 m and the trajectory of typhoon No. 15, which passed over Japan from 25 to 27 September, 1954.

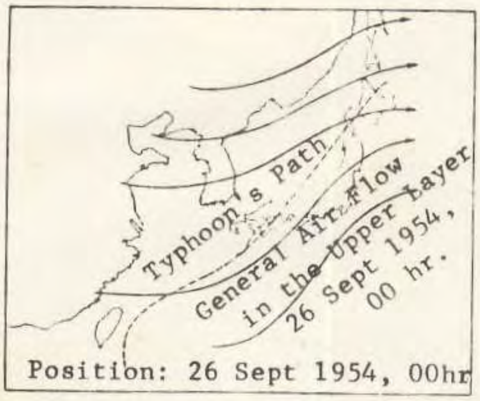


Fig. 1.24 General Air Flow Pattern in the Upper Layers and Typhoon's Path

The Ogasawara High (the North Pacific mid-latitudes High) extends to the upper layers, and, in consequence, the general air flow pattern is governed by this existing high-pressure. When this high-pressure spreads over the East China Sea, typhoons proceed to the west from the tropical sea and move away to the Philippine waters. When the high-pressure spreads over the area between Kyushu and Taiwan, typhoons turn their courses near Okinawa and approach Japan. When the high-pressure is weak and is located to the east of the Ogasawara Islands, typhoons never approach Japan. Since the seasonal variation of the Ogasawara High is very regular, the paths of typhoons are also very regular and vary seasonally as seen in Fig. 1.23.a.

2. Typhoons proceed along the belt of a front. When a typhoon approaches Japan, and if a prevalent front exists near Japan, the typhoon moves along the front. Since, however, a large-scale typhoon shifts the front in the course of its movement, this method of prediction is applied only in the case of small-scale typhoons.

3. A typhoon never changes its course and speed suddenly. Therefore, if the location of a typhoon and the pattern of the storm region are plotted on a chart successively, the prediction of the typhoon's behaviour, within the next 12 to 24 hours, is possible to a certain extent.

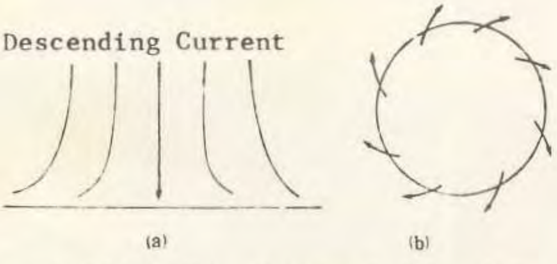
4. Some typhoons move towards an area of pressure decrease Therefore, the typhoon's course can be predicted by inspecting the area of the steepest gradient of pressure decrease.

5. Typhoons, occurring successively, follow a course similar to the preceding one.

6. The numerical computation method can be applied for the prediction of a typhoon's course.

1.13. High-pressure (Anticyclone)

On a weather chart we will see many isobars of different values, some of which have closed contours. Those with closed contours, where the pressure increases towards the inside, are called the high pressures (highs) or anticyclones. In the area of a high, wind blows outwards clockwise in the northern hemisphere, and anticlockwise in the southern hemisphere. As a compensation for the air blowing out, a descending current occurs in such an area of high pressure. Therefore, there is no cloud and the weather is clear. If the compensating current is not sufficiently strong, the high pressure decays (Figs. 1.25. a - b).



Figs. 1.25(a)-(b) Vertical (a) and Horizontal (b) Sections of Anticyclone

High pressures can be classified according to their mode of generation into: (1). Topographic high pressure, which is small-scale and formed owing to differences in the local temperature, (2). Continental high pressure, which is formed over a continent during winter, (3). High pressure caused by a process such as the general circulation of the air, and (4). Moving anticyclone.

1. Topographic highs. During night-time, the lower layer of air, which is just above the chilled ground surfaces, cools to produce a small-scale cold air mass, and this in turn forms a high pressure zone. Usually the high pressure zone decays during daytime. Since this high pressure is very weak, it does not greatly affect the weather. In coastal areas, it produces a land breeze, and forms a weak topographic front between the dry air over a land area and the moist air over the sea.

2. Cold high pressure. In winter, the lower layers of the air over a continent are chilled by the underlying cold ground surfaces, and thus a cold air mass is formed. The cold air mass thus produced or the high pressure covers the whole continent; an example is the Siberian High. A uniform air mass is formed in the region of high pressure and cold winds blow out of the region; the weather of Japan in winter is completely governed by the Siberian High. The Siberian High is horizontally gigantic, the diameter of the air mass reaching 5,000 km. Since, however, the air mass originates in the lower air, it is not so high vertically; the height is about 3,000 m and the characteristics of the high pressure cannot be perceived in the layers above 3,000 m.

A great pressure difference may develop between the continental high pressure and the low pressure over the seas east of the continent, and, in consequence, this produces a strong monsoon over Japan and neighbouring areas. In particular, heavy snow falls, sometimes even violent snowstorms, occur along the coasts of Japan facing the Japan Sea, whereas the weather along the coasts facing the Pacific is clear and dry winds blow. The contrast in these weather conditions depends on the following: The Siberian air mass, flowing out from the Siberian High, is originally cold and of low humidity, but, on passing over the Japan Sea, it is warmed and receives much moisture from the relatively warm underlying sea surface. This modified air mass is driven towards the high mountain ranges of Japan and the air is forced to ascend along the slopes of the mountains, producing clouds and, in turn, snowfall. Once the air has crossed over the top of the mountain range, however, it descends along the slopes on the opposite side of the mountain; thus the clouds disappear, the air becomes dry, and the weather continues to be clear (Fig. 1.26).

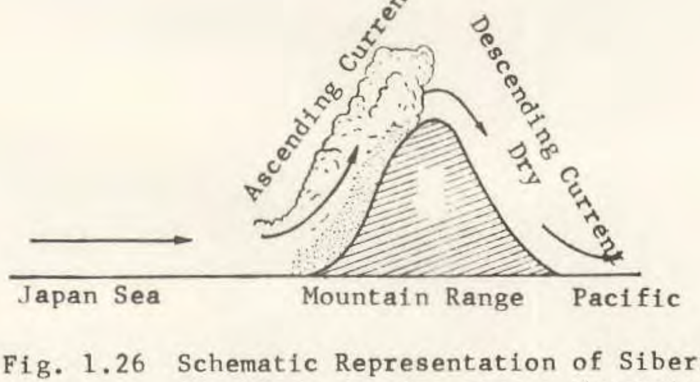


Fig. 1.26 Schematic Representation of Siberian Air Mass, passing over a Mountain Range

In winter, this Siberian High is not always equally strong, but changes its power following a regular cycle within one week. Owing to this meteorological variation, a phenomenon called "succession of three cold days and four warm days" occurs in Korea and North China.

Another cold high, which is located in an area neighbouring Japan, is that of the Sea of Okhotsk. This high pressure brings the rainy season to Japan. The northeast winds from the Sea of Okhotsk High make the weather of Japan characteristically bad. Although a high pressure generally produces a clear sky, the reason why only the Sea of Okhotsk High produces bad weather is as follows: the lower layers of a cold and moist air mass from the Sea of Okhotsk High are warmed by the sea surface below, with their movement towards the south, and thus the air body becomes unstable. Since, moreover, this air mass produces a front by contact with a warm air mass from the south, the weather of Japan is bad during this season.

3. <u>Warm high pressure</u>. Two belts of high pressure generally exist, one at about 30°N and the other at about 30°S (Fig.1.27). These

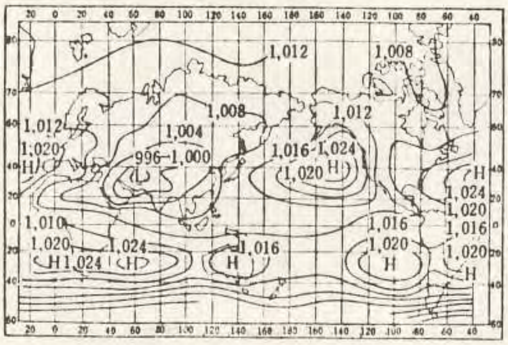


Fig. 1.27 High-pressure belts formed by General Circulation of the Air

belts of high pressure are formed by the general circulation of the atmosphere; they are, therefore, different in their properties from a cold high produced over a continent during winter. The warm high extends vertically to the upper layers. These highs exist almost all the year round. Although their locations vary to some extent. They are called the mid-latitudes high (horse latitudes highs).

In the regions of mid-latitudes highs, the temperature is usually high. Generally speaking, these highs are large-scale, and govern the long term weather conditions. Since these weather conditions have strong durability, once an area is covered with this high pressure, fine weather lasts a long time.

The Ogasawara High, a good example of a warm high pressure, develops in summer over the North Pacific Ocean and governs the weather in Japan. If this high pressure is strong enough to cover Japan, fair weather lasts for a long period, with associated southerly winds, and drought many result. This high pressure is so stable that even a typhoon or cyclone cannot enter the area.

4. Moving high pressure. Although both cold and warm highs have a tendency to stay in their original places, some of them are separated from the main body and move towards the east or the northeast like cyclones; these are called moving anticyclones. They often occur in spring and autumn, and even in winter a part of a continental high pressure may separate to form a moving anticyclone.

In the region of such an anticyclone, the weather is generally fine. However, clouds occur in the west side of the region and they change from middle clouds to low clouds with their movement towards the west. Usually this moving anticyclone is followed by a cyclone. Therefore, with the passage of the center of an anticyclone, the weather becomes cloudy, and low clouds appear, with associated rainfall (Fig. 1.28).

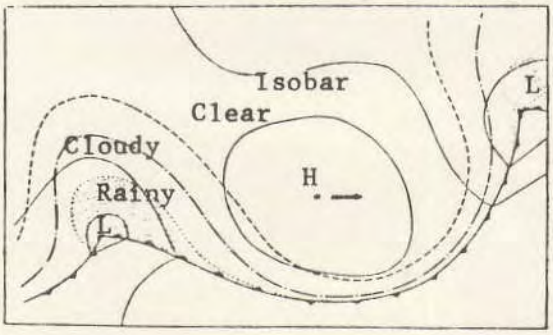


Fig. 1.28 Moving Anticyclone and Associated Weather Conditions

2. WEATHER CONDITIONS AND NAVIGATION

Our daily life is closely related to the weather conditions. It is no exaggeration to say that almost all activities of our societies are directly or indirectly affected by meteorological phenomena. In particular, it is necessary, for those who work on board a ship, to study the relationship between the weather conditions and navigation, taking the contrast between the weather conditions on the ocean and those on land into consideration.

Knowledge of meteorology is essential for mariners. Lack of such knowledge has caused many accidents at sea, which could evidently have been avoided. Generally speaking, shipwrecks occur owing to natural causes, such as the topography or the weather, or to human errors including defects in the construction of ships or in their navigational equipment. However, most of them, such as stranding or collision due to poor visibility, and sinking by high waves, are affected by meteorological conditions. In particular, shipwrecks in winter are often caused by wind waves or snowstorms, and those in summer by dense fog. Shipwrecks can be prevented to a large extent by taking appropriate measures. When a disaster is imminent action should be taken with cool judgement, and the utmost efforts should be made to confine damages to the minimum. In the following sections, sea fogs and storms, regarding which mariners should take special precautions, will be studied.

2.1. Sea Fogs and Navigation

Mariners should exercise special caution when sea fog or so-called gas is encountered. Sea fogs occur frequently over the seas adjacent to Japan from late spring to mid-summer (June to August). They form most frequently over cold sea surfaces. Notorious places where sea fogs develop are the areas extending from Hokkaido to the Kuriles; and the areas off Newfoundland to the east coast of North America: in the former case it is the Oyashio Current that plays an important role in producing the fog, and in the latter case it is the Labrador Current. In the regions where cold currents such as the Oyashio cold current and the North Korea cold current approach the coast-line, or in the regions where a cold water mass upwells to the surface from the lower layers as in the vicinity of Mokpo, Korea, dense fogs occur, in particular when warm winds from the south blow over these areas.

When dense fogs occur, the wind is usually weak. Such fors lift when the wind reaches 1 to 5 m/sec. However, dense fog during the passage of a cyclone has great difficulty in dispersing even in daytime and even when winds are relatively strong. Off the Sanriku district, Japan, the Oyashio cold current and the Kuroshio warm current meet and a boundary is formed between these water masses of different properties; consequently very dense fog occurs over the boundary. Since during the summer season fishing grounds for skipjack and whale are formed near the boundary, fishing vessels often encounter great difficulties owing to the dense fog.

In the summer of 1950, 54 purse seiners and 79 carriers, totalling 133 vessels, operated in a mackerel fishing ground south of Hokkaido. Of 133 vessels engaged in operations during the fishing season lasting three months, eight suffered sinking and sixteen collision. Most of these accidents took place in the Tsugaru Strait where the current is strong. The accidents are considered to have resulted from the fact that the vessels were hurrying back during night-time to Hakodate, their home port. At that time, dense sea fog prevailed over the cold sea surfaces along the coasts of Hokkaido. During dense fog generation, unusual currents often occur in the area.

Sea fogs usually form when southerly warm winds blow over a cold water surface. Therefore, fog generation can be predicted by examining the distribution pattern of atmospheric pressure on a weather chart. In particular, dense fog occurs with the passage of a cyclone, because a southerly warm wind blows into the area. Accordingly, fogs occur in most cases, after the passage of an anticyclone, over the areas of a gentle pressure gradient such as the forward or the southward of a cyclone.

Following a sea fog, heavy rain and heavy snow affect visibility and cause shipwrecks by stranding or collision. In the seas adjacent to Japan, the frequency of shipwrecks has its peaks in summer and winter, most of them resulting from rough sea conditions in winter and dense fogs in summer. According to statistical data, disasters due to fog account for about 25% of the total; of 840 cases of stranding accidents, those due to fog reached 270.

The areas in a strait, near a point, and around an island, where fogs are frequently generated, usually have strong currents. Therefore, these areas are dangerous to navigation. Navigating in dense fog is similar to a blind man walking with a stick; on approaching a coast, continuous soundings should be made as well as keeping a careful lookout. Caution should be exercised with all the senses for ships ahead, white-capped breakers, sounds of a whistle or bell, the sound or waves, etc.

With the development of radar and loran, navigation with low visibility has become much easier. However, excessive reliance on these instruments is not recommended; in particular, attempts to avoid other ships in fog by using radar alone involve many hazards; therefore, a careful watch out should be kept together with detection by radar.

Fig. 2.1 shows the frequency of occurrence of fog over the oceans of the world, during June to August. In this

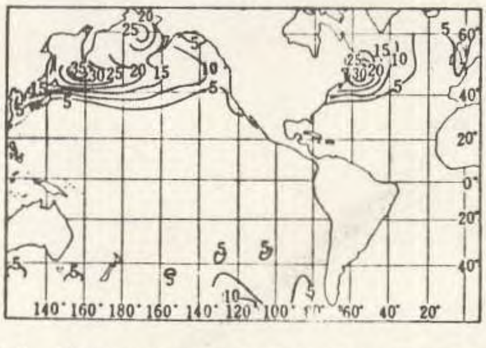


Fig. 2.1 Frequency of Sea Fog Occurrence during June to August

figure, 20% means that, of 100 navigations in the area, 20 will encounter fog.

When navigating in dense fog, the captain responsible for the ship should be on the navigation bridge and comman the ship. He should, in particular, take the following precautions: blowing of fog signals, standing by engine and cruising at appropriate speed, strict enforcement of lookout, confirmation of ship's position, lighting of lamps, standing by for anchoring, preparation for and carrying out of soundings, keeping quiet on board, proper measures when other ships' fog signals are heard. Under such circumstances, all available navigational instruments should be employed; when close to land, echo sounding and wire sounding should be made continuously and the ship's position should be confirmed by examining data on the navigation chart. When in an area of strong currents and when, moreover, the ship's position is uncertain on the chart, it is very dangerous to run into dense fog. Therefore, it is recommended to anchor and wait for the fog to lift, and later to pass through the area when the current is weak or the current is turning. In particular, on passing through a channel in dense fog, it is essential to ascertain the position of the entrance to the channel. In dense fog, many ships may be seen near the entrance of a channel, waiting for the fog to lift; this is the more advisable course to take.

The areas of frequent occurrence of dense fog coincide, in most cases, with the areas where warm wind blows from offshore towards the coast over a coastal cold water surface. It can, therefore, be expected that a drift current towards the coast will develop in the area. When navigating along a coast in dense fog, every precaution should be taken, in particular, against suffering stranding or shipwreck by drifting towards the coast. If a narrow channel is covered by dense fog, it is safer to wait for the fog to disperse. When, however, such a channel has to be passed through because of special circumstances, the central deep area of the channel should be followed, while also taking into account the direction and speed of the current and wind. If dense fog is encountered, when moving from islands to islands, it is necessary to adopt a course as far from the islands as possible, taking the currents towards the coasts into consideration.

When approaching, in dense fog, a coast, where the bottom slopes steeply, move slowly with suspended anchor down to about 10 meters, measure the depth continuously, and inspect the chart with special care in order to prevent stranding. In an area where the bottom has many ups and downs and the depth data on a navigation chart are not always precise, we should not rely too much upon the soundings. While cruising in a coastal area covered with fog, sailing directories and charts of the area should be prepared in advance so that, when part of a land contour become visible, it can be checked immediately to ascertain the ship's position. Since, in dense fog, white-capped breakers along a coast or near rocks can usually be observed earlier than land features, a careful lookout for these should be kept. In fog, attention should be paid to driftages such as seaweeds, driftwood, pieces of fishing gear, as well as to sea birds, water colour and smell of beach, and careful watch should be kept for every possible indication of approaching land. Temperature distribution and water droplets in fog affect the travel distance of fog signals; when there is wind, sound travels further to leeward than to windward.

Drifting in fog makes the ship's dead reckoning more difficult, so it is safer to turn back along the original course or to move offshore.

2.2. Storms and Navigation

It is well known fact that ships suffer from the rough sea conditions they may encounter and, if wrong measures are taken, disasters such as sinking and stranding occur. In stormy weather a ship's operation is obstructed by violent winds, high waves, and poor visibility, with associated heavy rain. Strong winds are produced by cyclones, monsoon, prevailing westerlies, and squall. However, the term "stormy weather" is generally accepted to mean that strong winds blow for a relatively long time making the waves grow larger. Accordingly, small-scale squall and whirlwind cannot be regarded as a storm. A vessel is seldom in danger because of strong winds alone, but more often parts of a vessel are damaged by the exceptionally high waves, associated with a storm. In the following pages, disasters due to storm and measures to avoid them will be mentioned.

2.2.1. Shipwrecks due to cyclone, monsoon squall

Drifting or shipwreck of fishing vessels have since time immemorial been caused mostly by cyclones in winter, violent westerly monsoons, associated with cyclones, and squalls occurring near a cold front. We should bear in mind that in the seas adjacent to Japan during the winter season, the westerly monsoon develops considerably after the passage of a cyclone and a cold front, accompanied with violent squalls.

In the afternoon of 7 December 1926, a tuna fishing boat, the Ryoei-maru (19 GT), of Wakayama Prefecture, Japan, left Choshi, Chiba Prefecture, for an offshore fishing ground, 25 miles distant from the port, and started engaging in tuna long lining at 3.00 pm on the following day. The wind was relatively strong, because a cyclone (740 mm in the central pressure) had just passed over the area the same day. The continental high was 780 mm at that time, and, in consequence, the pressure difference between the high and the cyclone was 40 mm; a cold wind of 15 to 20 m/sec was blowing over the sea, and continued for one week after the boat encountered the storm. The Ryoei-maru, which had engine trouble, drifted away from the fishing ground almost as far as the middle of the North Pacific. The Kuroshio extension contributed to this drift eastwards. The wind fell on 15 December, rose on the 19th, fell on the 22nd, and rose again on the 23rd. Thus, in spite of their efforts, the crew could not return to the west. By 6 March 1927, all the remaining food had been consumed, and the last two crew members remained alive until 20 May 1927 by catching birds and fishes. The above details were known later from a log book which remained on the boat. All the crew members were finally found as skeletons or mummies in the boat off Seatle, North America, eleven months after the boat had left Choshi, Japan. Professor Fujiwara of the Central Observatory, Japan, studied the problem and concluded: If a vessel, drifting under the action of a strong westerly monsoon, takes as southerly a course as possible, it will encounter the northeast trades near 20° N. Thereafter, the vessel can return to Japan within 20 or 30 days, by drifting towards the west in the northeast trades region. As can be concluded from the above example, knowledge of meteorology and oceanography is essential for mariners.

On 30 December 1950, four cargo vessels of the 2,400-ton class, including the Eijun-maru and the Tetsuzan-maru, drifted from the Tsugaru Strait under a strong northwest wind. They carried no cargo and were on their way to Muroran, Hokkaido, to load coal. The above mentioned two vessels were abandoned after one week of drifting, because of lack of food and fuel. Although the crew members were rescued by other ships, their vessels continued to drift and the Tetsuzan-maru and the Eijun-maru were towed back to Japan after 40 days and 74 days respectively. The weather chart relating to that time showed that the center of a cyclone (980 mb) was located in the vicinity of the Tsugaru Strait and an exceptionally cold front originating in the cyclone extended along the coasts of Japan towards the south as far as Taiwan. Just after this cold front had passed over the strait, the west wind became violent and the four vessels' drift was started. After the passage of the cyclone, a strong westerly monsoon, originating in the Siberian High (1,040 mb), continued to blow. These meteorological circumstances were responsible for the disaster suffered by the vessels.

On 14 February 1951, a cyclone, moving to the east from the north of Taiwan, developed considerably on approaching the Izu Islands. Owing to the cyclone, Japanese fishing vessels and merchant vessels, totalling 54, and a Swedish vessel were wrecked or damaged. Since, at that time, the Siberian

High extended eastward and reached the east of Hokkaido, snowstorms occurred and there was heavy snowfall even in the Tokyo area.

On 10 May 1954, a violent off-season cyclone struck the Hokkaido area. Of the salmon fishing vessels operating there, 409 were damaged or wrecked and 397 crew members lost their lives or were reported missing.

Disasters on the seas adjacent to Japan are nearly all caused by cyclones during winter and early spring, squalls associated with cold fronts or sometimes with warm fronts, and the subsequent violent westerly monsoon. Storms in the northern North Pacific during winter are particularly dangerous, because they are always accompanied with high waves and snowstorms. Most of these disasters could have been prevented by improvements in the maneuvering techniques of ships, shipbuilding techniques, engine manufacturing techniques and handling and upkeep of the engine, as well as by a thorough knowledge of oceanography and meteorology.

2.2.2. Shipwrecks due to typhoons

Typhoons are the most violent of the tropical cyclones. They cause damage to vessels on the oceans and property on land. Owing to the better equipment now installed on merchant ships and fishing vessels disasters due to typhoons have been decreasing in recent years. The reason may be attributed to the following facts: The actual stormy region of a typhoon is relatively narrow, and, in addition, with the development of telecommunication techniques, the location of a typhoon and its direction of movement can be known in advance. Therefore, ships can avoid the stormy region of a typhoon. Actually, at a distance of 300 km from the center, the sea conditions are often those of a small-scale storm. Most of the vessels damaged by a typhoon are either fishing vessels or cargo ships, operating in coastal waters which, failing to escape from the typhoon, encounter its full force, or vessels anchored in a harbour.

An example is the shipwreck of the Aoba-maru in June, 1950. When the typhoon Della approached the vicinity of Yakushima, Kagoshima Prefecture, Japan, the Aoba-maru was in Takahama, Shikoku (25 June 1950). Since, according to the weather forecast from the observatory, it was supposed that the typhoon would pass the offing of Shikoku and then move away to the east, the captain considered that conditions in the Seto Inland Sea might not be too rough and the vessel left for Shimonoseki around 9.00 pm. However, the typhoon proceeded straight to the north from Yakushima and crossed over Kyushu, the center of the typhoon reaching an area near Shimonoseki around 3.00 pm on 26 June. At that time, the vessel was on its way to Shimonoseki in the Sea of Suhonada. It was located near the center of the typhoon and in the right semicircle. Since, in addition, a warm front, originating in the center of the typhoon and extending to the east, was just above the vessel, strong winds blew from the south. Thus, the vessel capsized and 96 passengers and crew members lost their lives.

When a typhoon passes close to and west of a harbour, disaster generally occurs to vessels sheltering there. On 21 September 1934, the Muroto typhoon passed between Osaka and Kobe and proceeded to the northeast. Damage was less extensive in Kobe, but in Osaka, of 114 vessels (above 100 GT class vessels) in harbour, 111 were damaged. Among the vessels damaged, some in the several thousand ton class were washed up onto the wharf by the high tide and strong winds and overturned. The water level at that time was more than 5 m higher than usual, because of the superimposed effect of meteorological tide on astronomical tide. Apart from the above, there have been many similar disasters: In Osaka due to typhoon Jane (3 September 1950), in Yokohama and Yolosuka due to typhoon Kitty (31 August 1949), etc. There have been so many disasters in these ports that it is not possible to mentioned every one, but all of them occurred when the typhoons passed to the west of these harbours.

More recently, the shipwrecks of five vessels, including the Toya-maru, occurred in Hakodate on 26 September 1954. In this case, typhoon No. 15 passed over western Japan travelling towards the Japan Sea in the morning of 26 September. Thereafter, the typhoon proceeded to the northeast along the Japan Sea coasts of Japan at the high speed of of 110 km/hr. On the same day, the captains of the above ferry boats presumed, from the weather forecast that morning, that the typhoon would pass over the south of Hakodate in the direction of the Pacific Ocean, and that the wind direction would then veer to the left. They, therefore, remained at the quarantine anchorage outside the breakwater, and took no action to seek shelter. Contrary to their expectations, however, the typhoon moved to the north passing over the west of Hakodate, and the wind direction veered to the right. Since, at that time, the anchorage space inside the breakwater had been filled by ships seeking shelter, the Toya-maru and the other ships had no other alternative but to stay at the anchorage outside the breakwater. Usually, when typhoons pass the vicinity of Hokkaido, about 90 % of them decline and loose their power. Typhoon No. 15, however, did not decay even after moving to the Japan Sea, but regained its power as a cyclone, accompanied by a considerably developed front, travelling at the high speed of 110 km/hr. On approaching Hokkaido, the travelling speed suddenly decreased to less than 1/3 of its initial speed. The place where the Toya-maru and other vessels were anchored provided no shelter from the winds and waves of the Japan Sea, and, moreover, the place was near a coast. Thus, these vessels drifted onto the beach and overturned. As a result of the shipwrecks of the Toya-maru and the other four vessels, 1,414 persons lost their lives or were missing.

If the ships' structure had not been of the particular design of a ferry-boat, this disaster might not have happened. In such circumstances, various precedents have shown that, rather than stay in an anchorage, it is a better navigation technique for a ship of a standard type to proceed offshore and, after all necessary preparations have been made to counter stormy weather, to maneuver the ship by heaving to. The following points should be remembered by mariners: The weather forecast from meteorological observatories or stations is the best available information based on accurate data and scientific judgement. However, forecasts relating to natural phenomena, extending over a wide area, such as a typhoon or a cyclone are not yet technically advanced enough to cover the area completely. Therefore, weather forecasts from observatories should not be regarded as completely reliable. All available up-to-the-minute information should be taken into account; in particular, it should be borne in mind that information on meteorological phenomena peculiar to a specific locality will not be given in the weather forecast.

The Kashima-maru (296.96 GT, 500 HP), a training ship of the Nakaminato Fisheries High School, Ibaragi Prefecture, Japan, encountered typhoon No. 15 at about 22° 45'N, 124° 40'E on 25 September 1954; at that moment the vessel had passed through the Bashi Channel on its return voyage to Japan, after practice in tuna long lining in the Indian Ocean. The typhoon was initially 1,000 mb in its central pressure, and the travelling speed was so slow that the typhoon's course could not be predicted. However, the ship's captain presumed that they might encounter the typhoon while cruising in the East China Sea, and prepared for stormy weather. From the observed data and the weather forecast, the captain decided that navigation was possible and the vessel passed through the Bashi Channel. Just after they had passed through the channel, the atmospheric pressure dropped suddenly and the wind force increased. Since it was observed that the vessel was entering into the typhoon region, every possible countermeasure was taken to avoid the typhoon: since it was dangerous to keep the original course, the ship's course was changed so as to face the wind. The wind increased and the waves became larger. Since running at the original speed was considered to be dangerous, the speed was decreased to the lowest possible speed for steering. The vessel could fortunately avoid the typhoon after twenty hours' heaving to. The wind force was 10 to 11, and the central pressure was 977 mb.

On 19 June 1949, the Toraichi-maru (70 GT, 110 HP), from Yasuda, Kochi Prefecture, Japan, was engaging in tuna long lining in a fishing ground about 350 miles south-southwest of Muroto. The vessel received a weather forecast at 8.50 am informing it that "Typhoon Della, 980 mb, was generated near Ishigaki Island, moving northeast at 10 knots". Since it was considered that, if the original course was kept, the vessel might encounter the typhoon, the vessel changed its course and proceeded towards Kagoshima to avoid it. On the following day, at 4.00 am it received information that "Typhoon Della is moving north-northeast at 20 knots, she may change course to north". However, the vessel was already in the region of the typhoon, which had changed its course, at that time. Since the circumstances were felt to be dangerous, the ship's course was changed so as to face the wind, but this action was taken too late, the vessel capsized at 9.55 pm on 20 June, 20 miles southwest of Tanegashima. Later, the ship unexplainably righted itself and drifted in the Kuroshio current region for 8 days from 21 to 28 June 1949. The survivors were rescued off Ashizuri Point.

As causes of this disaster, the following points should be noted: the Toraichi-maru failed to escape from the typhoon, because wrong measures were taken. Since the ship had already been informed, through the weather forecast, that it was in the fore right quadrant of the typhoon, it should have been maneuvered according to the rule "When the wind rotates to the right, the ship is in the right semi-circle of a typhoon. Navigate facing the wind at 2 to 3 points starboard bow". However, the vessel ran with the wind towards the center of the typhoon. Since there is usually a time lag of about three hours between the time when weather forecasts are issued and that of the data observed, correction should be made on the location of the typhoon. In such circumstances, the location of a typhoon estimated from Buys Ballot's law should concurrently be taken into consideration. When waves are so violent that the bow of a ship cannot be kept against the wave, the ship should be allowed to drift using sea anchor and the waves should be calmed with oil; an endeavour should be made not to approach the center of the typhoon.

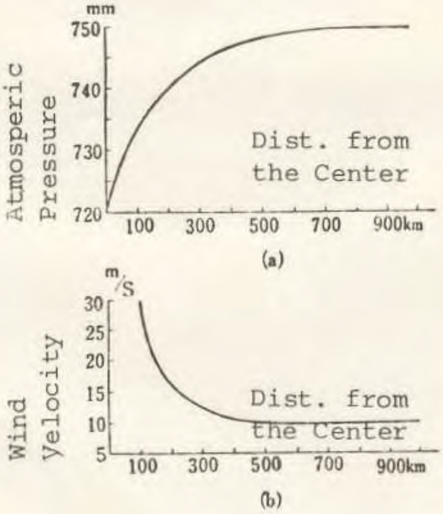
The location where the above disaster took place was an area of rough seas in the Kuroshio current. The vessel capsized because of exceptionally bad conditions making steering impossible on account of high waves.

2.2.3. Countermeasures in case of a typhoon

1. Movement of the center of a typhoon. Since in a stormy region, the area around the center is the most dangerous, the determination of the location of the center at the earliest stage is essential. When there is no effect of land, the center of a storm will be located along the direction of the swell, but this contains an error of 20 to 30°.

As already mentioned, in the case of typhoons in the northern hemisphere, the wind blows, rotating anti-clockwise, into the center and forms a gigantic eddy. Therefore, when a man is standing with his back to the wind at an arbitrary point in a storm region, the center of the storm will be along a direction about 2 to 3 points foreward from that of his laterally outstretched left arm, and, with the approach to the center, the location of the center will deviate to the left; this is an illustration of Bays Ballot's law.

Thus, when the direction towards the center of a storm is known together with the data on the atmospheric pressure and wind velocity, the distance between the ship's position and the center of the storm can roughly be estimated by the aid of the figures as given in Figs. 2.2. a and b. the



Figs. 2.2(a)-(b) Relationship between the Atmospheric Pressure and the Distance from the Center of a Typhoon (a), and Relationship between the Wind Velocity and the Distance from the Center (b). Data: Okinawa Typhoon.

location of the center of the storm should be studied with special care on a weather chart, using all available information. Once the location of the center is thus estimated, from the observed data on the changing wind direction, the course of the typhoon relative to the ship can be detected in the following manner:

(1) Case where the wind direction does not change. For example, suppose that the wind direction was observed at first to be north and this direction does not change in the course of time, then the ship is located on the typhoon's course. In such circumstances, if the wind force increases and the pressure drops sharply, the typhoon is approaching directly towards the ship. With the passage of the typhoon, the wind will reverse in direction. This wind direction will never change as long as the ship's course and that of the typhoon coincide.

(2) Case where the wind direction changes to the right hand side. For example, when the wind blows at first from the north, then changes its direction gradually clockwise to the north-northeast, and to the northeast, the ship is in the right semi-circle of the typhoon.

(3) Case where the wind direction changes to the left hand side. The ship can be judged to be in the left semi-circle of the typhoon.

2. Navigation to avoid a typhoon. When the signs of an approaching typhoon are observed, first check the following:

(1) The ship's position; whether or not there is any safe harbour of refuge in the neighbourhood, and, if any, the distance to this harbour.

(2) Variation in the wind force, pressure and wind direction, and the occurrence and properties of waves, clouds and precipitation.

(3) Rough estimate of the distance to the center of the storm.

Then, if there is enough time to take shelter, enter the harbour of refuge, or if not, move the ship to off-shore waters and heave to.

Detailed observation, in particular, of the meteorological and sea conditions is necessary. When the wind direction is indefinite and the pressure drops sharply, the center of a storm is approaching the ship directly. Under such conditions, run keeping the starboard bow facing the wind, endeavour to enter the navigable semi-circle and move away from the center. It is dangerous to run with the wind and wave. When the waves become higher and the circumstances are considered to be dangerous, maneuver the ship by heaving to. When necessary, use sea anchor and oil.

When the wind rotates clockwise (e.g., if the wind is initially northeast by east, the center of a storm is roughly south-southeast; then, if the wind rotates to the east by north, the center moves to the south-southwest), the ship is in the most dangerous area of the fore right quadrant. If the vessel is maneuvered keeping the starboard against the wind, it can move away from the center, but may encounter the opposite wind, with associated high waves. If the situation becomes dangerous, heave the ship to keeping the starboard bow against the wind and operate the engine slowly in such a way that the vessel does not drift leeward, and wait for the passage of the typhoon. When the ship is in the right semi-circle, it may gradually drift towards the center so that drifting leeward should be avoided.

When the wind rotates anti-clockwise (e.g., if the initial wind direction is northeast by east, the center of the storm liew to the south-southeast; if the wind direction changes to the northeast by north, the center moves to the southeast), the ship is in the fore left quadrant. This situation is the second most dangerous one after that of being in the right semi-circle. Therefore, if the situation allows, run in a westerly or northerly direction, keeping the course in such a manner that the starboard stern faces the wind; then the vessel can avoid the center.

3. Preparations for stormy weather. When any sign of encountering stormy weather is detected, the following preparations are necessary:

(1) As a precaution in case of rolling and pitching of the hull, all movable things on deck such as loadings (fishing gear, catch), boats and anchors should be tightly fastened. Do not load them on one side only, since this may result in overturn.

(2) In preparation for discharging water, check the pumps and scuppers.

(3) As a measure against leakage and impact of waves, check and tightly close the hatchways, ventilators, companionways and side lights.

(4) For the security of deck work, fasten the life lines, scatter sand on deck and check the ventilation and lighting systems inside the ship.

(5) Steer with the utmost caution, and prepare oil.

4. Maneuvering ship in stormy weather. When maneuvering a ship in stormy weather, be careful not to race the engine, guard against leakage, and adjust the speed and course to the situation. It is necessary to relieve the situation by careful steering. For successful maneuvering in stormy weather, perfect preparation is essential. When the waves beat the deck violently, oil is the most simple and effective way to calm the waves.

Running with the wind is frequently employed when escaping from the center of a storm in the navigable semicircle. In this case, if the ship has sufficient thrust and if oil is scattered on the weather side, the ship is rarely beaten by huge waves and, in consequence, the hull seldom receives violent shocks. Since, however, this operation tends to expose the propellers to waves, and tends to turn the bow suddenly by the wave action, steering should be done with the utmost caution. It is very dangerous for the stern to be hit by huge waves when running. It is also dangerous if it is hit on the broadside by waves while turning in stormy weather. When obstacles appear ahead suddenly, the turning operation to avoid them sometimes causes overturn.

When in the right semi-circle (dangerous semi-circle), navigation against the wind is practised. Under such conditions, vessels frequently suffer from violent pitching; their bows may be hit by high waves when the ship is unlanden, and their bows may be washed by waves when laden. The propellers may race, and thus maneuvering becomes very difficult. To reduce pitching, either the speed should be reduced or the course changed, and the ship should be maneuvered so that the cycle characteristic of the ship and that of the wave do not coincide.

Running with the broadside facing the waves is always unadvisable. The ship rolls violently, which may cause the movement of loadings, and it may scoop up water, thus placing it in a very great danger of capsizing.

When the wind and wave are violent and constitute a danger to navigation, try to keep the ship at a point by heaving to, so that it does not drift leeward, and do not strain the vessel's capability. For heaving to in stormy weather, the following operations are sometimes recommendable:

(1) Cast down the sea anchor from the bow, to keep the bow always facing the wind:

(2) Slow down the speed within the range where steering is still possible, and keep the bow against the wind by steering;

(3) Remove the anchor from the chain and lower the chain into the water, to keep the bow against the wind.

2.3. Navigation and Weather Conditions in Some Specific Waters

2.3.1. Navigation and weather conditions in coral seas

The waters of coral reefs are dangerous for navigation, because there may be many unknown reefs in the area. Therefore, even on a calm day, a sharp lookout should be kept. Running in daytime and at slow speeds is recommended. In particular, if there is any sign of stormy weather, the area should always be avoided.

2.3.2. Navigation and weather conditions in ice-carrying waters

When navigating in waters where ice is encountered, study the properties of the ice such as its extent, thickness and hardness; keep a sharp lookout, and run slowly so as to be able to detect the open water and places of thin ice. In particular, special caution should be exercised with regard to icebergs. When heaving to in stormy weather near icebergs, every precaution should be taken not to be surrounded by them. Since harbours towards which icebergs are drifting are dangerous, ships should not remain there.

2.3.3. Navigation and weather conditions in waters with a strong current

When passing through a narrow channel with a strong current, attempt to pass at a time of slack water. Careful lookout is necessary when passing through a channel in dense fog or a channel with sunken rocks. It is recommended to take other courses, if possible. When a storm is encountered in waters with a strong current, and, in particular, when the wind blows against the current, the waves become violent. Shipwrecks may occur, because eddy currents make it impossible to steer the ship properly.