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P&I Loss Prevention Bulletin

The Japan Ship Owners'Mutual Protection & Indemnity Association Loss Prevention and Ship Inspection Department

Marine Weather

Ship Handling in Rough Sea

Head and countering / Following Seas

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§ 1 Introduction

Although accidents due to dragging anchor occur during gales, in particular, most of them are caused by typhoons. To give an example, a coastal tanker(after discharging jet fuel) collided with and seriously damaged a connecting bridge at Kansai Airport, in September 2018, as a result of dragging anchor caused by Typhoon No. 21 that had landed in the Kansai region. A few months prior to this accident, we held a Loss Prevention seminar in Japan titled "Dragging Anchor - Case Studies and Preventive Measures -" (April through June 2018). We issued our "Dragging Anchor - Case Studies and Preventive Measures - (Loss Prevention Bulletin Vol.43)" in July, 2018, compiled from the contents of the seminar of which a large number of members thankfully participated. In this bulletin, we discussed typhoons.

This time, we are going to introduce "Ship Handling in Head and Countering Seas". This is something that deserves extra attention from ship operators when navigating in rough seas. We will focus on the generation mechanisms behind rough weather and sea conditions. When reading this guide, please refer to the above-mentioned bulletin No.43.

§ 2 Global Circulation of the Atmosphere

Although the motion (circulation) of the atmosphere is extremely complicated, a characteristically large and constant motion (circulation) can be observed from outer space. This is known as the global circulation of the atmosphere.

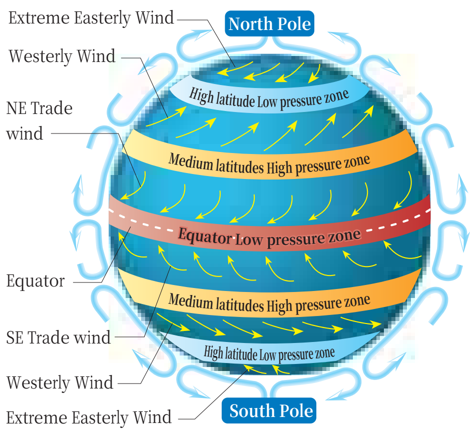


Fig. 1

Figure 1 is a schematic view of the wind patterns close to the ground (annual average) circulating in the atmosphere. The solar energy reaching the earth consists of a visible ray (approximately half), with the remainder consisting mostly of infra-red rays. The earth radiates the received solar energy as infra-red rays back into space. However, the actual radiant energy remaining in the atmosphere is positive at low latitudes and negative at high latitudes. Therefore, there will be a huge temperature difference between both latitudes as a result of this radiation.

If the heat were not carried from the equator to either of the poles, the equator zone would become too hot for any creature to live. On the contrary, if there were a large amount of snow near both poles, they would end up being glaciers that never melt. However, in reality heat in the vicinity of the equator is carried to each pole direction and the earth temperature is comfortably adjusted for animals and plants to survive.

It is the wind that moderately adjusts the temperature differences between the northern and southern regions of the globe. Winds are generated due to the temperature differences in the atmosphere and play a role in reducing the temperature differences. In addition to regulating global temperatures, the atmosphere serves the following three roles:

- To supply oxygen necessary for living creatures and carbon dioxide necessary for photosynthesis of plants.
- The ozone layer absorbs ultraviolet rays which are harmful to living creatures.
- To prevent meteorites reaching the surface of the earth. Meteorites disintegrate once having entered the atmosphere.

Figure 2 illustrates the sizes of the sun and earth and their relative positions. While the earth has a radius of 6,369 km, the sun has a radius of 695,508 km which is 109 times that of the earth. And, the distance from the earth is 149 million kms, which is equivalent to 23,395

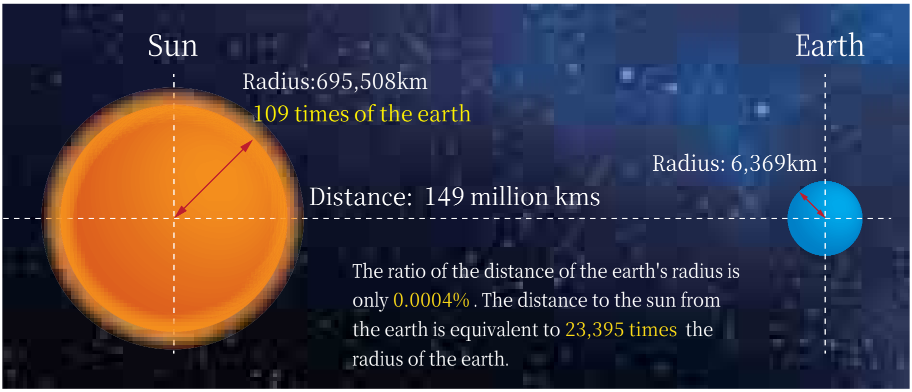


Fig. 2

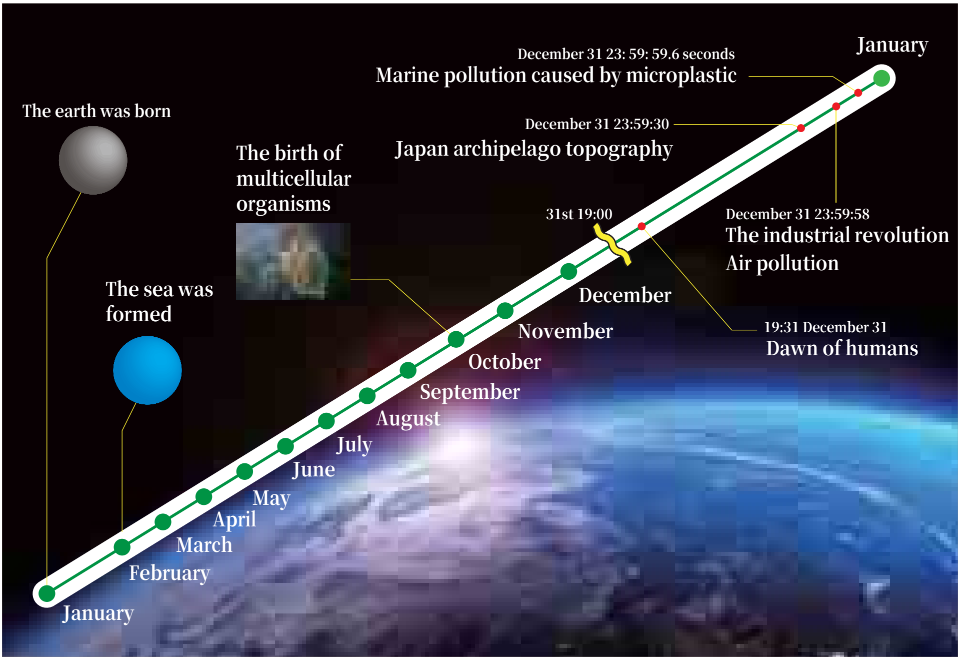


Fig. 3

times the radius of the earth, and the ratio of the distance of the earth's radius by comparison is only 0.0004%. Yet, the temperature difference between the equator and poles is more than 60 degrees centigrade.

Over the recent years, issues such as global warming and environmental pollution are becoming more serious. It is said that the earth was born approximately 4.6 billion years ago. Let us assume that this 4.6 billion years was compressed into 1 year and that the birth of the earth was set to 00:00 on January 1. The progressive emission of carbon dioxide began during the industrial revolution during the middle of the 18th century. Applying the compressed time frame, human beings started air pollution around “December 31 at 23:59:58”, which can be said to mean that a large amount of fossil fuel was consumed in only 2 seconds, which has led to the expansion of global environmental problems giving us global warming.

Marine pollution caused by microplastic started in the 1980s; if the one-year time frame was applied, it would have begun on December 31 at 23:59:59.6 seconds - which is only 0.4 seconds before the end of the year.

Comparing the diameter of the Earth (12,739 km) with the Kármán line (100 km), as can be seen in Fig.4, it is understood that the atmosphere occupies a thin range (only 0.8% of the diameter of the Earth).

Thus, it is easy to imagine how we, humankind, have dramatically changed the global environment, in a very short time, and within an extremely thin range of atmosphere that was created more than 4.6 billion years ago. Still, it is important that we understand the significant role of the atmosphere and continue to tackle the impending environmental issues.

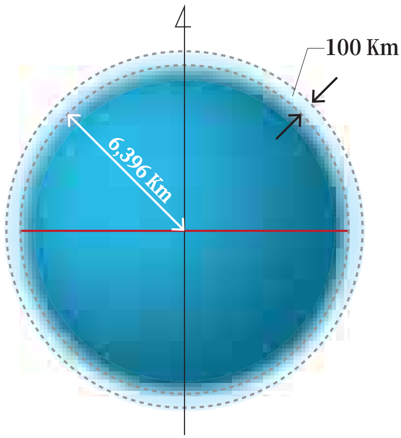


Fig. 4

§ 3 Air Mass

Viewing the earth from outer space, there are flat areas of land and sea that stretch out more than 1,000 kms around the earth. In addition, these areas almost all look homogeneous. While the air remains over these continents and oceans for extended periods of time (for instance, over a week), it will gradually assume particular characteristics associated with each region. This large mass of air is referred to as Air Mass, and the area where the air mass generates is called the point/place of origin.

Air masses change seasonally and influence the climatic changes in the regions covered. Figure 5 illustrates air mass by classification.

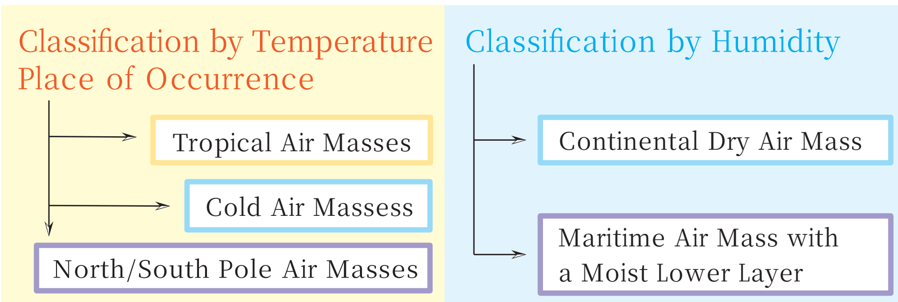


Fig. 5

Air masses do not originate in the vicinity of Japan. However, Japan is located in the mid-latitude where the vast Eurasian Continent meets the Pacific Ocean, thus its climate is strongly influenced by several air masses that change seasonally.

Figure 6 illustrates air masses that very much influence the climates of Japan.

Fig. 6 Created and modified based on the website of the Geographical Information Authority of Japan

§ 4 Low Pressure System

It is a low pressure system when the air pressure in the middle is lower than that of the surrounding air pressure. When the shapes of the isobars are vague and lack coherence, they are simply referred to as an air pressure depression. In the northern hemisphere, winds within low pressures blow counter clockwise into its centre, due to the rotation of the earth. This blown wind converges to become an updraft. Because adiabatic cooling [Note 1] is caused by an ascending air current which produces clouds and consequently rain, in general the weather is bad inside tropical cyclones.

Low pressure system is defined as follows according to the location and cause of generation. Extra-tropical cyclones are most frequently generated, and when referred to as low pressure system, an extra-tropical cyclone is usually what is being referred to.

An Extra-tropical Cyclone	It is generated in middle and high latitudes and has fronts.
A Cold-core Cyclone/ Orographic Cyclone/ Thermal low	It is generated in middle and high latitudes and has no fronts.
Tropical Cyclones	Tropical cyclones generated in tropical waters at low latitudes. Because these completely differ from extra-tropical cyclones in that their generation and structures are different, these will be covered in 4-2.

Note 1: Adiabatic cooling

“ Adiabatic change ”refers to a change in air state whereby no heat is exchanged with the surrounding air. When gas adiabatically expands, the temperature naturally decreases without cooling down (adiabatic cooling). On the contrary, when gas is adiabatically compressed, the temperature increases naturally (rise in adiabatic temperature).

The fact that gas adiabatically expands, under the condition that energy (heat) is not transferred, and because volume increases against the external pressure, this means that it is working against the external pressure. In other words, it uses its own (thermal) energy which means that the temperature decreases. Adiabatic compression is the opposite of this.

With the updraft of air mass, it will expand naturally because the nearby pressure decreases. At this moment when it expands, there is almost no transfer of heat between the external and internal pressure. However, because the adiabatic expansion releases energy, the temperature drops. The proportion is 1.0 °centigrade for every 100 meters of updraft. However, the condition at this time assumes that the water vapour is still unsaturated (the temperature has not dropped to dew-point), even if the temperature of the air mass has decreased. The way this water vapor descends, due to the high temperature as the air mass rises, along with water vapor that has not yet reached saturation, is referred to as dry adiabatic lapse rate. When the air mass drops, the temperature rises in proportion to the dry adiabatic lapse rate because of the adiabatic compression.

Dry adiabatic lapse rate = 1.0℃ /100m

However, general air mass contains water vapour. This is when it reaches dew-point, because the water vapour changes into water while the temperature of the updrafting air mass has been dropping. As the water vapour contained in the air mass condenses, fine moisture is generated and clouds are then formed. It is necessary to understand that latent heat will be released as the water vapour condenses, when the air mass rises while clouds are being generated (air mass in which water vapour has become saturated). Because the latent heat warms the air mass, the extent to which the air mass temperature decreases while clouds are forming is smaller than the proportion of dry adiabatic lapse.
The moisted adiabatic lapse rate can be defined as: the temperature that has dropped due to altitude, when the air mass rises while clouds are being generated (air mass in which water vapour has become saturated). This proportion can differ depending on the conditions, but on average it is approximately 0.5 ℃ per 100 meters of altitude. On the contrary, when air mass containing clouds descends, it absorbs (vaporization) heat when the moisture evaporates. As the temperature does not increase in proportion with the dry adiabatic lapse rate, it increases in proportion with moisted adiabatic lapse rate. It is for this reason that a can of compressed gas is cold.

Moisted adiabatic lapse rate = 0.5℃ /100m

Let's take a closer look at the circulation of the atmosphere. For instance, in the event that the temperature drops at the moisted adiabatic lapse rate, while moist southeast wind blows into the Japanese islands in the summer and even if it is raining at an updraft of 2,000 meters along the mountain range, the temperature of the top of the mountain will be 20℃ , which is 10℃ lower, when the temperature near the sea surface is 30℃ (moisted adiabatic lapse rate: 0.5℃ /100m x 2,000 meters).
When this atmosphere descends down the slope of the mountain, the temperature will reach 40 ℃ (2,000 meters x 1℃ /100m) at the sea surface. Because the temperature increases at the dry adiabatic lapse rate if there is no vapour present. Foehn phenomenon on the Japan Sea side is generated by this mechanism.

4－1　Extra-tropical Cyclones

4−1−1　The Generation Stage

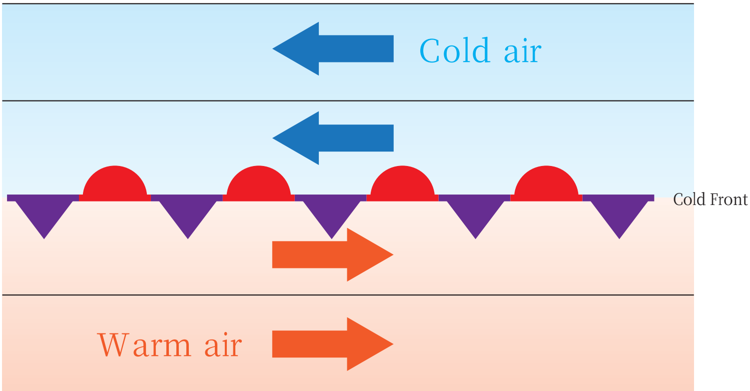


Fig. 7 Masanori Shiraki, 2007, Shin Hyakuman-nin no Tenki Kyōshitsu: Seizando

Fig. 8 Japan Captains' Association, DVD

Regarding extra-tropical cyclones with fronts, firstly, a stationary cold front (See Fig. 7) is generated where the cold air mass and open subtropical air mass converge at almost the same force. The energy needed to generate and develop an extra-tropical cyclone is the potential energy difference between the temperatures of those air masses.

Before long, when the difference between the wind speed of the cold and warm air exceeds a certain degree around this cold front, the wave of the front (air swell) starts to form. The same principle is true for waves that are formed by wind blowing across the sea. In other words, waves are generated on the boundary surface between two fluids that have different characteristics. Although sea waves go up and down, the wave of a front moves up and down from south to north. Figure 8 illustrates this.

At the point where the front swells and the warm air convects into the cold air, a depression of pressure is generated due to a pressure drop in the surrounding air pressure. In the northern hemisphere, on the eastern side of the front's bulge, because wind tends to blow in a northerly direction and the warm air rises up, seemingly creeping, over the cold air, it will become a warm front.

On the other hand, on the western side of the front's bulge, because wind tends to blow in a southerly direction and the cold air rises up, seemingly creeping, over the warm air, it will become a cold front. Other air pressure depressions other than these form at the junction of two fronts. In addition, the axis which connects the center of the surface air pressure depression with that of the upper-air pressure depression is referred to as the "axis of pressure". This axis inclines to the west.

4—1—2 The Structure and Development of Extra-tropical Cyclones

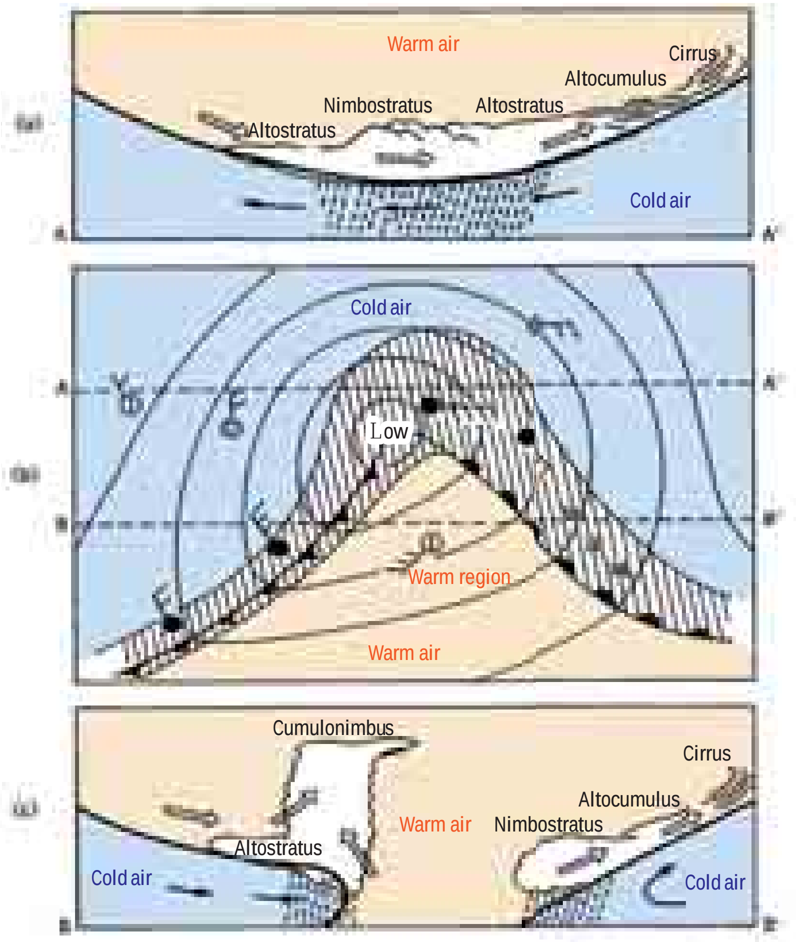


Fig. 9 The structure of Extra-tropical Cyclones
Masanori Shiraki, 2007, Shin Hyakuman-nin no Tenki Kyōshitsu: Seizando

Figure 9 illustrates the structure of extra-tropical cyclones when developing. Figure (b) is a bird's-eye view of a schematic weather chart; the cloud and rain areas etc. are shaded in. From the cyclonic central position, the warm front stretches out to the southeast and the cold

front extends out to the eastwest. Dense isobars generate an air circulation which constitutes even stronger low-pressure air, and the winds blow counterclockwise into the centre of the cyclone. Figure (a) is a cross-sectional diagram taken from figure (b) where A-A’ is in the direction of east-west and to the north from the centre of the Tropical Cyclone.
Figure (c) is also a cross-sectional diagram taken from (b) where B - B ‘ is in the direction of east-west to the south from the centre of the Tropical Cyclone.

Westerlies and the jet stream’s core are located on the upper layer of a developing extra-tropical cyclone (see Fig.8), where the lowest centre of the pressure is on the west side of the surface cyclone and where wave amplitude (degree of meandering) remains large. This structure is a common characteristic of developing extra-tropical cyclones. Another feature is that there is upward motion on the east side of the upper-level pressure and a downward flow on the west side.

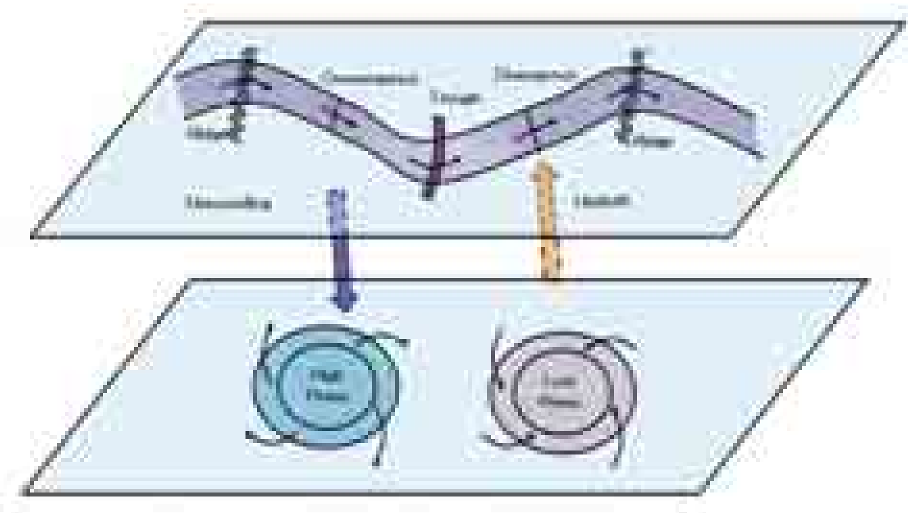


Fig. 10 The structure of Extra-tropical Cyclones
Masanori Shiraki, 2007, Shin Hyakuman-nin no Tenki Kyōshitsu: Seizando

Due to the upper-level pressure trough that moves eastward, the front undulates dramatically and unstably. The extra-tropical cyclone passes in the vicinity of Japan as it continues to develop (Fig.11).

Fig. 11 Japan Captains' Association, DVD

4−1−3 The Mature Stage of Extra-tropical Cyclones

The central air pressure of the extra-tropical cyclone reaches its lowest in the sea east of Japan. At this stage, the front begins to be occluded and forms the occluded front. This is when the force of the extra-tropical cyclone reaches its peak (Fig. 12).

Fig. 12 Japan Captains' Association, DVD

The Rapid Development of Extra-tropical Cyclones at the Nojimazaki Point (on the southern tip [at the southern extremity] of the Boso Peninsula in Chiba prefecture) in Winter

In winter, it should be noted that extra-tropical cyclones may rapidly develop in the region between east of the Nojimazaki Point and the western North Pacific Ocean. In this sea area, the Kuroshio Current raises the seawater temperature. Isotherm lines extend from west to east and the seawater temperature is higher in the southern area, more so than in the northern area where it gets colder (Fig.13).

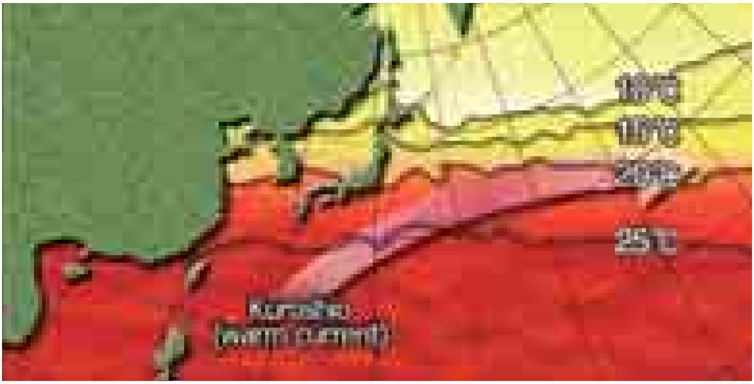


Fig. 13　Japan Captains' Association, DVD

The upper-level cold air protrudes southward like a "wedge" or "tongue" toward the cold front of the surface low and travels from west to east along with the easterly migration of the cyclone (Fig. 14).

Fig. 14　Japan Captains' Association, DVD

When upper cold air flows southward like a wedge over the waters off Nojimazaki Point, where water temperatures are high and the temperature difference between the cold air and warm seawater becomes greater as the cold air moves southward, ocean waves tend to increase in height. Because of the significant temperature difference between seawater and the cold air in the area behind the cold front and presence of additional water vapour, the sea waves off Nojimazaki Point are prone to be larger than usual.

In the event that a swell from a different direction collides with the low pressure passing before it, irregular waves such as pyramidal waves may be formed, and this may cause extremely dangerous waves for vessels. Please pay extra attention to high-wave sea areas (Fig. 15).

Fig. 15　Japan Captains' Association, DVD

On 5 January, 1969, bulk carrier "Boriba Maru" (33,814GT, Loa: 223m) sank, then on 9 February, 1970, another bulk carrier "Califorunia Maru" (34,002GT, Loa: 218m) sank. Two other vessels in the same area and at around the same time became distressed and sank: tanker "Sophia P." (details unknown) on January 5, 1970, and a cargo ship "Antonio Demades" (details unknown) on February 7 in the same year.

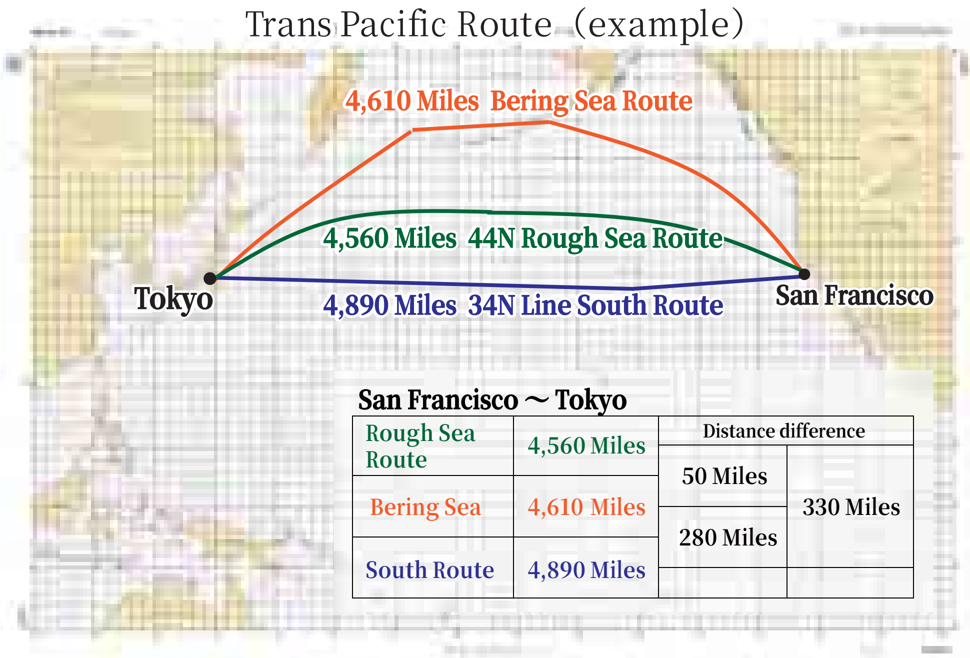
4−1−4 The Attenuation Stage of Extra-tropical Cyclones

On approaching or almost reaching the waters around the Aleutian Islands, and the front of the cyclone has completely occluded, at this point, the lowest centre of the upper-level pressure is almost above the centre of the surface cyclone causing the axis of pressure (See Fig. 8) to become vertical, and the cyclone becomes an isolated air-eddy without fronts and is completely merged with a cold air mass. The extra-tropical cyclone begins to attenuate and finally decays (Fig. 16).

Fig. 16 Japan Captains' Association, DVD

However, in more recent years, during the winter season in the North Pacific Ocean, cyclones have been crossing east to south of the Aleutian Archipelago while maintaining full force to frequently land in North America where they dissipate, after having peaked in force in the vicinity of Alaska bay. Therefore, in the winter season of the North Pacific Ocean, especially when navigating en route North America to Japan, it is always difficult to choose from the following routes: 1) through the rough sea area: North America ⇒ Umnak Strait ⇒ Bering Sea ⇒ Ats Island ⇒ Kinkasan (or Inubozaki) ⇒ Tokyo (total distance is 4,610 nautical miles) or 2) via a longer southernbound route (total distance is 4,890 miles) which avoids the rough sea area, that will add an extra 280 nautical miles to the distance.

When operating a container ship between San Francisco and Tokyo, if one is to choose the southernbound route, it means that the total distance will be longer than that of the northern-bound route via the Bering Sea by 280 nautical miles. In addition, it would take an extra 14 hours when navigating at 20 kts, meaning that one would be behind on schedule because of the incurred extra distance, compared with taking the northbound route to avoid rough seas. One is left with no choice but to increase speed in order to make up for the delay. This in turn results in a large amount of fuel being consumed, which makes it a truly painful decision for the Master to select the southernbound route (Fig. 17).



		Distance difference	
Rough Sea Route	4,560 Miles	50 Miles	330 Miles
Bering Sea	4,610 Miles	280 Miles	
South Route	4,890 Miles		

Fig. 17

When navigating the North Pacific Ocean en route North America to Japan during the winter season, it is important that the safest and most suitable route be selected. A mutual agreement between related parties is highly important: consideration of the Master's judgement and in-depth pre-meetings with the ship management company and charterer are paramount.

4－1－5 Blocking Anticyclones or “Cut-off High”

The “blocking phenomenon” is observed often in the Aleutian Sea area in winter. It is a phenomenon by which a “cut-off high” [Note No.2] produced in the upper air is located at the front of the extra-tropical cyclone and blocks the eastward migration of the cyclone. If its migration is blocked, the cyclone may, however, maintain its intensity. This results in rough seas for a prolonged period. Therefore, one should pay attention to the “blocking phenomenon” when drawing up a navigation plan to such areas (Fig. 18).

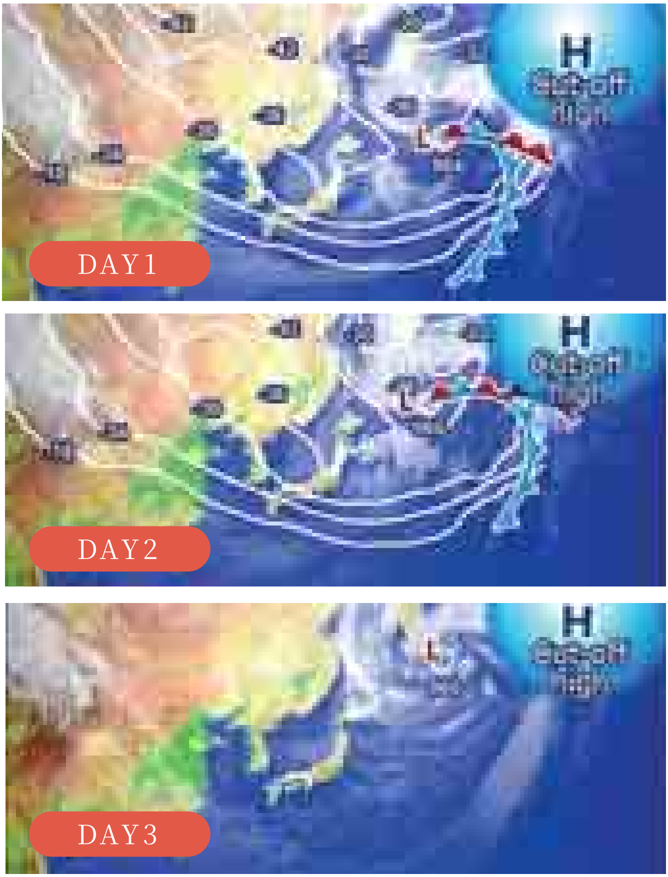


Fig. 18　Stationary low pressure, Japan Captains’ Association, DVD

[Note No.2]

This is also referred to as " cut-off high ". A warm anticyclone in the upper air which is generated by the separation of the warm air at low latitudes and the high latitudes to the north, when the core located in the westerly belt of the upper air significantly moves south-northward. Normally, the blocking phenomenon occurs after a large stationary low pressure which seems to react with the ground, appears. The migration of the high or low pressure (as can be seen on a surface weather chart) normally moves to the east, carried by the westerlies. However, this phenomenon tends to detour south-north, accompanied by a back flow and so on, because the air is blocked at the west of the blocking anticyclone, and ascendant high pressure which penetrates the troposphere in the middle latitude stays in the area for a prolonged period. This is when cut-off high pressure most notably manifests in the upper-air (Fig. 19).

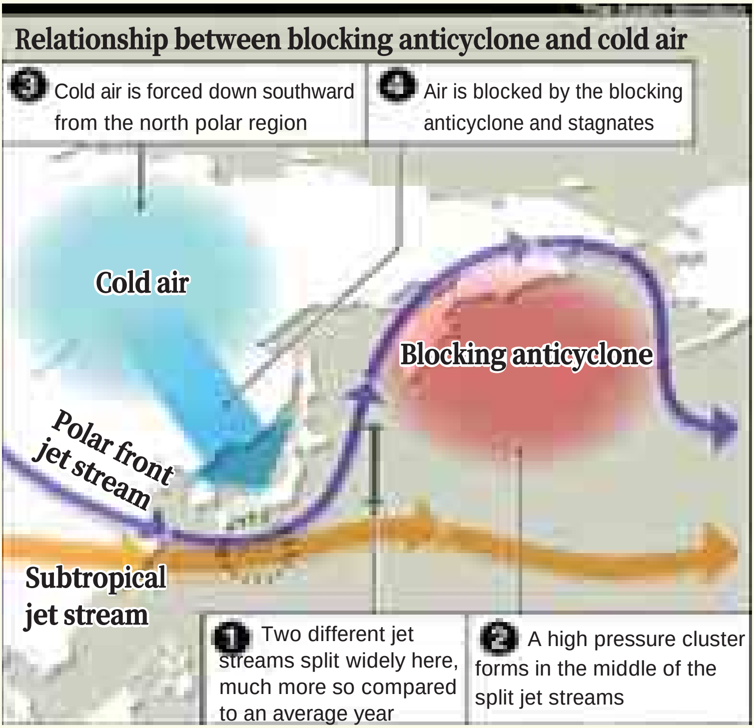


Fig. 19 Blocking Anticyclone
From the Japan Meteorological Agency website

4—1—6 Low Pressure Rapidly Develops (Bomb Cyclone) (Figs. 20 and 21)

An extra-tropical cyclone which develops rapidly is referred to as a “bomb cyclone” in Japan. According to an encyclopaedia of meteorological science, the bomb cyclone is defined as “an extra-tropical cyclone that decreases its central pressure at more than 24hPa ×sin (φ) within 24 hours (Note: φ refers to latitudes)”. For instance, if the position is latitude 40° North, the air pressure will decrease more than 17.8hPa/24h per day.

Cyclones on the Japan Sea which have strong winds covering a wide area in early spring, have low pressures which rapidly develop close to Northern Japan along with other low pressures that rapidly develop in the east of Japan or off the coast near Chishima in winter, are known as bomb cyclones. Today, however, the Japan Meteorological Agency does not use the term, because the word “bomb” is not appropriate, thus it is replaced by “rapidly developing low pressure” instead (Fig. 20 and 21).

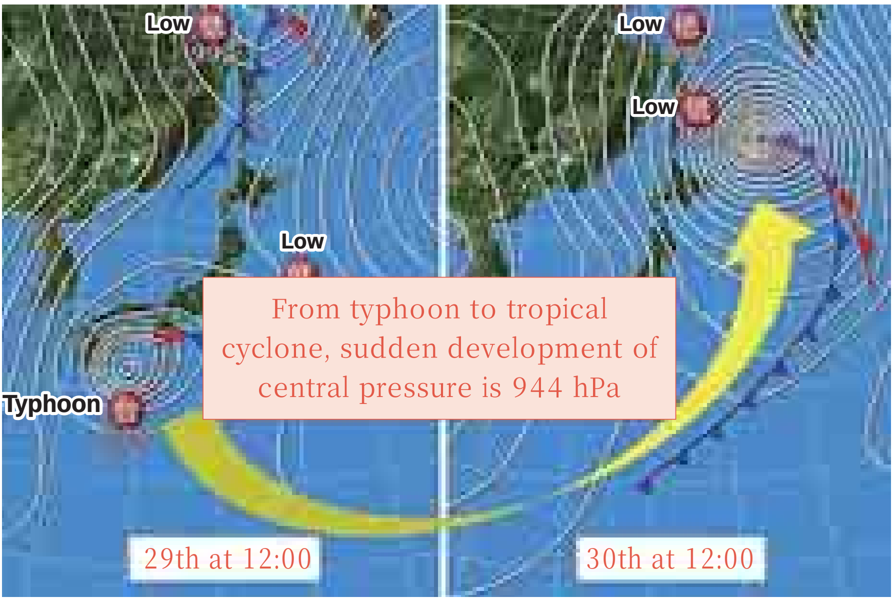


Fig. 20 From the Japan Weather Association

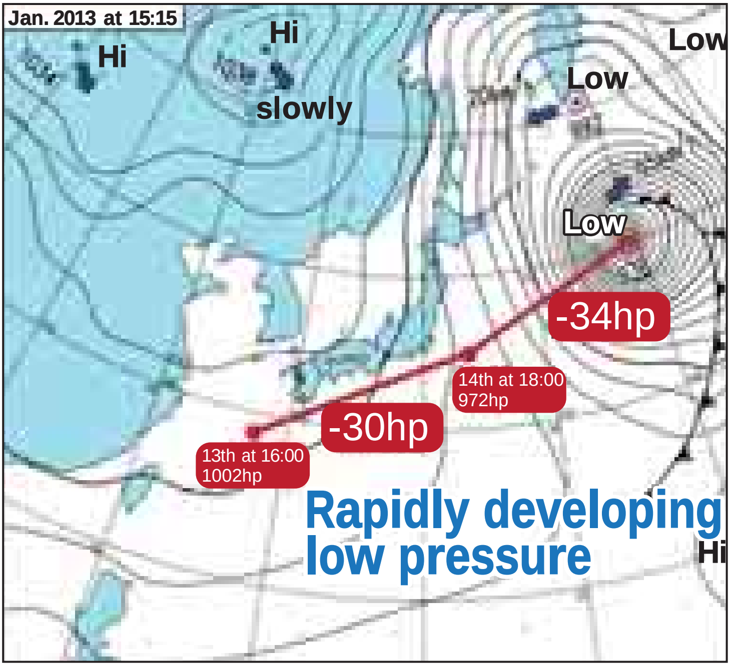


Fig. 21 From the Japan Meteorological Agency website

Regarding these types of cyclones, since they can cause rough weather and sea conditions to be worse than expected, in order to safeguard one's ship, close attention must be paid to them.

4－2　Tropical Cyclones and Typhoons

4－2－1　Classification and Naming of Tropical Cyclones

Tropical cyclones refer to cyclones generated in tropical or subtropical waters, and the generation of which requires a continuous supply of water vapour energy. Therefore, tropical cyclones are formed in sea areas where sea surface temperatures exceed 26 degrees Celsius. Generally, this means tropical cyclones are formed in sea areas between 5 and 20 degrees latitude, excluding equatorial waters (Figs. 22 and 23).

Fig. 22 From the Japan Weather Association

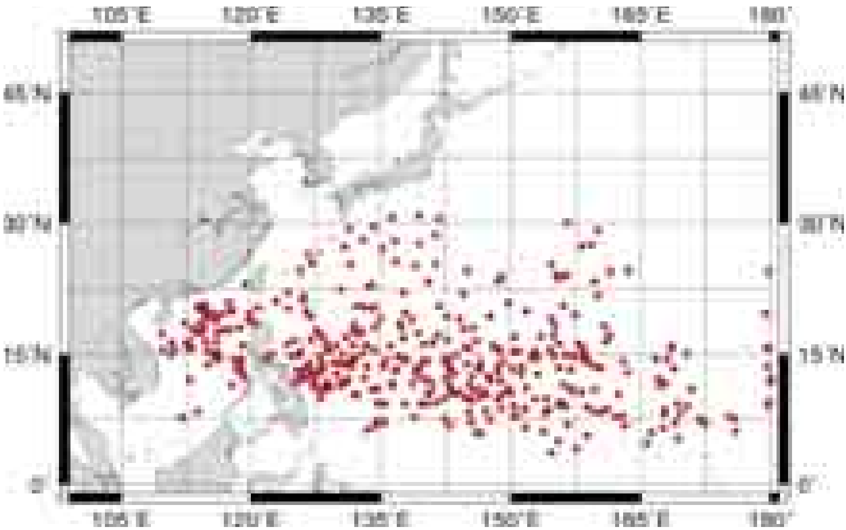


Fig. 23 From the Japan Meteorological Agency website

Tropical cyclones are internationally classified into four categories according to the maximum wind speed as shown in Fig. 24.

International Tropical Storm Classification

Symbol		TD	TS	STS	T
Classification		Tropical Depression	Tropicl Storm	Severe Tropical Storm	Typhoon
Max Wind (m/sec)	(m/sec)	～17.1	17.2～24.4	24.5～32.8	32.7～
	Knots	～33	34～47	48～63	64～
Beaufort Scale (Wind Speed)		～7	8～9	10～11	12～
East Pacific Ocean and Caribbean Sea		Tropical Depression	Tropicl Storm	Severe Tropical Storm	Hurricane
Japan (Japan Meteorological Agency)		Tropical Cyclone	Taifu ＊(Typhoon)		
Indian Ocean and South Pacific Ocean		Tropical Depression	Cyclone		

Fig. 24　Classification of Tropical Cyclones

As can be seen in the chart, those that have the maximum wind speed of more than 64kts (32.7m/sec) and can be found in the western part of the North Pacific Ocean are called Typhoons, while those that exist in the eastern part of the North Pacific Ocean in the vicinity of the Caribbean Sea are referred to as Hurricanes.

*In Japan, those that have a maximum wind speed of more than 34kts (17.2m/sec) are called Taifu (Typhoon). In the Indian Ocean and the western South Pacific, they are referred to as “cyclones”. In general, they are called tropical cyclones (Fig.25).

Fig. 25 The Naming of Extra-tropical Cyclones
Japan Captains' Association, DVD

4–2–2 The Generation Mechanism of Tropical Cyclones

Northeast and southeast trade winds in the northern and southern hemispheres blow into the equatorial area and form a trough (Figs. 26 and 27).

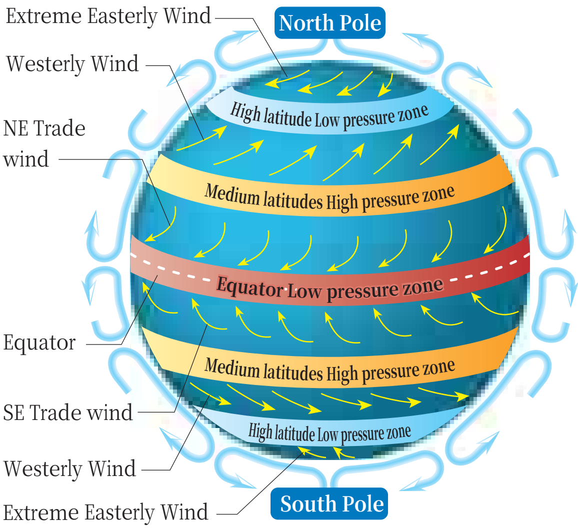


Fig. 26

Fig. 27 Japan Captains' Association, DVD

This trough is known as an "equatorial trough" or "Intertropical Convergence Zone" (ITCZ). This ITCZ usually migrates westward while undulating north to south. When this undulation becomes unstable and increases, it forms an eddy that generates a tropical cyclone (Fig. 28).

Fig. 28 Japan Captains' Association, DVD

The potential energy of extra-tropical cyclones can be generated by the difference between the temperatures of those air masses. This energy source for a tropical cyclone is the latent heat from a continuous supply of water vapour that is discharged when humid air rises, is cooled, and then condensed into droplets. (See Note:1 on P.6)

In other words, when humid air near a sea happens to start rising (Fig. 29), especially because it tends to become an updraft as the cyclone converges in the ITCZ, once the water vapours start condensing, cumulus and cumulonimbus clouds are produced (Fig. 30).

Fig. 29 Japan Captains' Association, DVD

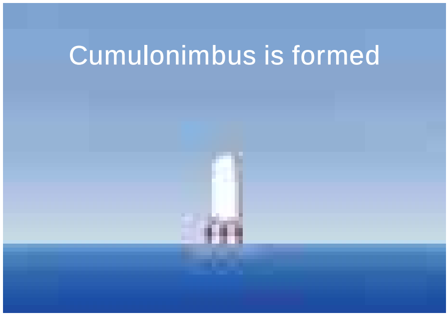


Fig. 30 Japan Captains' Association, DVD

Because of the emission of latent heat, the temperature increases, compared with the region without clouds. Then, the rising warm air becomes less dense than the surrounding atmosphere, as it continues to rise. This lowers the central atmospheric pressure of the tropical cyclone and keeps the cyclone developing. In these unstable atmospheric conditions, several cumulonimbus clouds of approximately 10 km in scale form horizontally (Fig. 31) and these effects produce tropical cyclones exceeding approximately 100 km in scale horizontally (Fig. 32).

Fig. 31 Japan Captains' Association, DVD

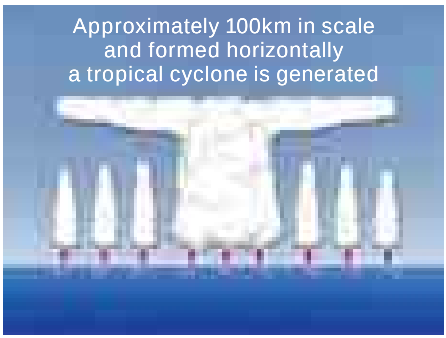


Fig. 32 Japan Captains' Association, DVD

Tropical cyclones produced in tropical waters can develop into typhoons (shown in Table 24), if the maximum wind speed within the area develops to exceed 34 kts (17.2m/sec) under the Japanese classification. As to what kinds of cloud mass can develop into typhoons is still yet to be revealed. However, since it is understood that the energy source of a typhoon comes from sea water surface vapour, it follows that the higher the temperature at an area where the typhoon begins, the stronger the typhoon will be. In addition, for a strong typhoon to develop, it needs to pass an area of sea where the seawater temperature is more than 28 degrees centigrade.

On the contrary, if a typhoon reaches an area of sea that is less than 28°C (or less than 26°C to be exact) or ends up on land, it will start to weaken because of the typhoon's energy excretion. Later, it attenuates and the extra-tropical cyclone finally decays.

Fig. 33 Photograph Image (not Typhoon generated)

4－2－3 Structure of Tropical Cyclones

Typhoons are huge atmospheric eddies with diameters ranging between hundreds to thousands of kilometres. Inside the eddy, strong updrafts form cumulonimbus. The "eye of a typhoon" is formed by a downdraft at the centre of the typhoon, and the heaviest rain and strongest wind occur below the "eye wall." On the other hand, in the vicinity of the tropo-pause above the eye of the typhoon, an eddy of cirrus clouds is formed that flows outward clockwise due to the Coriolis' force which is formed as a result of the earth's rotation (Figs. 34 and 35) .

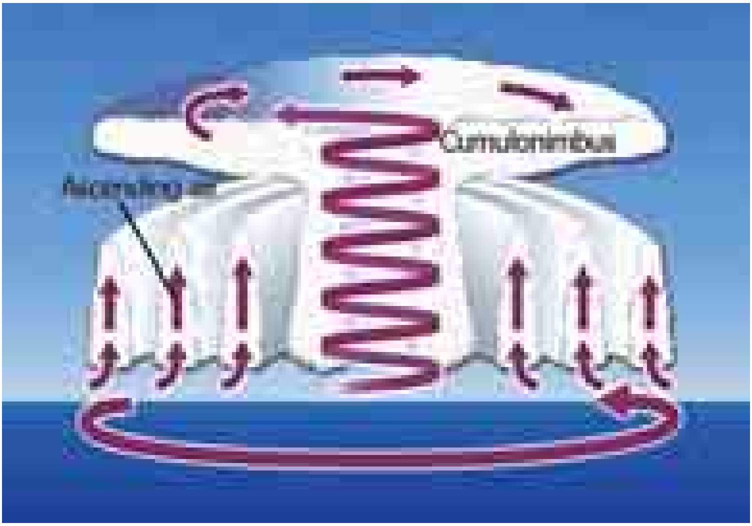


Fig. 34 Japan Captains' Association, DVD

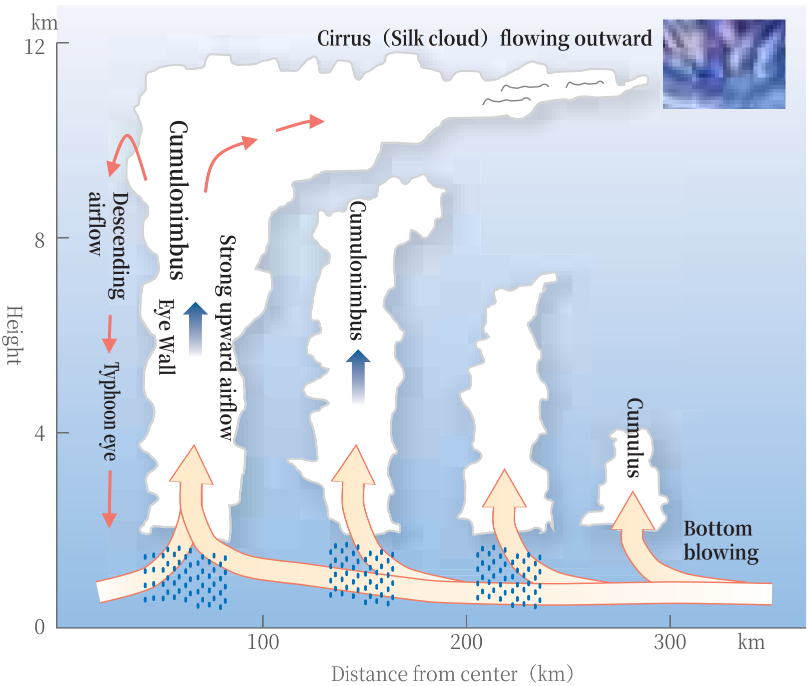


Fig. 35 Cross-sectional diagram of a typhoon

"The spiral cumulonimbus band" extending from the centre of a typhoon is known as the spiral band. Within the spiral band, strong wind and heavy rain are generated by the strong general air flow of the typhoon and strong downdrafts derived from huge cumulonimbus. Attention should be paid to this weather condition and poor visibility (Figs. 36 and 37).

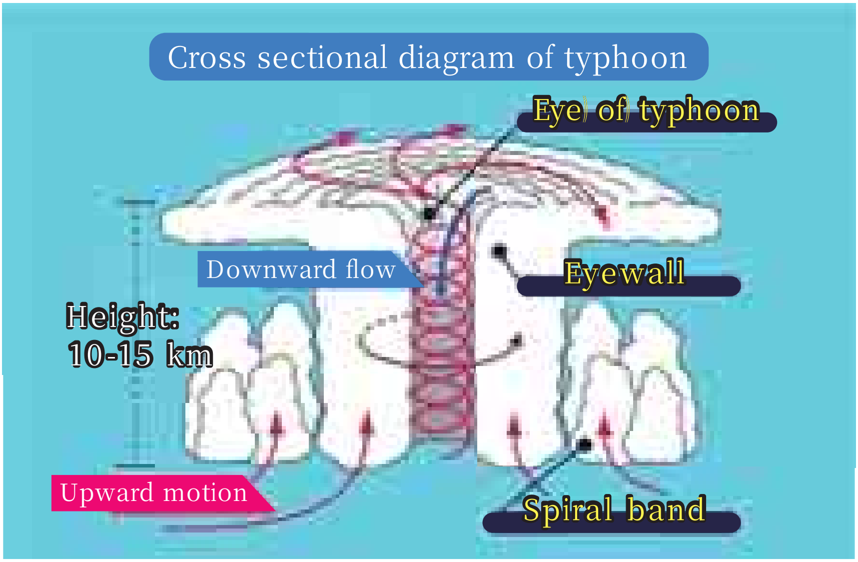
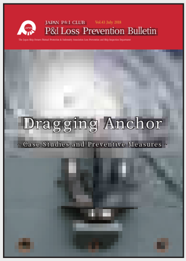


Fig. 36 From the Japan Meteorological Agency website

Fig. 37 Japan Captains' Association, DVD

4−2−4　Courses of Tropical Cyclones

We introduced typhoon courses in sea waters around Japan in our Loss Prevention Bulletin " Dragging Anchor - Case Studies and Preventive Measures - (Vol.43) " issued in July, 2018. Please refer to this for more details.



At its early stage, the typhoon migrates westward slowly at a speed of 10 to 20 kms per hour pushed by the easterly trade wind (Fig. 38).

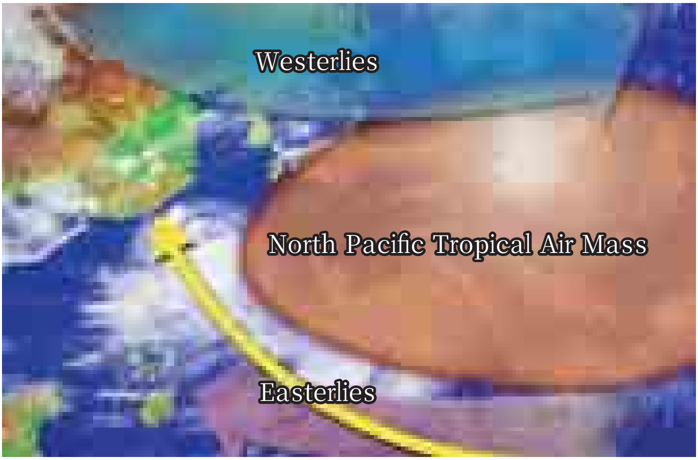


Fig. 38 Japan Captains' Association, DVD

Then, it turns northward under the influence of the general circulation of the North Pacific High. As it migrates northward, the typhoon changes its course eastward, influenced by westerlies in the upper air. This point of course change is known as the "point of recurvature." After changing course to the northeast, the typhoon's speed increases to 30 to 40 kilometres per hour at about 30° north latitude, and to approximately 50 kilometres per hour at about 40° north latitude.

In general, a typhoon's intensity weakens due to the cold waters and low atmospheric temperature as it moves northward. Finally, by the time it reaches the Okhotsk Sea or the North Pacific waters off Hokkaido, it has become an extra-tropical cyclone (Fig. 39).

Fig. 39 Japan Captains' Association, DVD

On a 500 hPa upper-air chart, if the Northern Pacific High expands westward widely to the Chinese Continent, it is unlikely that the typhoon will turn and migrate eastward. On the other hand, as the North Pacific High retreats to the east and the continent becomes a pressure trough, it is highly likely that the typhoon, drifting on a westerly path, will turn eastward at the western edge of the North Pacific High and be steered to the northeast.

That is, on a 500 hPa upper-air chart, the typhoon frequently takes a course around the North Pacific High, with the North Pacific High remaining on its right. This motion is called "steering." Statistically speaking, if a typhoon passes the eastern area of the point at 20° north latitude and 130° east longitude, it will turn eastward and head for the southern coast of Japan. If it passes the western or southern area of that location, we know that it will keep westward and head for Taiwan (Fig. 40) .

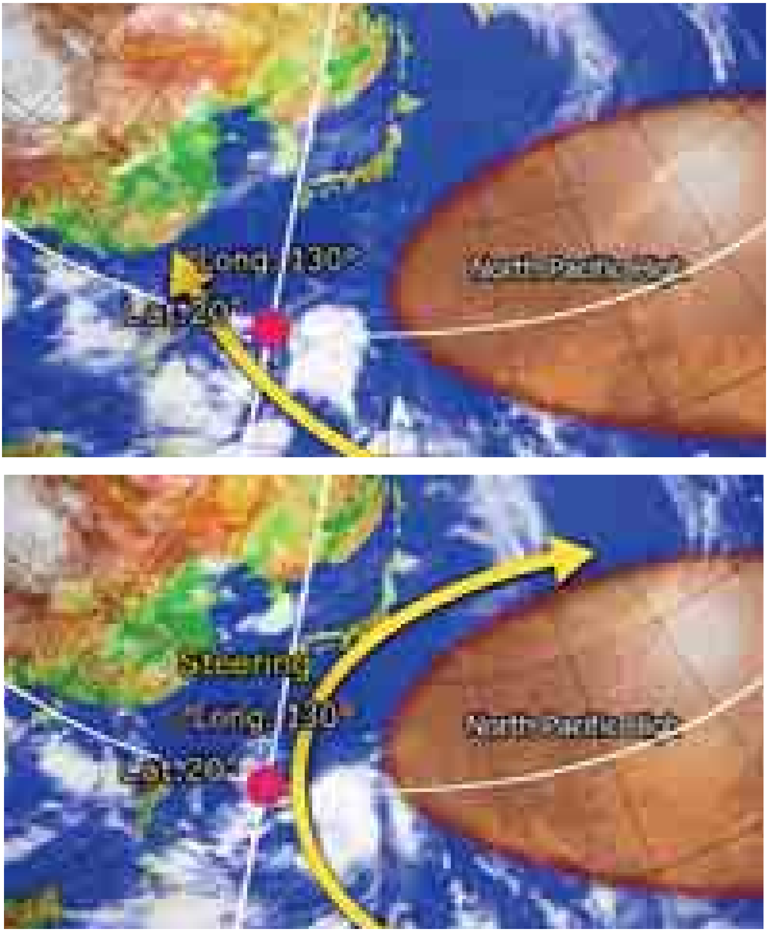


Fig. 40 Japan Captains' Association, DVD

4−2−5 How to read a route map of Tropical Cyclones

We often see nowcasts of typhoon and tropical cyclone tracks in weather forecasts on TV, in newspapers and on the internet (Fig. 41). It is necessary that these nowcasts be properly understood.

Fig. 41 From the Japan Meteorological Agency website

❶ Centre position current typhoon

This shows the typhoon's centre position at the time the forecast was broadcasted.

❷ Storm zone

The red line refers to a range where strong winds of average speed in excess of 25 meters per second are presumed to be blowing. No. 2 is the storm zone of No. 1.

❸ Strong wind area

The yellow line refers to a range where strong winds have an average speed of at least 15 meters per second, at the time the forecast was broadcasted, are presumed to be blowing.

❹ Forecast circle

This indicates a 70% probability that the typhoon ' s centre position at the time of forecast will move into the forecast circle.

❺ Storm alert zone

The red line around the typhoon forecast circle identifies the area that will enter the storm zone if the typhoon's centre advances into the forecast circle.

When working on an evacuation (sheltering) plan, it is necessary to check the estimated positions of each heading the ship will take towards her destination following the originally plotted (charted) course while checking the progress of the typhoon's track at each interval using nowcasts. Also, if the ship enters the storm alert zone, it is a necessary requirement to revise the evacuation plan while checking the weather charts every time there is an announcement - in order to escape.

4−2−6 Dangerous Semicircle and Navigable Semicircle

A typhoon's winds blow counterclockwise into its centre. Wind speed in the right semicircle is strengthened as the typhoon's migration speed increases. Therefore, because wind speed and waves are always higher in the right semicircle than in the left semicircle, the right semicircle of the typhoon is known as the "dangerous semicircle". On the other hand, because a typhoon's wind speed and blowing wind are reversed, wind is always weaker than in the right semicircle. Thus, the left semicircle of the typhoon is known as the "navigable semicircle" (Fig. 42).

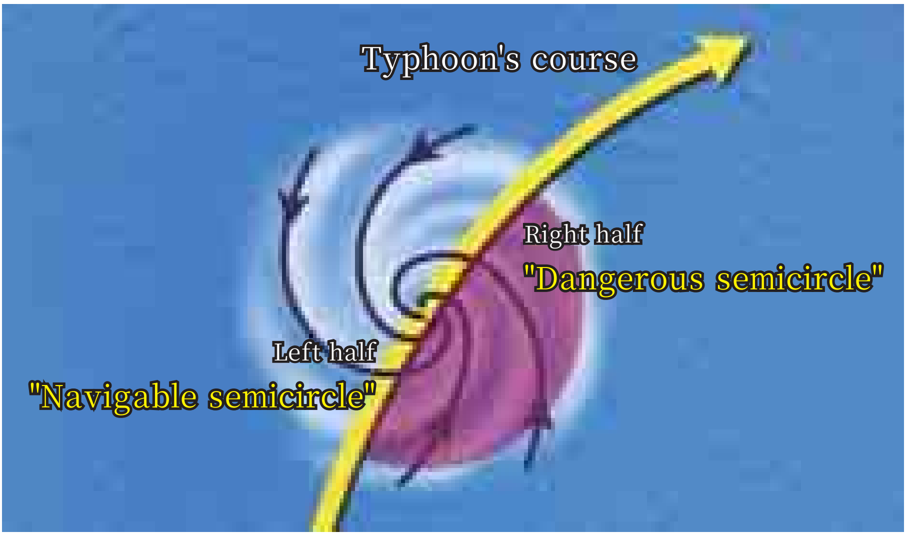


Fig. 42 Japan Captains' Association, DVD

Suppose a typhoon approaches your ship, and your ship enters the "dangerous semicircle" which is the storm zone, navigating along the migrating direction (Fig. 43) of the typhoon. When she navigates having winds and waves from a quarter stern on the starboard side, she cannot escape from the stronger storm zone (Fig. 44).

So, if a ship is about to enter the edge of the typhoon's right-side semicircle, it is a requirement that she avoid the rough sea area and leave it by turning clockwise having winds and waves from a quarter head on the starboard side (Fig. 45).

If a ship enters a storm zone of the left semicircle of the typhoon, she can escape and leave from the storm area by turning her counterclockwise having winds and waves from a quarter stern on the starboard side. She navigates outward of the typhoon and can escape and leave from the storm zone.

Fig. 43 Japan Captains' Association, DVD

Fig. 44 Japan Captains' Association, DVD

Fig. 45 Japan Captains' Association, DVD

Fig. 46 Japan Captains' Association, DVD

Therefore, if a ship is about to enter the left-side semicircle, she can escape and leave the rough sea area by turning counterclockwise with winds and waves from a quarter stern on the starboard side (Fig. 46).

It is important to remember that the semicircle is a rough sea area even if it is the navigable semicircle. So always bear in mind that your vessel should stay away from a typhoon. It is best to think of the navigable semicircle as **"the semicircle where she can escape from rough seas"** rather than the semicircle "where she can navigate safely" .

If your ship is likely to encounter a typhoon during her voyage, do your best to avoid the storm zone taking her course and size into account, as well as her position relative to the typhoon – in other words relative to the "right-side or left-side semicircles" – and the performance capability of your ship.

Also, when the typhoon is likely to approach while anchoring or loading or unloading in port, take every possible evacuation action well in advance by collecting and analysing weather information as well as following the harbour master's instructions.

§ 5 How to Obtain Weather Information

During voyages, obtaining and then analysing the latest information is essential for any ships seeking to avoid rough weather due to typhoons, extra-tropical cyclones which rapidly develop ("bomb cyclone") and so on. The final examination of meteorology at my university was to draw surface weather charts on a blank map while listening to the weather information on the radio. However, these days, meteorological information can be obtained from the following sources: weather charts distributed by the Japan Meteorological Agency; typhoon course forecasts available for free on the Internet; and weather information supplied for a fee by weather information companies. Among them, weather information from the Internet and companies is useful when working an evacuation plan because both provide estimated typhoon courses at least a week in advance. Because of this, it is a must that masters and each navigation officer are able to interpret weather information obtained in this way. As there are many weather reference books available, it is necessary that they be distributed throughout the entire crew and that they be reviewed on a daily basis. Here we will introduce the various weather charts issued by the Japan Meteorological Agency and show you how to use them.

5－1 Surface Weather Charts

Usually, "weather charts" refer to "surface weather charts" that show weather conditions on the Earth's surface. On a surface weather chart, isobars for each 4 hPa are drawn with 1,000 hPa as the standard. The chart is published every six hours. Besides barometric pressure distribution, temperature, wind and weather are also drawn. Weather phenomena such as isobars and fronts are analysed using these charts (Fig. 47).

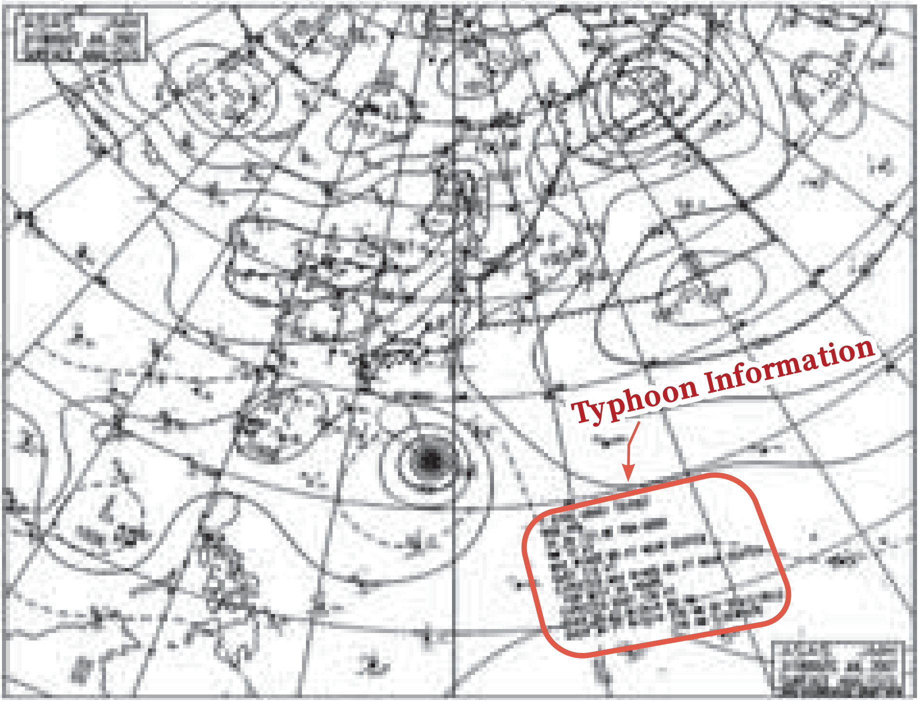


Fig. 47 Surface weather chart
From the Japan Meteorological Agency website

Typhoon information can also be found on the surface weather chart. For instance, information related to the precision of the typhoon's center position are shown as follows. It is also important that this be understood. "Good" means that the margin of error for the position of the typhoon's centre is less than 30 miles. "Poor" means the margin of error is more than 60 miles, and "Fair" means the margin of error is more than 30 miles but less than 60 miles. It is a must that each piece of written information be understood, this includes other information which is not discussed here.

5－2 Wave Charts

Wave charts issued by the Japan Meteorological Agency are as follows:

1	Ocean Wave Analysis Chart
2	Ocean Wave Prognosis Chart (24hour)
3	Coastal Wave Analysis Chart
4	Coastal Wave Prognosis Chart (24hour)

The nowcast and forecast wave charts display "equal wave height lines" composed of meter-by-meter heights of significant waves [Note No.3] and swells, along with "prevailing wave directions," "anticyclonic and cyclonic central positions" and "fronts" (Fig. 48). Just as with surface weather charts and upper-air Weather Charts (upper-air Charts) that will be mentioned below, it is important read the descriptions.

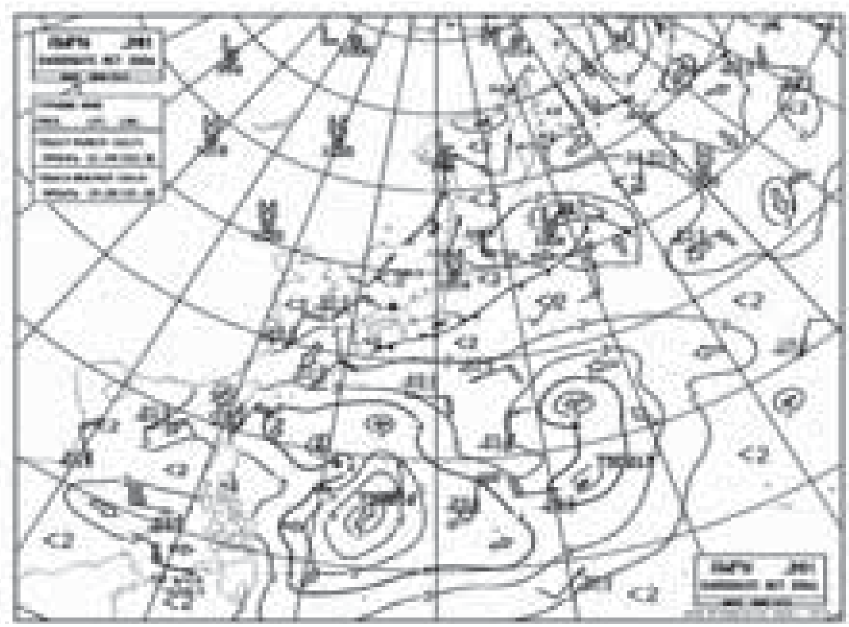


Fig. 48 Ocean wave chart
From the Japan Meteorological Agency website

Especially when operating in rough seas, it is important to understand the actual wave cycles, wave heights, wave lengths and so on. By referring to the wave charts, it is a requirement that actual conditions be compared with those on the wave charts.

For example, the outlined arrow shown in Figure 49 represents the propagation direction of the waves that appear to be most prominent in that area. The outlined arrow on the wave chart indicates the prevailing direction of wave propagation in the sea area concerned. Waves propagate in the direction of the arrow. From this example, you can see that the prevailing waves are propagating from northwest to southeast.

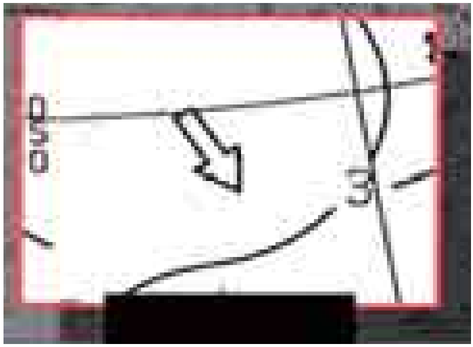


Fig. 49 Japan Captains' Association, DVD

Also, as can be seen in Fig. 50, if an “outlined arrow in a white circle” is indicated on the wave forecast chart, it means anticipated direction of wave propagation. The number assigned to it represents a forecast value for wave cycles in one-second units; the first decimal place represents a forecast value of the significant wave heights (Note 3) in one-meter units. As such, this example forecasts Northerly waves at a cycle of 11 seconds and wave heights of 2.3 meters.

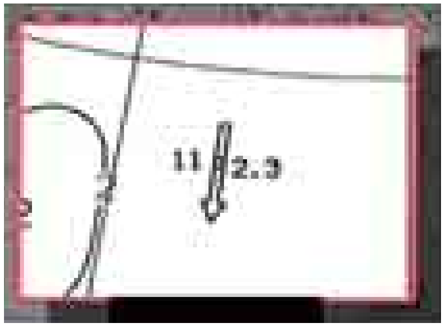


Fig. 50 Japan Captains' Association, DVD

Note 3: Significant wave height

Significant wave can be defined as follows: Choose 1/3 of the wave observations (within a timeframe of 20 mins.) in descending order from the top. Of those, the average wave height and period becomes the significant wave. According to this definition, this is also referred to as the " 1/3 maximum wave ". (From the Japan Meteorological Agency website)

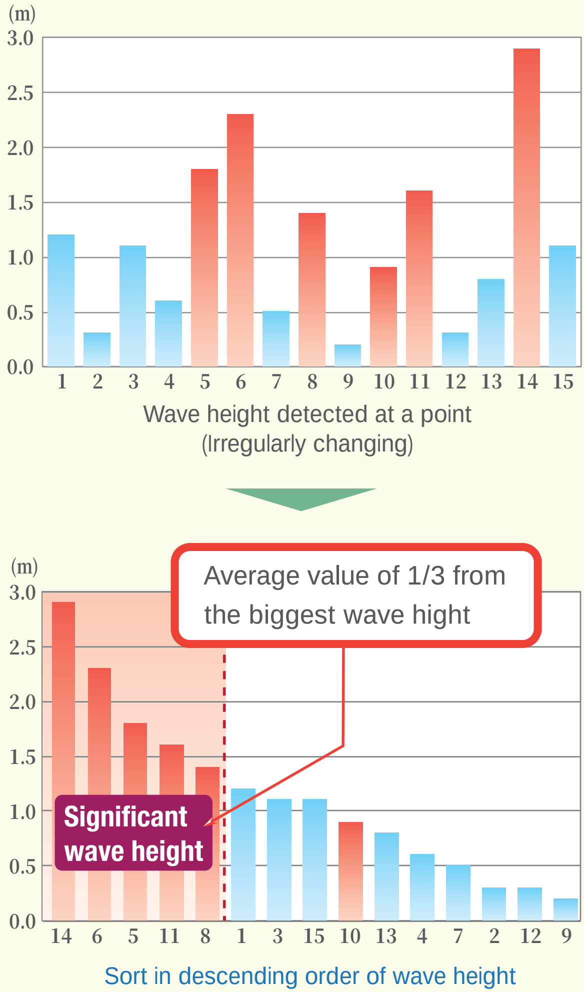


Fig. 51

5－3　Upper-air Weather Charts (Upper-air Charts)

Regarding the upper atmosphere, air pressure, wind, temperature and humidity are commonly observed using a balloon. Upper-air Weather Charts are also known as Upper-air Charts, which show the values of upper meteorological parameters that are measured in each area of the world on the atmospheric pressure surface. The surface where atmospheric pressure is constant is known as constant pressure surface. The curve shown on the upper weather chart is the height of the constant pressure surface, the same that is shown on a terrestrial map. All four different upper weather charts (or upper-air chart)　shown in Table 52 are issued by the Japan Meteorological Agency.

Constant pressure surface（hPa)	850	700	500	300
Altitude（m）	1,500	3,000	5,500	9,500

Fig. 52

Because the meteorological phenomenon is an atmospheric motional phenomenon in the Troposphere from the ground to the Thermopause, it is necessary to observe it three-dimensionally. In this respect, a surface weather chart is insufficient, because it only illustrates the surface weather condition. Therefore, it is only representing one aspect of the weather. On surface weather charts that can be largely influenced by the form of the land, solar insolation and eradiation, both potential temperature analysis (analysis of air mass) and equivalent potential temperature (analysis of the front) cannot be carried out. Therefore, it is difficult to understand and forecast accurately the generation and migration of large-scaled high or low pressure, typhoons and so on. On the other hand, as the upper layer is even without air turbulence, it is possible to trace the atmospheric-pressure migration over a long period of time and forecast it. Further, it is known that there is a close relationship between the upper and lower layers. Therefore, it would be important to analyse the weather using upper-air weather charts also.

Along with surface weather charts, upper-air weather charts, which are often used on ships, are 850 hPa（AUAS85）and 500 hPa (AUAS50) upper weather charts (upper-air weather charts).

5−3−1　500 hPa (AUAS50) Upper-air Weather Chart (Upper-air Chart)

An Example of a 500 hPa upper-air chart (Upper-air Weather Chart) is shown in Figure 53.

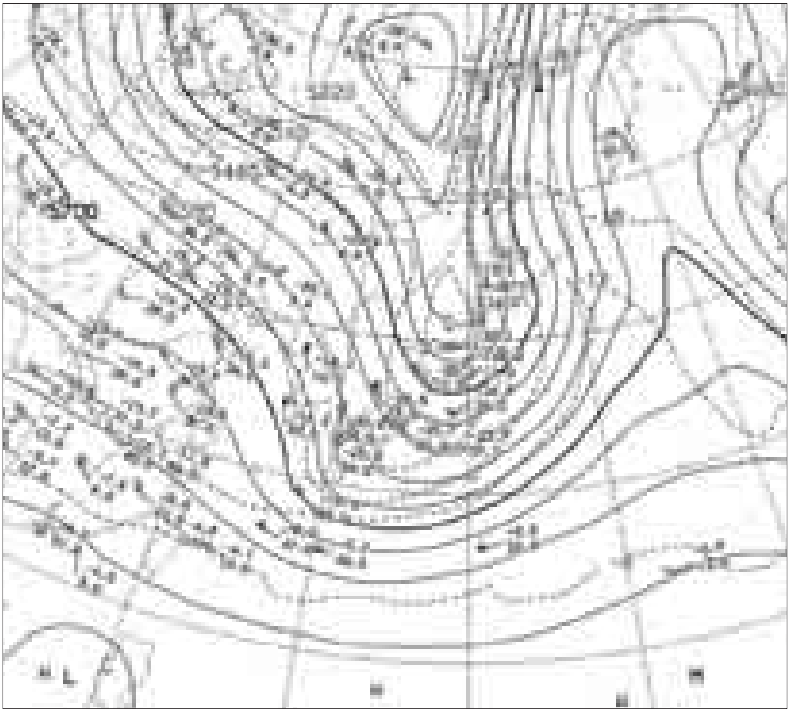


Fig.53　500 hPa Upper-air chart
from the Japan Meteorological Agency website

In this figure, solid lines on a 500 hPa upper-air chart are contour lines, and broken lines are isothermal lines. The contour lines show 60-meter increments and the isothermal lines represent increments of 6 degrees (or 3 degrees, if necessary). W denotes a warm region, and C denotes a cold region. The temperature is shown on the upper left of the “point circle” and the dew-point (spread) is indicated on the lower left of the point circle. Both are indicated at one decimal place. For your reference, regarding the dew-point (spread), the numerical number whose temperature minus dew point temperature is indicated with a unit ℃ applies to temperature. Therefore, when relative humidity is 100%, its dew-point (spread) becomes 0℃.

From the distribution of the contour lines on a 500 hPa upper-air chart, it is possible to estimate the locations and strengths of westerly sea waves and cores of jet streams. In addition, barometric pressure distribution helps us to locate the regions of cold or warm air. Also, depending on the degree of cold air, it is possible to determine the strength of precipitation and discriminate between rain or snow.

If sea waves of westerlies on the upper layer are closely related to the anticyclones and cyclones on the ground, then, according to the contour lines on a 500 hPa upper-air chart, we are able to interpret the fundamental circulation of the atmosphere among various meteorological phenomena shown in the surface barometric pressure distribution. With this, by inserting a pressure trough and the movement of/variation of peaks (and troughs) on a 500 hPa upper-air chart, we are able to make a more accurate forecast of the circulation, more so than inserting movements of the anticyclones and cyclones, using a surface weather chart.

5—3—2 850 hPa (AUAS85) Upper-air Weather Chart (Upper-air Chart) (Fig. 54)

Observed wind direction is not always in accordance with the that of barometric gradients on the surface weather chart, because surface friction is influential. On a 850 hPa upper-air chart, the height is so that there is no influence caused by surface friction. Thus, convergence or divergence of the lower layer can be more frequently seen on this weather chart. In addition, front and air masses can be located easily using temperature distribution information. In other words, the isothermal lines are crowded at the point where 850 hPa and the front intersect. This area shows a significant change of wind direction and wind speed. It is also possible to ascertain temperature advection from temperature distribution and wind patterns. On both of the 850 hPa and 700 hPa weather charts, the regions, where dew-point (spread) is less than 3°C, are shaded. At 850 hPa, this area is almost equal to that of the spread of lower clouds.

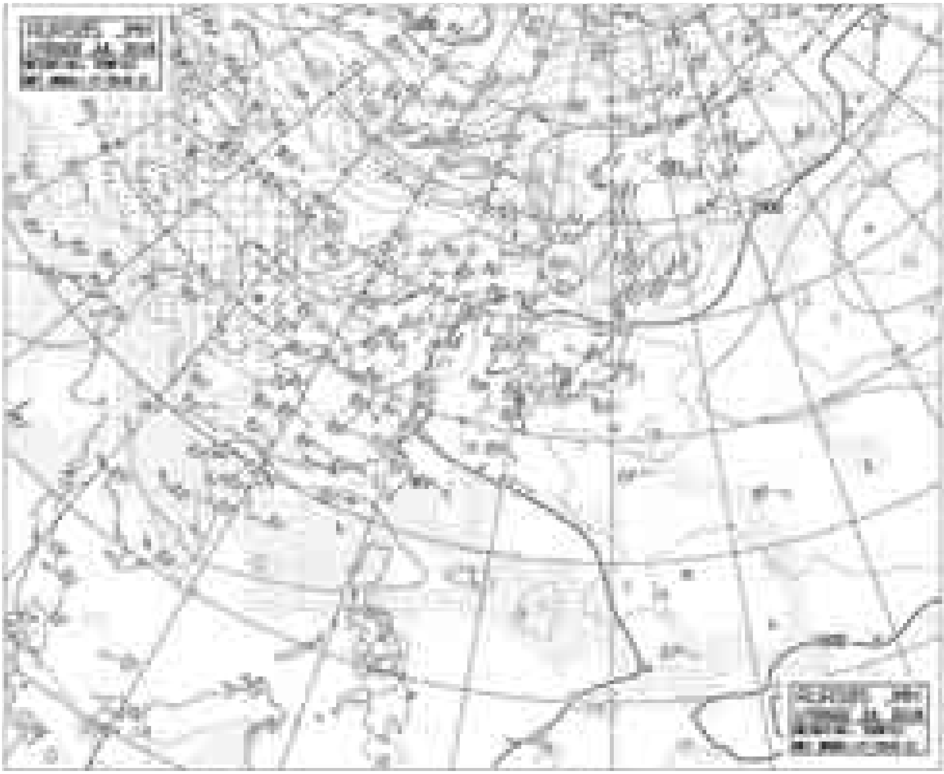


Fig. 54　850 hPa Upper-air Weather Chart
From the Japan Meteorological Agency website