MARINE METEOROLOGY

NUTSHELL SERIES
BOOK 2

BY

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Dedicated to my mother, without whose patient and constant encouragement, this book would not have been possible.

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Bombay, 16th May 1977

FOREWORD

I met Capt. Subramaniam, of the L.B.S. Nautical and Engineering College, in two meetings – one of the Indian Meteorological Society where he presented a paper on "Marine aspects of Meteorology" and the other of the Institution of Marine Technologists and the Company of Master Mariners of India where he presented a paper on "Weather routeing of ships". I found that he had a very lucid style of presentation. I find the same lucidity in his book titled "Marine Meteorology".

The India Meteorological Department was established more than a hundred years ago and one of its main functions, since then, is to serve the mariner. In fact the word "Cyclone", so well known to all and particularly to mariners, was coined in India during the last century. As an officer of the Indian Meteorological Service, therefore, it gave me great pleasure when Capt. Subramaniam requested me to write the foreword to this book.

Meteorology might have been a common subject of joke to laymen, due to their lack of realisation of the complexity of the subject, but mariners have always taken the subject seriously and accepted the predictions, given by meteorologists, with all seriousness. Weather is a question of life and death for them. It is here that the value of this book lies. Mariners have to learn the subject of Meteorology by heart because it is so important for them. This book presents to mariners, in a crisp as well as lucid manner, the necessary knowledge of the subject. With the author's wide experience, at sea and also in teaching merchant navy officers at the L.B.S. Nautical and Engineering College, combined with his personal knowledge of the background of students in India, he has written a good text book suitable for mariners. In fact, the layout of the book is in keeping with the syllabus followed. Yet the book is interesting enough and can be used by mariners at other times also. I am very happy to find that the author has tried to give enough examples from weather events in India and her neighbourhood. This will make the book more interesting to Indian students.

I understand this is the second book for merchant navy officers, by Capt. Subramaniam, the first one being "Practical Navigation". I wish this book great success and popularity among all for whom the book is intended.

(A.K. MUKHERJEE)

Preface

Meteorology can be a very interesting subject if tackled properly. The secret is the order in which the topics are studied. Everything would then seem to fall into a proper pattern whereby nothing needs to be *conned by rote* (learned by heart).

Meteorology is a vast subject and there are many books on it. However, this book is meant to give the mariner the necessary knowledge in a simple and concise manner (in a nutshell!), enable him to become competent with less effort.

The sketches and maps have been personally drawn by me and simplified to make the subject easier to understand.

In this edition, the third, minor changes have been made throughout especially in the weather reporting system, the various weather codes, meteorological instruments, the International Ice Patrol and weather routeing with cross-references, wherever necessary, to the 2000 amendments to SOLAS 74.

Mumbai,
13th September 2002 Capt.H.Subramaniam.

CONTENTS

CHAPTER 1

THE ATMOSPHERE

General description

The air around the earth is called the atmosphere and extends to over 200 km* above the surface of the earth. Different layers of the atmosphere are called by different names. In ascending order, they are the troposphere, stratosphere, mesosphere and the ionosphere. The troposphere affects the weather while the ionosphere affects navigation and communications when using electro-magnetic waves.

ATMOSPHERE		Over 200 km above S.L.
	IONOSPHERE	
		About 80 km above S.L.
	MESOSPHERE	
		About 50 km above S.L.
	STRATOSPHERE	
	TROPOPAUSE	8 to 16 km above S.L.
	TROPOSPHERE	
	EARTH'S SURFACE	

The troposphere

Nearly all of the weather changes occur, and nearly all the water vapour of the atmosphere is contained, in the troposphere, which extends to a

*In this book, all distances are expressed in nautical miles and all heights, in kilometres. 1 M = 1.852 km & 1 km = 0.54 M.

height of about 8 km above the poles and about 16 km above the equator.

In the troposphere, atmospheric temperature normally falls steadily as height increases. In the stratosphere, the air temperature remains fairly steady around minus 56.5°C (216.5°K).

Separation zones

The zone of separation between the troposphere and the stratosphere is called the *tropopause*. This is of interest to mariners as it is the upper limit of the troposphere, within which weather changes occur.

The separation zone between the stratosphere and the mesosphere is called the *stratopause* and that between the mesosphere and the ionosphere, the *mesopause*. However, these are of no direct interest to mariners.

Composition

The atmosphere consists mainly of Nitrogen (about 78%) and Oxygen (about 21%). Water vapour and rare gases including CO_2 occupy about 1%.

Temperature of the atmosphere

S.I. Units of air temperature are degrees *Celsius* and degrees *Kelvin*. Freezing temperature of water = 0°C or 273°K. Boiling temperature of water = 100°C or 373°K.

Variation of temperature with height

In the troposphere, the temperature of air normally falls steadily as height increases. Sometimes, local influences cause the temperature of air to:

(a) Increase with height instead of falling. This is called a *temperature inversion*

OR

(b) Remain constant with height. The air is then said to be an *isothermal layer*.

However, both above conditions, (a) & (b), are temporary and will return to normal subsequently.

Adiabatic lapse rate

Adiabatic change of temperature of a parcel of air is the change in its temperature due to increase or decrease of its volume, without any exchange of heat from the surroundings. If the volume was increased, the temperature of the parcel would decrease and vice-versa. This is due to a law in physics. If a parcel of air is made to rise, its volume would increase in accordance with the rarer air at that height. This expansion causes the parcel of air to cool, though no exchange of heat has taken place with the surrounding air. This cooling is hence adiabatic.

Wet and dry air

Any parcel or sample of air that is *fully* saturated is called wet air or saturated air.

Any sample of air that is *not fully* saturated is called dry air.

DALR

It has been observed that the temperature of a dry parcel of air, which is made to rise, falls at a steady rate of 10°C for every km of ascent i.e., the adiabatic lapse rate of a dry parcel of air, or Dry Adiabatic Lapse Rate (DALR) is 10°C per km.

SALR

The temperature of a saturated parcel of air, which is made to rise, falls at a rate of *approximately* 5°C per km of ascent i.e., the adiabatic lapse rate of a saturated parcel of air, or Saturated Adiabatic Lapse Rate (SALR), is about 5°C per km.

SALR is less than DALR because, as the saturated air is cooled, its capacity to hold water vapour decreases and the excess moisture condenses into water droplets. This condensation releases latent heat that warms up the parcel of air. The temperature of the rising parcel of saturated air, therefore, falls only by about 5°C per km instead of 10°C. SALR is slightly variable – less at the equator and more at the poles.

When we require an average value of the adiabatic lapse rate of any parcel of rising air, and we do not know its exact moisture content, an average value of 6.5°C per km height would give a reasonably approximate result.

Diurnal variation of atmospheric temperature

It has been observed that atmospheric temperature reaches its maximum at about 1400 hours local time and reaches its minimum at about half-hour after sunrise. Since this happens once per day this is called diurnal variation of atmospheric temperature.

Diurnal range of atmospheric temperature

The difference between the maximum and minimum values in a day is called the diurnal range of atmospheric temperature for that day.

Diurnal range of air temperature over land is large (as much as 20°C) whereas over sea, it is very small (less than 1°C), for the following reasons:

	Over land	Over sea
1.	Land, being a solid, has a low value of specific heat and so heats up or cools very quickly.	Sea, being a liquid, has a higher value of specific heat and so heats up or cools slowly.
2.	Heat received from the sun is retained by the top layer of land (only a few centimetres deep) as land is a poor conductor of heat.	Heat received from the sun is distributed over a large mass of water by convection currents.
3.	Negligible evaporation	Evaporation of water during day causes adiabatic cooling which balances some of the heat received from the sun.

The temperature of the land surface, therefore, varies greatly between day and night. Consequently the air in contact with it has a large diurnal range. Since the temperature of the sea surface does not vary much between day and night, the air in contact with it has a practically negligible diurnal range.

However, one interesting point to note is that whereas the *minimum* ground temperature may be only a couple of degrees below the air temperature, the *maximum* ground temperature may be as high as 40 degrees higher than the air temperature.

Atmospheric pressure

Atmospheric pressure is the force exerted, per unit area, by air. It is thus the weight of the column of air above a unit area.

S.I.Units of atmospheric pressure: hectopascals or millibars.

1 hectopascal = 1millibar

1000 mb = 1 bar = 750.1 mm of mercury

1 bar = 1.02 kg per cm^2 or 10.2 t per m^2.

The average atmospheric pressure at the earth's surface is about 1013 mb.

Lapse rate of atmospheric pressure

Atmospheric pressure always decreases as height increases. The graph of the lapse rate of atmospheric pressure against height above sea level is a curve. The average lapse rate is about 115 mb per km height in the lower levels of the atmosphere (upto 5 km height). At higher levels, the lapse rate is higher.

Semi-diurnal variation of atmospheric pressure

Owing to many causes, which are not fully understood by man, atmospheric pressure changes with the time of the day. It has been observed that it is maximum at about 10 & 22 hours and minimum at about 04 & 16 hours Local Mean Time. Since this happens twice a day, it is called semi-diurnal variation of atmospheric pressure.

Semi-diurnal range of atmospheric pressure

The difference between the maximum and minimum values is called the semi-diurnal range of atmospheric pressure. The average semi-diurnal range is more in the tropics than in middle latitudes. In tropical regions it is about 3 mb (i.e., upto ±1.5 mb from normal) and in UK (lat 51°N) it is about 0.8 mb (i.e., upto ± 0.4 mb from normal). In high latitudes, it is negligible and frequently masked by fronts and frontal depressions.

Barometric tendency

Barometric tendency is the difference between the atmospheric pressure at the time of observation and the atmospheric pressure three hours earlier. It is expressed in millibars and up to one decimal of a millibar.

Barometric tendency gives the forecaster a good idea of the rate of change of pressure, which is useful for predicting the movement of pressure systems (also called isobaric patterns). It is for easy comparison by the forecaster that barographs and barometer readings should be in accordance with UTC (GMT) and not ship's time.

Characteristic of the barometric tendency

This is explained under later in this book under "Barograph".

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CHAPTER 2

HEAT

Transference of heat

Heat is transferred from one place to another in three ways:

1. **Conduction**: In this case, heat is transferred from one place to another, through a solid, by direct contact between molecules. Metal objects are very good conductors of heat whereas wooden pieces are not. If one end of an iron rod is heated, the other end also gets hot, but it is well known that even if one end of a wooden stick is burning, the other end does not get hot. Land surfaces are generally poor conductors of heat though different types of soil have different conductivity e.g., sand is a better conductor than mud.

2. **Convection**: Is the transference of heat in a fluid (gas or liquid) by the movement of molecules. If one corner of a bowl of water is heated, the water particles move about and the heat is distributed throughout the entire body of water. If small, visible dust particles were present in the bowl of water, it will be observed that the convection currents in the water follow definite patterns. On the earth's surface, heat is transferred from one place to another by ocean currents and also by convection currents of air.

3. **Radiation**: Is the transference of heat from one place to another through space, without the necessity

of any intervening medium. Heat given off by the sun travels through space and reaches the earth by the process of radiation.

Insolation

Insolation is the name given to all forms of energy received by the earth, from the sun, by the process of radiation. Insolation includes light, heat, ultra-violet rays, infra-red rays, etc.

Insolation comes in the form of energy of very short wave length. Energy of such short wave length has the property of passing through transparent media without heating the media. Insolation, therefore, passes through the earth's atmosphere without heating it.

Why cloudy nights are warmer

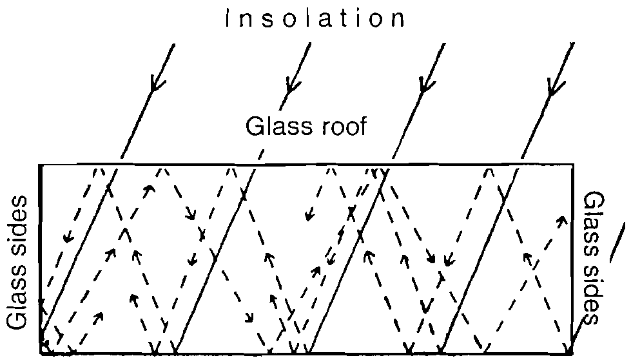
On striking the earth's surface, most of the Insolation is directly reflected off and only a small fraction is absorbed. If this was not so, the earth's surface would melt due to the great heat. The energy, thus absorbed by the earth, is re-radiated by it. This re-radiation, called terrestrial radiation, is of very much longer wave length than insolation and hence cannot easily penetrate the atmosphere.

Terrestrial radiation, therefore, heats the atmosphere. Whereas insolation can easily penetrate through clouds, terrestrial radiation cannot. That is why cloudy nights are much warmer than nights with clear skies - terrestrial radiation, trying to go out to space at night, is reflected back towards the earth's surface by the clouds.

Green house effect

The foregoing phenomenon is called green house effect because this principle is used to grow tropical plants in cold regions, in a special structure called a *green house*. A large room is built with glass roof and glass sides with small windows for air circulation.

Sunlight (insolation) easily enters the room through the roof and/or the sides. Terrestrial radiation, from the floor of the house, cannot pass easily through the glass and gets trapped inside the room, thereby raising the temperature of the room.

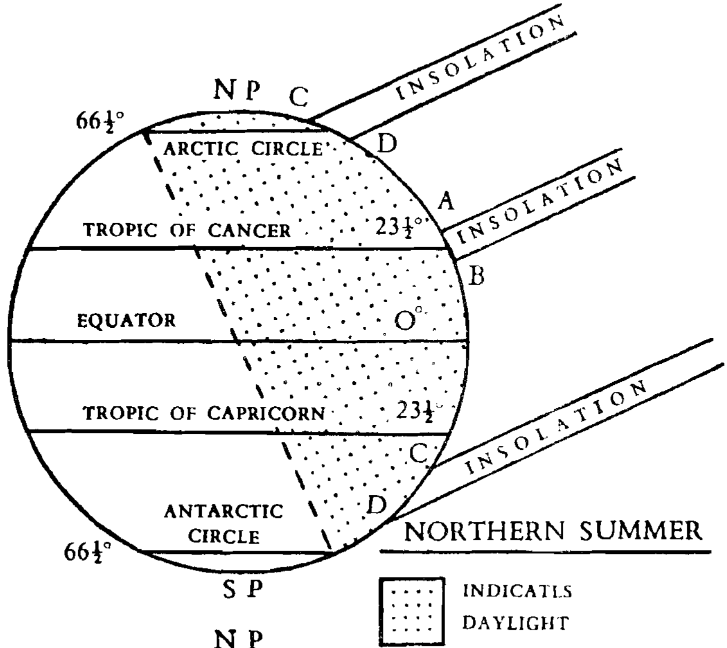


GREEN HOUSE EFFECT

The seasons

Because of the tilt of the earth's axis of rotation, the sun appears to be overhead (dates are for 2002):

1. The Equator on 20th March;
2. The Tropic of Cancer (23½°N) on 21st June;
3. The Equator on 22nd September;
4. The Tropic of Capricorn (23½°S) on 21st December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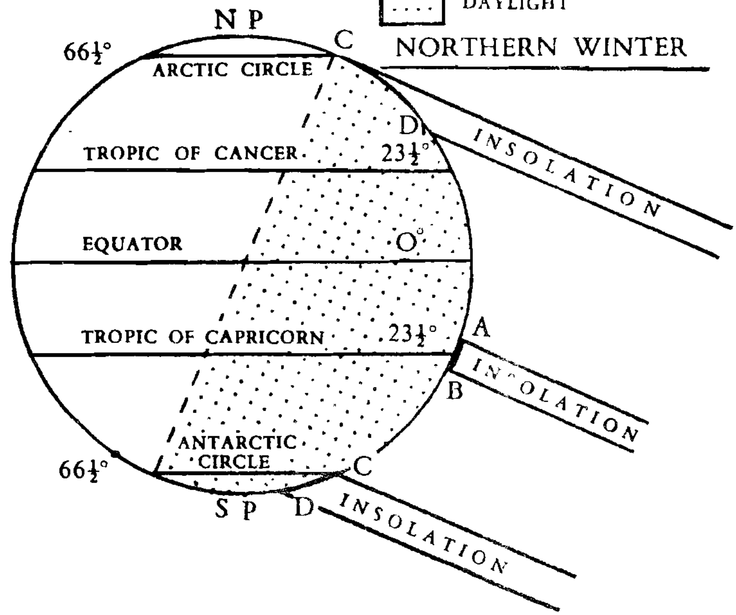
INDICATES DAYLIGHT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NORTHERN WINTER

This causes the seasons listed below:

	Northern Hemisphere		Southern Hemisphere	
	From	To	From	To
Spring	Mar 20	Jun 21	Sep 22	Dec 21
Summer	Jun 21	Sep 22	Dec 21	Mar 20
Autumn	Sep 22	Dec 21	Mar 20	Jun 21
Winter	Dec 21	Mar 20	Jun 21	Sept 22

If desired, the exact dates for any particular year when the declination is zero, maximum north and maximum south may be extracted from the nautical almanac.

Why polar regions are colder than equatorial regions

Since the earth is so far away from the sun, the sun's rays may be assumed to be parallel to each other when they arrive. That half of the earth that is towards the sun gets sunlight, during daytime, as shown in the foregoing figure. It will be noticed that each pole receives sunlight only during its summer but not during its winter. This is one of the reasons why the poles are cold.

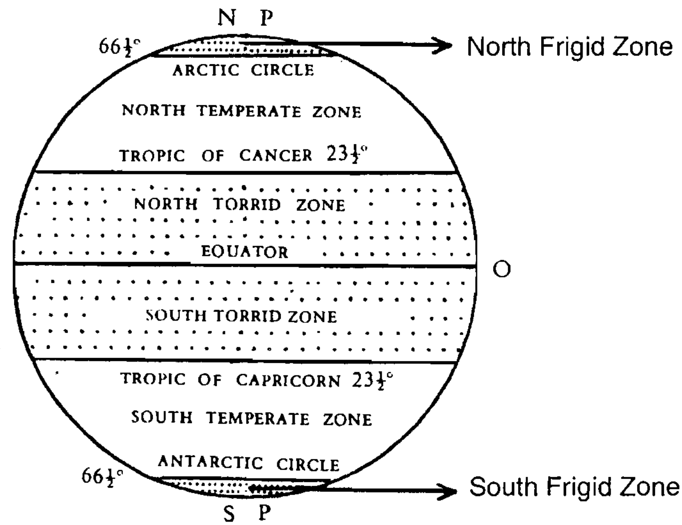
Imagine two identical, parallel, equidistant sets of rays, one set reaching perpendicular to the earth's surface (AB in the foregoing figures) and the other set reaching at a slant (CD). The heat received by CD is equal to the heat received by AB but because of the slant, arc CD is larger than arc AB and the heat received is thus spread over a larger area. Surface temperature of CD is therefore less than that of AB. The more the slant away from the perpendicular, the greater the surface area heated by the same rays and the less the surface temperature.

Over the equator, the sun's rays are never more than 23½° away from the vertical. The equatorial region is hence warm throughout the year compared to the tropics where the angle of incidence may vary between 23½° and 66½°.

That is why polar regions and high latitudes are colder than equatorial regions. That is also why the northern hemisphere is warmer when the sun is north of the equator (northern summer) and vice versa.

Temperature zones of the world

Because of the reasons explained earlier in this chapter, the earth is divided into the following temperature zones:



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CHAPTER 3

WATER VAPOUR

IN THE ATMOSPHERE

Humidity

Humidity is the quantity of water vapour present in the atmosphere.

Absolute humidity

Absolute humidity is the mass of water vapour contained in a sample of air. It is usually expressed in grams per cubic metre (gm/m^3).

Relative humidity

Relative humidity is the percentage ratio of the actual water vapour contained in a given sample of air, to the maximum quantity of water vapour that the sample can hold at that temperature.

$$\text{R H \%} = \frac{\text{Present quantity of water vapour}}{\text{Max. possible at that temperature}} \times 100$$

If the temperature of the sample of air is raised, its capacity to hold water vapour increases and, assuming that no water vapour is allowed to come in or go out of the sample of air, relative humidity decreases - the air becomes relatively drier. The opposite happens if the sample of air is cooled - its relative humidity increases.

$$RH \propto \frac{1}{t}$$

Saturation and dew point

If a sample of air was progressively cooled, its relative humidity would steadily increase i.e., the air would become relatively more moist. At some temperature, the air would become wet i.e., its relatively humidity would become 100%. The air is then said to be saturated and the temperature at which this occurs is called the dew point temperature of that sample of air. Dew point of a sample of air would depend on its temperature & relative humidity.

Both relative humidity and dew point of air are found by using a hygrometer or a psychrometer and then consulting meteorological tables - dry bulb reading on one axis and the difference between wet and dry readings on the other axis. The point of intersection gives the relative humidity and the dew point.

Meteorological application to hold ventilation

Sweat in a cargo hold

Sweat in a cargo hold is the condensation of water vapour into droplets of water. Sweat can cause damage to dry cargo. Though this topic is closely related to cargo work, the causes of the formation of sweat lie in the subject of meteorology under the topic of 'Water vapour in the atmosphere'. There are three causes of sweat in a hold:

1. **Atmospheric sweat:**

A hold contains a very large volume of air. Any air brought in by ventilators at any instant is very small compared to the volume of the hold. If the temperature of the air in the hold is low, the incoming air will be cooled and, if the incoming air is cooled below its dew point, it will give off moisture. This will condense as sweat on cargo and in the steel parts of the hold and is liable to cause damage to cargo. It is therefore essential to compare the temperature of air in the hold with the dew point of the outside air.

If hold temperature is less than dew point of outside air, restrict ventilation.

If hold temperature is greater than dew point of outside air, ventilate freely.

A classic example of the above is when a ship is coming to India with cargo from Europe, in winter. The ship, cargo and the air in the hold are all initially very cold. Within a few days of the ship's departure from Europe, the vessel enters warmer regions. Though the temperature of air outside is then much higher than before, the cargo in the hold takes a week to increase its temperature by even a couple of degrees Celsius. Hence the temperature of the air in the hold is very low due to its contact with the cold cargo and will most probably be well below the dew point of the air outside. If ventilation was allowed, the air entering the hold will give off its moisture which will condense as sweat on all cold surfaces in the hold and is liable to damage cargo. Under these circumstances, hold ventilation has to be restricted nearly throughout the passage until the temperature of the air in the hold is above the dew point of the outside air.

On sophisticated ships carrying highly perishable cargoes, where ventilation has to be done even under the circumstances mentioned earlier, de-humidifying units are fitted whereby the air entering the hold is dried before hand so that sweat does not form.

2. Cargo sweat

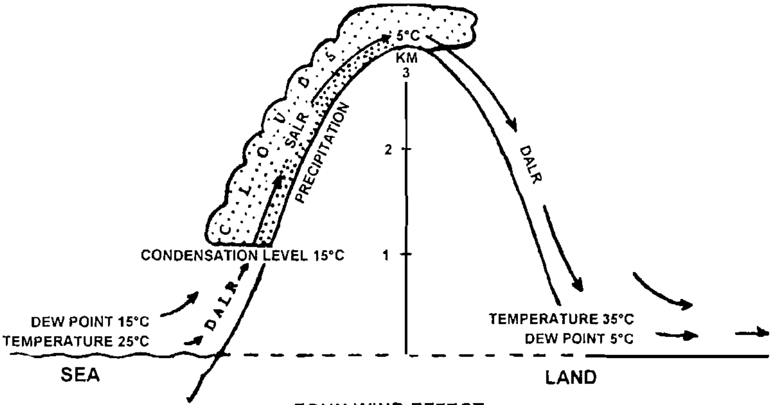
Some cargoes such as hides, skins, ores, etc., exude (give off) large quantities of water vapour making the relative humidity of the air inside the hold very high. The slightest cooling would cause sweat to form on the steel parts of the hold. This would drip on other cargoes in the hold, possibly causing damage to them. This can only be prevented by use of large capacity exhaust fans (fitted on most cargo ships), using dunnage to keep the cargo off the steel and covering the top of the cargo in the hold with bamboo mats or cardboard sheets.

3. Ship sweat

When the temperature of the sea is much lower than that of the air above it, the underwater parts of the hold would be cooled by contact with the sea. Hence sweat would form on the steel parts of the hold below the waterline. This normally would flow into the bilges. The use of dunnage to keep the cargo off the steel parts of the hold and also to keep it a few centimetres above the bottom of the hold would suffice. Ventilation would also help, in reducing the relative humidity in the hold.

Föhn wind effect

Fohn Wind Effect is an effect whereby the leeward side of a mountain range is drier and warmer than the windward side. This would be more pronounced if the wind was blowing from the sea towards a coastal mountain range, as the air would then be moist. Fohn wind effect is the direct result of the difference between the DALR and the SALR of air as illustrated below:



FOHN WIND EFFECT

Imagine an onshore breeze, of 25°C temperature and 15°C dew point, blowing against a mountain range 3 km high.

This onshore breeze begins to ascend and its temperature drops by 10°C per km height (DALR). On reaching a height of 1 km, the temperature of the air has fallen to 15°C, which is also its dew point. The air is then saturated. On ascending further the temperature drops by about 5°C per km height (SALR). The excess moisture in the air is given off as orographic cloud and then heavy rain falls on the windward side. On reaching the top, the air will still be saturated and its temperature would be about 5°C. While descending on the leeward side, the temperature of the air would increase at 10°C per km (DALR). This is because, once the temperature of the air begins to rise even by a small amount, the air is not saturated any more. On reaching sea level on the leeward side, the temperature of air would have increased to 35°C. Since the same air was saturated at 5°C and no water vapour has been let in or taken out, the dew point of the descending air would be 5°C. Comparing the temperature and dew point on the windward side (temperature 25°C, dew point 5°C), it is clear that the leeward side is warmer and drier than the windward side. It is also clear that heavy precipitation occurs only on the windward side and no precipitation occurs on the leeward side, which is hence referred to as the 'rain shadow area' of the mountain range.

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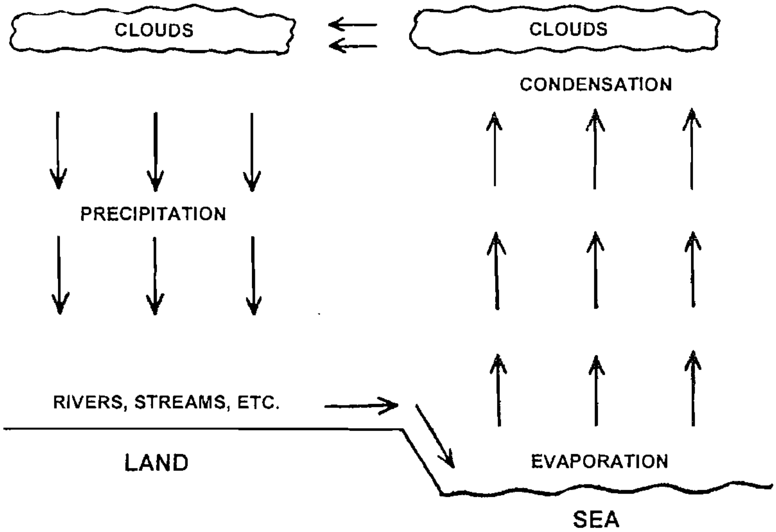
CHAPTER 4

THE HYDROLOGICAL CYCLE



THE HYDROLOGICAL CYCLE

1. **Three main stages**:

There are three main stages in the hydrological cycle - Evaporation, Condensation and Precipitation - and each is described below:

1.1. **Evaporation**: is the transformation of water into water vapour. It is accelerated if the air is warm and dry (has a low relative humidity). Since about three-quarters of the surface of the earth is covered by water, enormous quantities of water-vapour form daily, from the sea surface.

During evaporation, latent heat is absorbed from the surrounding air and from the water surface. It is this latent heat that provides the energy required for tropical revolving storms and thunderstorms.

1.2. **Condensation**: is the transformation of water vapour into water. It is the opposite of evaporation. During condensation, latent heat is given off to the surrounding air.

Condensation occurs if air is cooled below its dew point. This is usually the result of:

- Contact with cold surface of land or sea.
- Adiabatic cooling when air rises.
- Contact with colder masses of air.
- Radiation of heat into space from upper layers of air.

If condensation is caused by contact with cold land surfaces, dew is formed and deposited on the surface. However, if a light wind is blowing over the cold land surface, or if condensation is caused by any of the other causes mentioned above, the water droplets form on dust or minute salt particles and are so small that they remain suspended in the air. The droplets have a radius of less than 10 microns (one million microns are equal to one metre). Large quantities of such droplets near each other are visible to the human eye. If these droplets are very near ground level, they are called mist (or fog) as explained under the chapter titled 'Visibility') and if they are well above ground level, they are called clouds (described under the chapter titled 'Clouds').

As many as a million such droplets have to join together to become one drop of water large enough to fall towards the ground.

1.3. **Precipitation**: is the name given to water drops from a cloud, which fall towards the ground. Whilst falling through different layers of atmosphere, the water drops may freeze into soft ice (snow) or into hard ice (hail). Mist and fog are not called precipitation because the water droplets remain suspended in the air and do not fall. Sometimes, precipitation evaporates completely, during its transit through the atmosphere, and does not reach the ground. It may then be visible as vertical streamers below clouds and is called "Virga".

The hydrological cycle is thus the continuous process whereby water from the sea surface evaporates, precipitates and returns to the sea by way of rivers and streams. Short circuits in the system do take place. Evaporation takes place directly during precipitation and also from streams, rivers, lakes, vegetation and soil. Precipitation takes place over sea also.

The most important point in the hydrological cycle is that during evaporation, salt and other impurities are left behind and hence water obtained through precipitation is very pure. However, in industrial areas the impurities present in the air (air pollution) can be absorbed by precipitation before it reaches the ground.

2. Condensation near the ground

2.1. **Dew**: When water vapour condenses into droplets of water and gets deposited on exposed surfaces on or near the ground, it is called dew.

On clear nights, land gives off its heat into space very quickly. If clouds are present they reflect much of the escaping heat back towards the earth's surface and hence cooling is much slower. By late night or early morning the surface of the land gets very cold and hence the air in contact with it may get cooled below its dew point, resulting in the formation of dew. Dew can also be formed at other times of the day if a warm moist wind blows gently over a very cold land surface. The presence of water or ice particles on the surface speeds up the formation of dew.

2.2. **Hoarfrost**: Is the name given to ice crystals deposited on exposed surfaces on or near the ground, when the ground temperature is much lower than freezing point. In this case, the water vapour directly turns into ice without becoming water. The presence of ice particles on the surface quickens the formation of hoarfrost.

When vapour turns into solid without becoming liquid, it is called 'deposition' in chemistry, but in meteorology the name "sublimation" is more commonly used. Hoarfrost should not be confused with frozen dew. In the case of frozen dew, the water vapour becomes water and then freezes.

2.3. **Glazed frost**: Is a thin, transparent, smooth layer of ice formed when rain or drizzle falls on a surface whose temperature is below freezing point. Glazed frost can also form if a warm moist current of air blows over a very cold surface.

In the UK, glazed frost is also called "Black ice" as it cannot be distinguished against a black road surface. It is dangerous to walk or drive on glazed frost as it is very smooth and slippery.

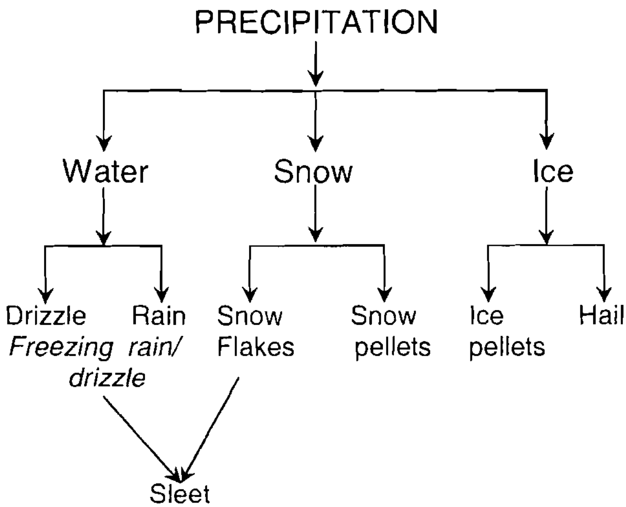
2.4. **Rime**: If the temperature of water particles in a fog is below 0°C, they are said to be supercooled droplets of water. When super-cooled water droplets in a fog come into contact with very cold solid objects such as ship's masts, superstructure etc., whose temperature is well below freezing point, they freeze almost immediately and remain struck to the object in the form of ice. This white deposit of ice is called rime.

Since these fog particles are carried by the wind, rime forms only on the windward side of objects. With continuous super-cooled fog, rime can grow at the rate of one centimetre thickness per day. It is initially soft but can freeze later into hard ice.

Rime should not be confused with hoarfrost. Rime forms only on the windward side of objects by freezing of water and is non-crystalline. Hoarfrost forms on all sides of objects by sublimation and the ice is in the form of crystals.

2.5. **Mist and fog**: These are discussed in detail in the chapter titled 'Visibility'.

2.6. **Types of precipitation**



1. Drizzle: Fine drops of water, diameter less than 0.5 mm. Termed heavy or light depending on intensity of precipitation.
   Clouds: St, Sc.
2. Rain: Water drops larger than 0.5 mm diameter. Termed heavy or light depending on intensity of precipitation.
   Clouds: Ns, As, Sc, Ac, Cu, Cb.
3. Freezing rain/drizzle: The water drops freeze on impact with cold ground.
   Clouds: Same as for rain/drizzle.
4. Snow flakes: Loose clusters of ice crystals, in very soft, small particles having branches.
   Clouds: Ns, As, Sc, Cb.

5. Snow pellets: White opaque grains of ice, very soft and spherical or conical in shape, diameter between 2 and 5 mm.
   Clouds: Cb in cold weather.
6. Sleet: Sometimes rain and snow fall together or partly melted snowflakes fall. This is called sleet and is common in the U.K.
   Clouds: Same as for snowflakes.
7. Ice pellets: Transparent pellets of ice, frozen hard, less than 0.5 mm diameter.
   Clouds: Ns, As, Cb.
8. Hail: Balls of hard ice, 0.5 to 50 mm diameter or more.
   Clouds: Cb.

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CHAPTER 5

VISIBILITY

Visibility is the transparency of the atmosphere and is defined as the maximum distance at which an object can be clearly seen and distinguished in normal daylight.

Visibility can be reduced by liquid or solid particles in the air as in the following cases:
(a) Mist or fog (b) Precipitation (c) Spray (d) Smoke (e) Dust, volcanic ash, etc.

Visibility can therefore vary in different directions. Water vapour is a transparent gas and does not reduce visibility. In the absence of any particles in suspension in the air, visibility through the atmosphere is about 130 nautical miles.

Mist/Fog

Mist is said to exist when visibility is reduced by water particles that have condensed on dust, minute particles of salt, etc., but are so small that they remain suspended in the air. If mist becomes dense and reduces visibility to 1 km or less, it is called fog. Mist can occur when relative humidity is an low as 80% - the radius of the droplets of water is less than 1 micron (one million microns are equal to one metre). Fog generally occurs when relative humidity is 90% or more - the radius of the droplets of water is between 1 & 10 microns. Mist is always experienced before and after fog.

Haze

If visibility is reduced by solid particles such as dust, sand, volcanic ash, etc., in suspension in the air, haze is said to exist. Haze can, in rare cases, reduce visibility to 200 metres or less.

Spray

Spray is the name given to small droplets of water driven by the wind, from the tops of waves. Spray affects visibility when the wind force is 9 or more (wind speed of over 40 knots).

Judging and reporting visibility

Shore stations have selected objects at known distances off and can ascertain visibility very accurately. They hence report visibility in their weather reports by two code numbers between 00 & 89. Visibility at sea cannot usually be ascertained accurately and is hence obtained by estimation. It is then reported in weather messages by two code numbers between 90 & 99. When visibility has different values in different directions, the lowest value is to be reported.

TYPES OF FOG

1. Radiation fog

Also called land fog because it forms only over land, not over sea. During the night, land gives off its heat very quickly. On clear nights, the radiation of heat from the land surface into space is quicker as it is unobstructed by clouds. The air in contact with the ground thus gets cooled and if cooled below its dew point, a large quantity of dew is deposited. If, however, a light breeze is blowing, turbulence causes the cold from the land surface to be communicated to the air a couple of metres above the ground and shallow fog called 'ground fog' results. The visibility at eye level above this ground fog may be good but, in the fog, it may be only a couple of hundred metres or less. If the wind is a bit stronger, radiation fog may extend upto a height of about 150 metres or so above the ground. Strong winds cause too much turbulence, resulting in low clouds (stratus type) and no fog.

Radiation fog, which can form over land only, may drift on to rivers, harbours, lakes and other coastal regions. For example: fog on the Thames River, Dover Straits, the Sandheads of the Hooghly, etc.

Radiation fog forms over land because of the large diurnal range of air temperature over land. It does not form over sea because of the very small diurnal range of air temperature over sea.

Radiation fog reaches its maximum about half hour after sunrise because air temperature is at its lowest at that time. It generally dissipates after the sun has shone for a few hours and the land surface has warmed up.

Conditions favourable for radiation fog are:

- Large moisture content in the lower layers of air.
- Little or no cloud at night.
- Light breeze at the surface.
- Cold wet surface of land.

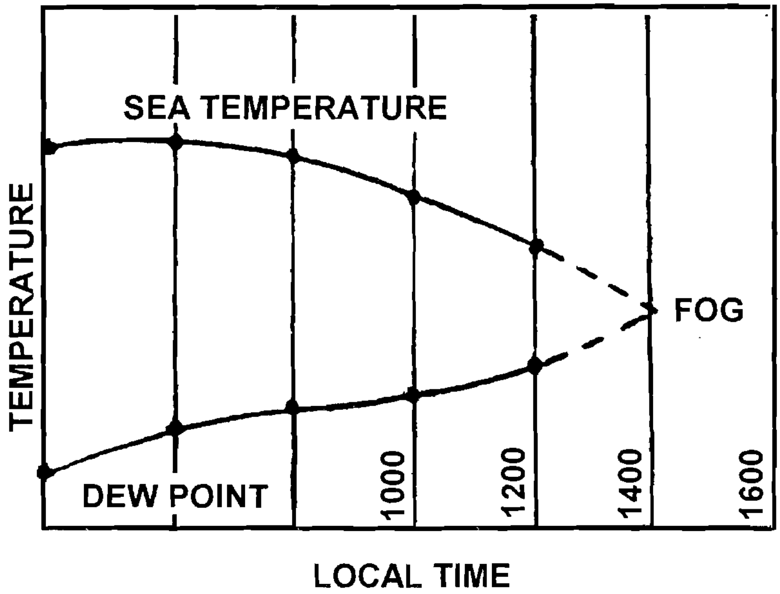
2. Advection fog.

Is also called sea fog because it is mostly found over sea. It can, however, form over land also. It is formed when a moist wind blows over a relatively cold surface of sea or land. When the most air is cooled below its dew point, the excess water vapour condenses into small droplets of water on dust or minute particles of salt, resulting in advection fog. Wind causes advection fog to form and also to spread. If the wind is quite strong, turbulence causes advection fog to form to considerable depth. However, very strong winds carry the moisture too high, resulting in low clouds (Stratus type) and no fog. Best examples of advection fog are:

- On the Grand Banks of New Foundland where the warm, moist Westerlies, blowing over the warm Gulf Stream, cross over the cold Labrador Current.
- Off the east coast of Japan where the warm, moist Westerlies, blowing over the warm Kuro Shio, cross over the cold Oya Shio.
- The south coast of the UK in winter, whenever SW winds blow. These winds come from lower latitudes and blow over the sea and are hence warm and moist, compared to the cold land surface.

The possible time of occurrence of advection fog can sometimes be predicted by plotting the temperature of the sea surface and the dew pcint temperature of the air as two separate curves against ship's time as shown in the following figure.

In the case illustrated, it is observed that the two curves appear to converge. By extending the two lines as shown in dotted lines, it is noticed that the curves would intersect at about 1400 hours. We can then expect to experience advection fog at about 1400 hours.



3. Other types of fog

3.1. **Smog** is radiation fog mixed with industrial smoke.

Smoke + Fog = Smog

It is a thick, black, oppressive blanket, which not only wets all exposed surfaces but also makes them black due to carbon particles in the smoke. Example: London, Glasgow, Newcastle, Tokyo, Los Angeles, and Calcutta.

3.2. **Steam fog** or **arctic sea smoke**: When very cold, dry air passes over a relatively warm sea surface, the water vapour, evaporating from the sea surface, is quickly condensed into water-droplets and it appears as if vertical streaks of smoke are rising from the sea surface. This is called steam fog or arctic sea smoke as it is commonly seen in the Arctic Ocean.

3.3. **Hill fog** or **orographic fog**: When a wind comes against a mountain range and begins to climb over it, it progressively cools adiabatically. After dew point is reached, any further cooling causes the excess moisture to condense into water droplets forming hill fog or orographic fog (in Greek, *oros* means mountain).

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CHAPTER 6

CLOUDS

When air is cooled below its dew point temperature, the excess water vapour condenses into minute (very small) particles of water, which remain suspended in the air. Millions of such particles, close together, become visible as cloud.

It is, however, necessary that minute particles of salt (carried up by spray), volcanic ash, industrial smoke or dust are present to act as nuclei on which condensation can take place.

The cooling of air below its dew point can be due to any of the four causes mentioned in chapter 4 (i.e., contact with cold surface of land or sea, adiabatic cooling during ascent, contact with colder masses of air or radiation of heat into space by upper layers of air).

Clouds can form at any height from sea level upto the tropopause, which is about 8 km above the poles, about 13.5 km above temperate latitudes and about 16 km above the equator. They are hence grouped according to their height of base above sea level.

Low clouds consist entirely of water droplets and have their bases between sea level and 2 km height.

Medium clouds have the prefix “Alto” to their names and consist of both, water droplets and ice particles, but more of the former. Their bases will be between 2 km and 6 km above sea level.

High clouds have the prefix "Cirro" to their names and consist entirely of ice crystals. Their bases will be between 6 km above sea level and the tropopause.

Note: These heights are average only. They are slightly lower over the poles and slightly higher over the equator. The ***tops*** of medium clouds & the ***bases*** of high clouds can overlap by as much as 3 km.

Clouds are of four main types, classified according to their appearance:

- Cirrus: A silvery cloud in the form of feathers or fibres seen high up in a blue sky.
- Cumulus: A white cloud, shaped like a cauliflower, which can have great vertical extent.
- Stratus: An even layer of grey cloud, not giving rain.
- Nimbostratus: An even layer of grey cloud giving rain. Nimbostratus is the modern name for Nimbus. Hence it is an original type of cloud and not a combination of nimbus and stratus.

Cloud names have abbreviations, which consist of two letters, of which the first is a capital letter. The various type of clouds their abbreviations, and grouping according to height, are given below:

High	**Medium**	**Low**	**Special**
Bases between 6 km above sea level & tropopause.	Bases between 2 km and 6 km above sea level.	Bases between sea level and 2 km above sea level.	Bases at low cloud level but tops may extend well into high cloud level.
Cirrus Abbrev: **Ci**	Altostratus Abbrev: **As**	Stratus Abbrev: **St**	Cumulus Abbrev: **Cu**
Cirrostratus Abbrev: **Cs**	Altocumulus Abbrev: **Ac**	Stratocumulus Abbrev: **Sc**	Cumulonimbus Abbrev: **Cb**
Cirrocumulus Abbrev: **Cc**		Nimbostratus Abbrev: **Ns**	

Given below is a brief description of the ten cloud types listed above. It is suggested that whilst at sea the "International cloud atlas", which is available on nearly all ships, should be consulted when making observations of clouds for weather reports. After sufficient practice and experience, it will be noticed that navigating officers will need to consult the cloud atlas only on rare occasions. One important point to remember is that stratiform clouds indicate a stable atmosphere whereas cumuliform clouds indicate an unstable atmosphere.

1. **Cirrus**: Silvery, high clouds appearing like feathers or fibres. Being so high up, they always have a background of blue sky and, during twilight, often appear bright red or yellow. On dark nights, cirrus can be detected only by its dimming effect on stars.

2. **Cirrostratus**: A thin whitish veil of high cloud through which the sun or moon have a watery look. The outline of the sun and moon are sufficiently clear for altitude observations by a sextant. Haloes are often seen due to cirrostratus clouds. Cirrostratus clouds should not be mistaken for altostratus clouds which are described below.

3. **Cirrocumulus**: A high layer of cloud in the form of small flakes or cauliflowers, white in colour with no dark shadows in between.

4. **Altostratus**: A thin greyish or bluish veil of cloud through which the sun or moon appears very dim - as if seen through frosted glass. The outline of the sun and moon are hazy and not clear enough for altitude observation by a sextant. Altostratus does not give

rise to haloes. Dark, shadow-like patches may be seen due to variation in the thickness of the veil.

5. **Altocumulus**: Clouds in patch, layer or sheet form, white or grey or both in colour. Have dark shadows in between and have the appearance of small flattened globules or rolls or long bands or almonds, all of which may be in regular patterns aligned in one, or sometimes two, directions.

6. **Stratus**: A low, even layer of dark grey cloud with light and dark patches. It has a dry look and does not cause precipitation. It resembles fog, but is not experienced at sea level. It can obscure the sun completely and can greatly weaken daylight. It should not be confused with nimbostratus, which is described below. Small patches of stratus, spread out, are referred to as fracto-stratus.

7. **Nimbostratus**: A low, even layer of dark-grey cloud generally uniform and threatening in appearance with no light coloured patches. It has a wet look. If precipitation takes place it is continuous, not intermittent. Nimbostratus is usually formed by gradual thickening and lowering of a layer of altostratus. It can completely obscure the sun and greatly weaken daylight.

8. **Stratocumulus**: Clouds consisting of a layer or patches of globular masses which appear soft. They are grey in colour with dark shadows. The patches generally align themselves in regular patterns in one, or sometimes two, directions. The patches often join together and form an overcast sky, but is

distinguishable from stratus by its wavy or linear appearance.

9. **Cumulus**: Brilliant white, thick clouds with flat bases and rounded cauliflower-like tops. Dark shadows are usually seen in them. The outline of each such cloud is very clear cut. Cumulus clouds may be in small patches with ragged edges and little vertical extent - called fair weather cumulus or fracto-cumulus, or they may have very great vertical extent - called towering cumulus. Precipitation, if any, caused by even, well developed cumulus is light.

10. **Cumulonimbus**: Mass of grey, heavy cloud having its base in low cloud level, of great vertical extent, with its top well in high cloud level. It has a threatening appearance and is called a thundercloud. The top of a well-developed cumulonimbus cloud will have attached to it, a cap of white cirrus cloud in the shape of an anvil. It is then called anvil-shaped cumulonimbus. Its base resembles that of nimbostratus.

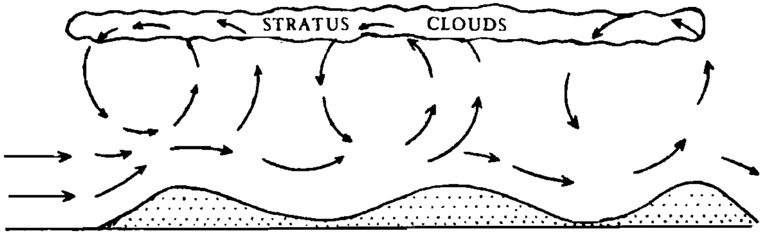
If cumulonimbus covers the sky completely, its top cannot be seen and hence it cannot be visually distinguished from nimbostratus. However if precipitation is experienced, they can be distinguished - Cb gives showers (intermittent precipitation with rapidly fluctuating intensity) whereas Ns gives continuous precipitation with little variation in intensity. However, in both cases, the precipitation may sometimes evaporate before reaching the ground and is then visible as vertical streamers called “virga”, below the base of the cloud.

FORMATION OF CLOUDS

Clouds are formed in four main ways:

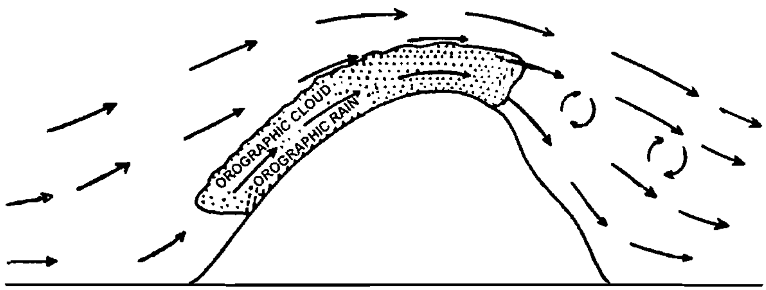
(a) **Turbulence**: Strong winds blowing over uneven ground strike against the various obstructions and the air gets deflected upwards. This causes thorough mixing of the air and, as the air rises, it cools adiabatically. If during this process, the air gets cooled below its dew point, clouds will form. These clouds will be of an even, layer type (stratus) and their bases will generally be not more than 600m high. Turbulence clouds will be formed in great quantities if the air is maritime (moisture laden) and blows over cold, uneven ground. Over sea, wind speeds of more than 13 knots only (force 4 and over) can produce sea waves of sufficient height to create turbulence clouds.

TURBULENCE CLOUD



(b) **Orographic lifting**: When a warm, moist wind blows against a mountain range, it begins to climb up the mountainside. During this ascent, it cools adiabatically and after cooling below its dew point, orographic clouds are formed. These are of the stratus type. If the mountain is quite high, further ascent results in nimbostratus and continuous precipitation.

On the windward side of the mountain peak, clouds are forming steadily whereas on the leeward side, they are dissipating at the same rate (while descending, the air warms up adiabatically and the clouds evaporate). It therefore appears as if a stratiform cloud is stationary over the mountain peak.

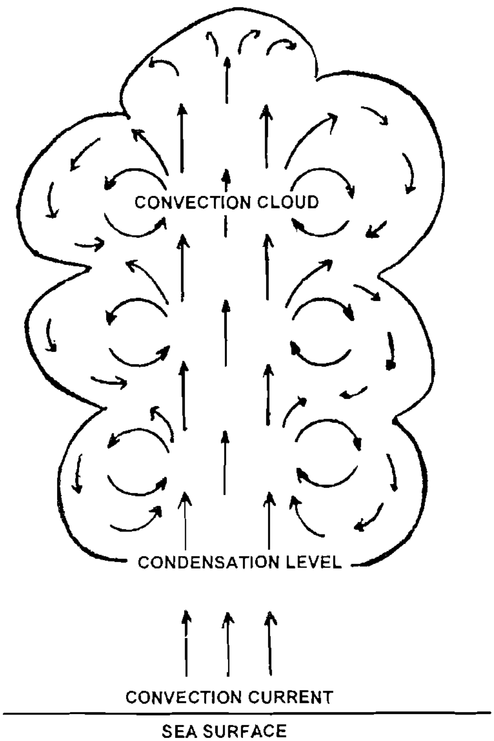


OROGRAPHIC CLOUD

This is called a “Banner Cloud” e.g., the Cap of Gibraltar, the Tablecloth of Table Mountain of South Africa, the Banner of the Matterhorn, etc. In Greek, the word “Oros’ means mountain.

(c) **Convection**: When a parcel of air gets heated due to any local cause, it expands, becomes less dense than surrounding air, and rises. This is called a convection current. This local heating can be caused by contact with warm sea or ground. So long as the parcel is warmer than the surrounding air at each level, it will continue to rise (unstable condition of air).

During this ascent, the rising air cools adiabatically and, when cooled below its dew point, condensation takes place resulting in convection clouds that are always of the cumulus type. That is why a large island (more than about 10 miles long) in mid ocean may be seen to have a stationary cumulus cloud above it during daytime. Actually the cloud is continuously forming from below and dissipating to leeward. It is for the same reason that, during daytime, the coastline of a large landmass may have a long line of cumulus cloud above it, parallel to the coast, though there may be no other clouds to windward.



The greater the ascent of air, the greater the vertical extent of the cloud - as the air ascends more and more, it gets progressively cooled further and the excess moisture gets condensed into more and more cloud, resulting in great vertical extent of the cloud - towering cumulus.

If the ascent is very rapid, cumulonimbus cloud may form with its head well into high cloud level until it reaches the tropopause, beyond which convection currents cannot rise. The top of the cloud then spreads sideways, resembling an anvil. This is called anvil-shaped cumulonimbus. Actually the anvil consists of ice crystals and is a cirrus cloud.

Over land, cumulus clouds generally begin to form in the morning after sunrise, reach their maximum quantity around late afternoon, when the land temperature is at its highest, and begin to dissipate after sunset as the land cools.

Over sea, there is little change of air temperature during day and night and hence cloud development is very little. However clouds may develop over sea at night due to cooling caused by radiation of heat into space, by the upper layers of air. Cloud development over sea, therefore, is opposite in time to that over land - over land it forms during day and dissipates at night whereas over sea, the opposite happens.

(d) **Frontal lifting**: Where a warm air-mass and a cold air-mass are in contact, their line of separation, at sea level, is called a front. The boundary between them is not vertical. It is inclined towards the colder air mass because the cold air, being denser, acts like a wedge and lifts up the warm air.

In the case of a warm front, the slope is gradual and the upsliding warm air forms stratiform clouds - nimbostratus, altostratus, cirrostratus and finally cirrus.

In the case of a cold front, the slope is very steep and the upsliding warm air forms cumulonimbus and cumulus clouds.

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CHAPTER 7

PRESSURE GRADIENT,

WIND AND WAVES

Isobars

An isobar is a line drawn, on a weather map, joining all places having the same atmospheric pressure *at the time for which that weather map was drawn.*

It is important to note that atmospheric pressure is dynamic – it may change frequently. Hence, its value, when stated, holds good only for that particular time.

Standardisation

So that proper comparisons can be made, the reading of the barometer is converted to that at sea level and the value of index error, if any, allowed for.

For mercury barometers, two more corrections are necessary – correction for difference of latitude away from 45°, and correction for temperature variation from the standard temperature of that barometer.

For standardisation, isobars are drawn at 4 mb intervals and the pressure denoted by an isobar must be divisible by four i.e., 996, 1000, 1004, etc. and not 997, 1001, 1005 or 998, 1002, 1006. Where consecutive isobars are very far apart, intermediate isobars at 2 mb intervals may be inserted.

It is also for standardisation that all barographs and barometer readings should be according to UTC (GMT) and not ship's time.

Isobars are smooth lines which curve gently without any sudden changes of direction except at 'Fronts' where they may change direction suddenly by as much as 90°. This is described in later chapters titled 'Air-masses and fronts' and 'Frontal depressions'.

Isobars cannot cross or meet because one place cannot have different values of atmospheric pressure at the same time.

By a study of past weather and weather maps, meteorologists have found that isobaric patterns fall into seven basic types and the weather associated with each type could be predicted with reasonable accuracy based on past experience. The seven basic isobaric patterns are described later, in a chapter of that title.

Pressure gradient

Pressure gradient is the fall of pressure with distance, as shown on a weather map. If the distance between consecutive isobars is small, the pressure gradient is said to be high and strong winds are expected to blow. If the distance between consecutive isobars is large, the pressure gradient is said to be small and winds of lower speed will be expected. For a given pressure gradient, stronger winds are expected in lower latitudes than in the higher latitudes.

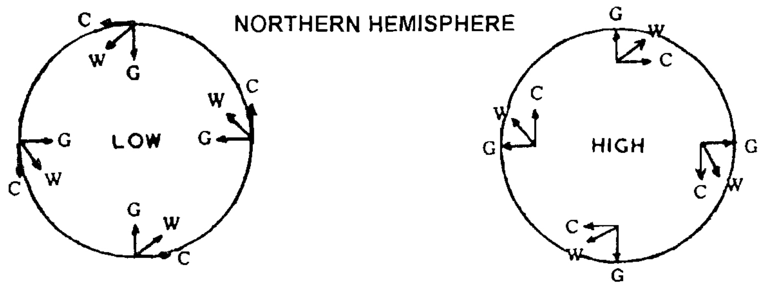
Prediction of wind direction

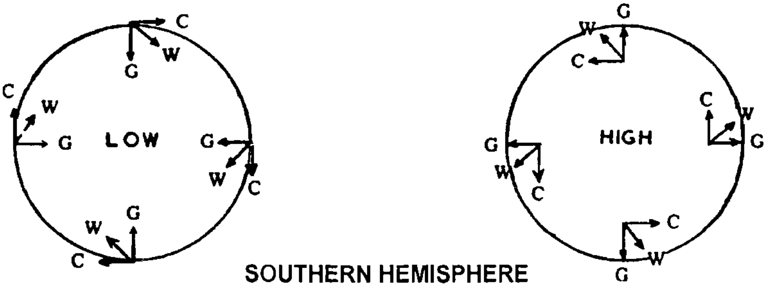
On the surface of the earth, winds always try to blow from an area of high pressure (HP) towards an area of low pressure (LP), because of gradient force.

Coriolis force: Whilst blowing from HP to LP areas, the wind is deflected by Coriolis (also called Geostrophic) force. Coriolis force is caused by the rotation of the earth. Coriolis force is minimum at the equator and increases as latitude increases, becoming maximum at the poles. Coriolis force always acts at right angles to the direction in which the wind is blowing. It deflects the winds to their right in the northern hemisphere and to their left in the southern hemisphere. Winds actually blowing over any area are the resultant of gradient force and Coriolis force. Because of this, it will be observed that:

- Winds blow spirally inwards towards a depression (LP area surrounded by areas of HP), anti-clockwise in the NH and clockwise in the SH.

- Winds bow spirally outward from the centre of an anti-cyclone (HP area surrounded by areas of LP), clockwise in the NH and anticlockwise in the SH.





SOUTHERN HEMISPHERE

In the foregoing figures, G represents Gradient force, C represents Coriolis force and W represents the resultant wind. The angle of indraft, or the angle that the actual wind direction makes with the isobars, depends on:

1. **Gradient force**: This in turn depends on pressure gradient - the greater the pressure gradient, the greater the gradient force & vice versa.

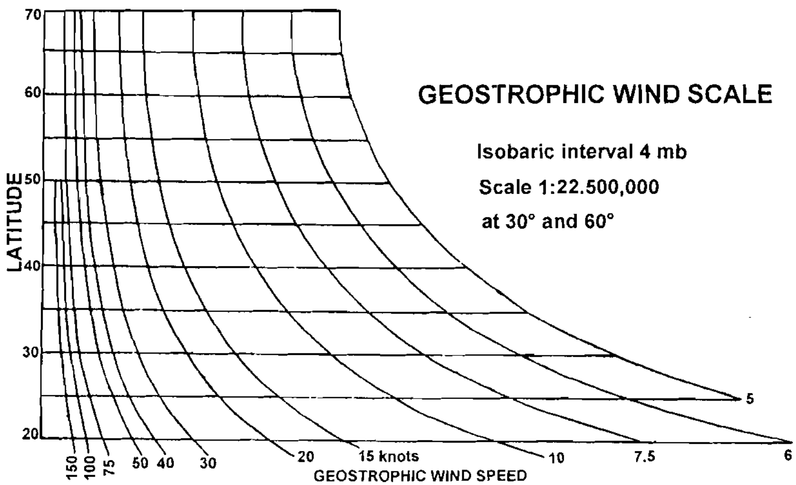
2. **Latitude**: The greater the latitude, the greater the Coriolis force and vice versa.

3. **Friction:** Greater friction is experienced by wind when blowing over land surface than when blowing over sea surface.

A rough thumb rule whilst predicting the wind direction is to make the angle of indraft about 30° over land and about 10° over sea, the difference being due to differing values of friction over land and over sea. However, this thumb rule should not be applied in the case of severe depressions or Tropical Revolving Storms because of the appearance of a new force called cyclo-strophic force or centrifugal force which is discussed later in a chapter bearing that name.

Prediction of wind speed

On a weather map, a geostrophic wind scale is provided, drawn to the scale of the map. The distance between two consecutive isobars is taken off the weather map by a divider. The divider is then placed on the geostrophic wind scale, both legs on the horizontal line corresponding to the latitude in which the measurement is being made. The left leg of the divider is placed on the margin and the position of the other leg gives the geostrophic wind speed, interpolating as necessary between the curves. For example, on the geostrophic wind scale illustrated, a distance between consecutive isobars on the map equal to 1.65 cm (200 M) in 35° latitude will result in a geostrophic wind speed of about 20 knots. Because of friction between the air and the earth's surface, the surface wind speed over land would be about half the geostrophic wind speed & over sea, about two-thirds.



If a geostrophic wind scale, drawn to the scale of the map, is not available, the following table may be used to obtain geostrophic wind speed.

Geostrophic wind speeds in excess of 130 knots rarely occur, if at all. Both, the geostrophic wind scale and table, given in this chapter, are meant for straight or gently curving isobars. If the curvature is appreciable, corrections for that would be necessary, based on latitude and radius of curvature, but they are beyond the scope of this book which is intended for officers of merchant ships.

Distance between consecutive 4 mb isobars	LATITUDE									
M	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
20							132	122	118	115
25	Geostrophic wind speed					121	105	98	93	92
30	In Knots				119	101	88	81	79	77
35				131	102	86	75	70	67	66
40				115	89	75	66	61	59	57
45				102	80	67	59	54	52	51
50			136	92	72	60	53	49	47	46
60			113	77	60	50	44	41	39	38
80			85	57	45	38	33	31	29	29
100		133	68	46	36	30	26	24	24	23
150		89	45	31	24	21	18	16	16	15
200		67	34	23	18	15	13	12	12	11
300		44	23	15	12	10	9	8	8	8

The following are a few important definitions concerning wind:

1. **Sea (waves)**: Is the name given to waves, on the sea-surface, created by wind that is presently blowing. The height of sea disturbance, *in open waters*, is directly related to the wind force as per Beaufort scale.

2. **Swell**: Is the name given to waves, on the sea-surface, formed by wind that has subsequently stopped blowing or is blowing at some other place quite far away. Swell travels quickly and has been known to have been felt over 1000 miles away. Swell travels radially outwards from the centre of a storm and is usually the first indication of the presence and bearing (direction) of a TRS.

3. **Gust**: A gust of wind is the sudden increase of wind speed for a very short period of time. It is usually caused by terrestrial obstructions to the flow of wind.

4. **Squall**: A sudden increase of wind force by at least 3 stages of the Beaufort scale (increase of at least 16 knots wind speed), reaching upto at least force 6 (22 knots) and lasting at least one minute. A squall is different from a gust of wind by its greater duration.

5. **Veering:** A clockwise change of direction from which the wind is blowing e.g., from N to NE, from S to SW, from W to NW, etc.

6. **Backing**: An anticlockwise change of direction from which the wind is blowing e.g., from N to NW, from E to NE, from SW to S, etc.

Buys Ballot's Law

Face the true wind and the low-pressure area will be on your right in the Northern Hemisphere, left in the Southern Hemisphere.

Caution when applying Buys Ballot's Law

1. **Near the equator**: Buys Ballot's law should not be applied within a few degrees of the equator. This is because Coriolis force is negligible at the equator and therefore the winds blow directly across the isobars from HP to LP areas.

2. **In the vicinity of land**: The wind experienced may not be the free unobstructed wind. It may be wind deflected by the land.

[Continued on next page]

The Beaufort Wind Scale

In 1805/6, Commander Beaufort, subsequently Rear Admiral Sir Francis Beaufort, of the British Navy, devised a scale for estimating wind speed at sea based on observations of the sea surface and the effect the wind had on the sails of a war ship. He, therefore, used the words 'Wind Force' and not 'Wind Speed'. As a sailor, Beaufort felt there were 13 levels of behaviour that mariners could recognise in a sailing man-of-war and numbered them 0 to 12. In 1838, the Beaufort wind force scale was made mandatory for log entries in all ships of the Royal Navy.

Subsequently, the WMO (World Meteorological Organisation) accepted the Beaufort Wind Scale and internationally standardised the probable wind speeds attached to each Beaufort number.

The Beaufort wind force, and hence the wind speed, may be judged by the appearance of the sea only in open, deep waters where the wind has considerable fetch (hundreds of miles of flow unaffected by land features). In harbours, rivers, lakes, and other areas close to land, the actual wind speed may be much higher than that estimated by the appearance of the water surface because of two important points:

1. The lag effect between the wind getting up and the sea increasing should be borne in mind.

2. Fetch, depth, swell heavy rain and tide effects should be considered when estimating wind force from appearance of sea.

Beaufort Wind Force	Mean Wind Speed in knots	Limits of Wind Speed In knots	Beaufort Scale of Wind Force		Probable Height of Waves in m *	Probably Maximum Height of Waves in m *
	Measured at height of 10 m above sea level		Descriptive Term	Sea Criterion		
0	00	< 1	Calm	Sea like a mirror.	—	—
1	02	1-3	Light air	Ripples with the appearance of scales are formed, but without foam crests.	.1	.1
2	05	4-6	Light breeze	Small wavelets, still short but more pronounced, crests have a glassy appearance and do not break	.2	.3
3	09	7-10	Gentle breeze	Large wavelets, Crests begin to break. Foam of glassy appearance. Perhaps scattered white horses.	.6	1
4	13	11-16	Moderate breeze	Small waves, becoming longer; fairly frequent white horses.	1	1.5
5	18	17-21	Fresh breeze	Moderate waves, taking a more pronounced long form; many white horses are formed. (Chance of some spray.)	2	2.5
6	24	22-27	Strong breeze	Large waves begin to form; the white foam crests are more extensive everywhere. (Probably some spray.)	3	4
7	30	28-33	Near gale	Sea heaps up and white foam form breaking waves beings to be blown in streaks along the direction of the wind.	4	5.5
8	37	34-40	Gale	Moderately high waves of greater length; edges of crests being to break into spindrift. The foam is blown in well-marked streaks along the direction of the wind.	5.5	7.5

9	44	41-47	Strong gale	High waves. Dense streaks of foam along the direction of the wind. Crests of waves begin to topple, tumble and roll over. Spray may affect visibility.	7.5	10
10	52	48-55	Storm	Very high waves with long overhanging crests. The resulting foam in great patches is blown in dense white streaks along the direction of the wind. On the whole the surface of the sea takes a white appearance. Tumbling of the sea becomes heavy & shock-like. Visibility affected.	9	12.5
11	60	56-63	Violent storm	Exceptionally high waves. (Small and medium-sized ships might be for a time lost to view behind the waves.) The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility affected.	11.5	16
12†	68†	64-71†	Hurricane	The air is filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.	14	>14

* These columns show roughly what may be expected in the open sea, remote from land. In enclosed waters, or when near land with an off-shore wind, wave heights will be smaller, and the waves steeper.

† The scale actually extends to Force 17 (up to 118 knots), but Beaufort Force 12 is the highest that can be identified visually from the state of the sea.

NOTES:

1. It may be difficult to estimate wind force by the sea criterion. The wind force & direction may therefore be estimated by other means, e.g., the 'feel' of the wind or the smoke, making due allowance for course and speed of ship.
2. The lag effect between the wind getting up and the sea increasing should be borne in mind.
3. Fetch, depth, swell heavy rain & tide effects should be considered when estimating wind force from appearance of sea.

THE BEAUFORT WEATHER NOTATION

The following are the symbolic, Beaufort letters used for making entries in Bridge logbooks and Weather logbooks:

Weather	Beaufort letter	Weather	Beaufort letter
Blue sky (0 - 1/8 clouded)	b	Overcast sky (whole sky covered – unbroken cloud)	o
Sky partly clouded (1/8 - 3/8)	bc	Passing showers	p
Cloudy (> 3/8 clouded)	c	Squally weather	q
Drizzle	d	Rain	r
Wet air (without precipitation)	e	Sleet	rs
Fog	f	Snow	s
Gale*	g	Thunder	t
Storm#	G	Thunderstorm with rain	tlr
Hail	h	Thunderstorm with snow	tls
Precipitation in sight of ship	jp	Ugly threatening sky	u
Line squall	kq	Unusually good visibility	v
Storm of drifting snow	ks	Dew	w
Sandstorm or dust storm	kz	Hoarfrost	x
Lightning	l	Dry air	y
Mist	m	Haze	z

Notes:

(1)	A capital letter indicates great intensity e.g., R = heavy rain.
(2)	The suffix "o" denotes very slight intensity e.g., r_o = slight rain.
(3)	The prefix "i" denotes intermittent e.g., if = intermittent fog, ir = intermittent rain.
(4)	The prefix "p" indicates "shower of" e.g., pR = shower of heavy rain.
(5)	Repetition denotes continuity e.g., ss = continuous snow, dd = continuous drizzle.
(6)	A solidus distinguishes present weather from that of the previous hour e.g., o/d_o = overcast after slight drizzle.
(7)	*Gale = Beaufort force 8 or 9 maintained for not less than 10 minutes.
(8)	#Storm = Beaufort force 10 maintained for period of not less than 10 minutes

DESCRIPTIVE TERMS FOR STATE OF SEA

State number*	Average wave height (metres)	Descriptive term
0	0	Calm (glassy)
1	0 - 0.1	Calm (rippled)
2	0.1 - 0.5	Smooth (wavelets)
3	0.5 -1.25	Slight
4	1.25 - 2.5	Moderate
5	2.5 - 4.0	Rough
6	4.0 - 6.0	Very rough
7	6.0 - 9.0	High
8	9.0 - 14.0	Very high
9	Over 14.0	Phenomenal

Descriptive terms for height of swell

<2m high	low
2 – 4m	moderate
>4m	heavy

Descriptive terms for length of swell

<100m long	short
100 – 200m	average
>200m	long

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* The state number is not generally used in bridge logbooks or weather logbooks on Indian ships.

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CHAPTER 8

TRUE AND APPARENT WIND

The direction and force of wind experienced on a moving ship is the apparent wind. This is the resultant of true wind and ship's *reversed* movement (correct speed but opposite course). This is illustrated in the following simple examples:

Imagine a vessel steaming 000° (T) at 20 knots.

1. If there was no true wind at all (calm), the observer on the vessel would feel the apparent wind coming ***from*** North at 20 knots. Actually, the air is still but the ship's movement causes this apparent wind to be experienced.
2. If the true wind was coming from North at 10 knots, the apparent wind, to an observer on the vessel, would be from North at 30 knots.
3. If the true wind was coming from South at 12 knots, the apparent wind, to an observer on the vessel, would be from North at 8 knots.
4. If the true wind was coming from South at 20 knots, the apparent wind, to an observer on the vessel, would be nil (calm).
5. If the true wind was coming from South at 24 knots, the apparent wind, to an observer on the vessel, would be from South at 4 knots.

In the foregoing examples, results were easily obtained directly. In other cases, a simple triangle of forces would have to be drawn to obtain the results. This method is illustrated later, in this chapter. For making log entries and weather reports, it is true wind that is required, not apparent wind.

Methods of estimating true wind at sea

Out in open sea, the direction and force of true wind can be judged easily. The direction of true wind would be at right angles to the line of waves. This is, however, difficult to judge if both sea and swell are from different directions. The force of true wind is judged by the appearance of the sea and comparison with a 'State of sea card' or a meteorological book that gives photographs of the sea surface for various values of wind force. The force is expressed in numbers of the Beaufort wind scale, described in the previous chapter.

In restricted waters (harbours, estuaries etc.), the wind force estimated by the appearance of the sea would be less than the true wind force because the wind has restricted fetch (does not have an open and free stretch to influence the sea surface as much as in the open sea).

Another important thing to bear in mind, when estimating wind force, is the time lag between the increase of wind force and the corresponding increase of sea disturbance.

PROBLEMS ON TRUE & APPARENT WIND

The solution of problems on true and apparent wind involves the application of the triangle of forces. However, it is simplified by using the thumb rules given below:

Consider a triangle OAT where,
AT is the course and speed of the vessel
OT is the direction and speed of true wind
OA is the direction & speed of apparent wind.

Knowing any two of the above, the third can be found by simple construction, somewhat similar to radar plotting, as illustrated in the following examples.

Important note: Wind is named by the direction from which it comes.

Worked example 1:

Course 045° speed 15 knots. Apparent wind 100° at 20 knots. Find the direction and speed of true wind.

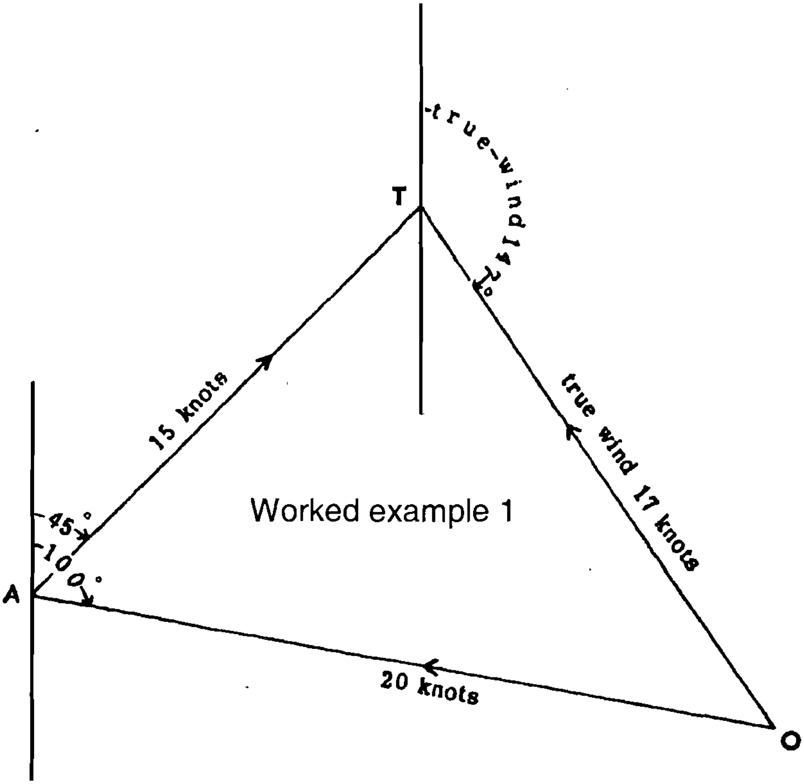
Draw a line representing North-South and take any point A on it. At A, draw an angle equal to the course (045° in this case) and cut off AT equal to ship's speed (15 knots in this case), using any convenient scale. AT now represents the course and speed of the vessel.

At A, draw an angle equal to the apparent wind (100° in this case) and cut off AO equal to the apparent wind speed (20 knots in this case), using the same scale. OA now represents the apparent wind.

Join OT and this represents the true wind. Using the same scale as before, convert distance OT into knots. To obtain the direction of true wind, draw a North-South line through T and read off the angle between it and OT.

The true wind in this case is 147° at 17 knots.

Note: North-South lines are to be drawn through A and T, **never** through O.



Worked example 1

Worked example 2:

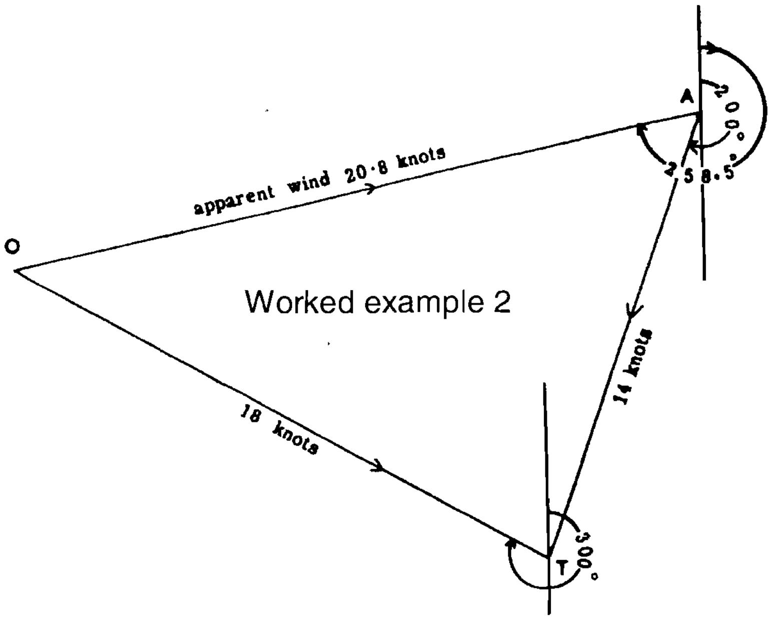
Course 200° speed 14 knots. True wind 300° at 18 knots. Find the direction and speed of apparent wind.

Draw a North-South line and take any point A on it. Draw AT equal to course and speed of vessel (200° at 14 knots), using any convenient scale.

At T draw a North-South line and insert the true wind OT (300° at 18 knots), using the same scale.

Join OA, which now represents the apparent wind. Using same scale, convert distance OA into knots.

The angle that OA makes with the North-South line at A is the direction of the apparent wind.
Apparent wind in this case is 258.5° at 20.8 knots.

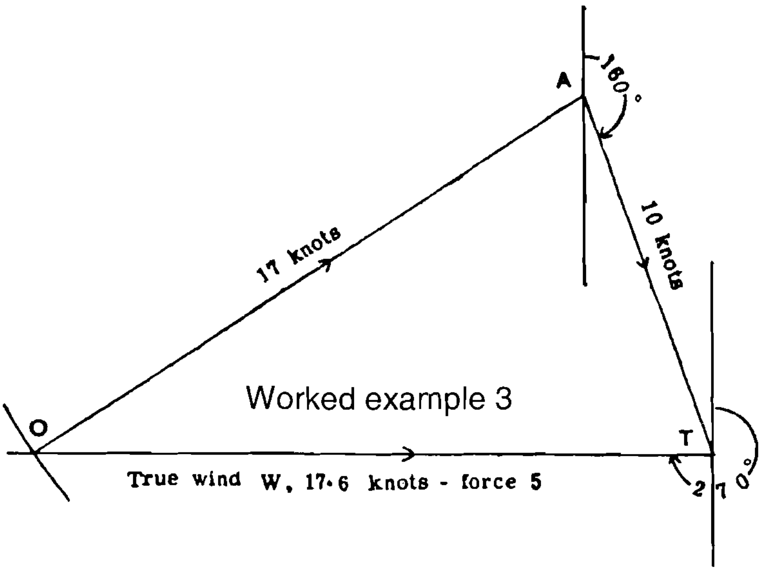


Worked example 3:

Course 160° speed 10 knots. Direction of wind (obtained by observing line of waves) was 270°. Wind speed by shipboard anemometer was 17 knots. What direction and force of wind is to be entered into the ship's logbook?

Note: (1) A shipboard anemometer measures speed of apparent wind.
(2) The direction of wind obtained by observing the line of waves is the direction of true wind.

Draw AT = Course & speed = 160° at 10 knots. At T, draw a North-South line and insert direction of true wind, 270°. Centre A, radius = apparent wind speed of 17 knots, cut off the arc AO. OA now represents the apparent wind and OT, the true wind. Distance OT converted into knots is the speed of true wind.
Log entry for wind in this case: West, Force 5.



Worked example 3

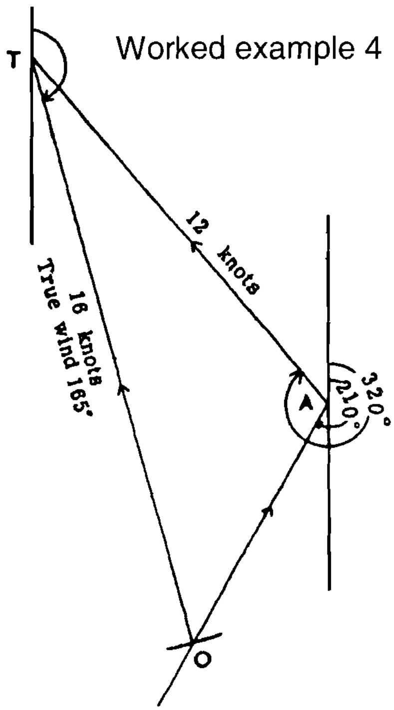
The angle that OA makes with the North-South line at A is the direction of apparent wind but this is not asked in this case.

NOTE: To convert knots into Beaufort numbers and vice versa, use the Beaufort wind scale given in the ship's logbook or any meteorological publication. In the examination hall, use the "Ship's Code and decode book" supplied there. The Beaufort wind scale is also given in the previous chapter of this book.

Worked example 4:

Course 320° speed 12 knots out in open sea. Wind force 4 (16 knots), estimated by appearance of the sea surface. Smoke from the funnel was observed to be blowing to 030°. What entry is to be made in the weather report regarding wind direction and speed?

NOTE: (1) Wind speed/force obtained by appearance of the sea is true wind speed/force.
(2) If smoke from the funnel is blowing to 030°, apparent wind is coming from 210°.



Draw AT = course and speed (320° at 12 knots). At A draw a North-South line and then an angle of 210° to it, to represent the direction of the apparent wind. With centre T, radius equal to the true wind speed of 16 knots, cut off arc TO. OT now represents the true wind and OA, the apparent wind.

At T, draw a North-South line and the angle between it and OT is the direction of true wind.

The angle between OA and the North-South line at A, is the direction of the apparent wind but this is not asked in this case.

Entry in the weather log for wind is 165° at 16 knots.

Examples for exercise

1. On a vessel steaming 346° at 15 knots, the apparent wind was observed to be NW at 22 knots. Find the direction and speed of the true wind. (Answer 275° at 12 knots).

2. From a vessel on a course of 243° at 12 knots, the apparent wind was observed to be 120° at 15 knots. Find the direction and speed of the true wind. (Answer 095° at 23.8 knots).

3. On the monkey island of a ship doing 117° at 16 knots, an anemometer and wind vane showed 15 knots and 036°. Find the direction and speed of wind required to be mentioned in the weather report. (Answer 344.5° - 20 knots).

4. A vessel is steaming 267° at 14 knots through a true wind blowing from SE at 11 knots. Find the direction and speed of the apparent wind experienced. (Answer 216° at 10.5 knots)

5. A vessel is proceeding on a course of 063° at a speed of 18 knots. If the wind direction by observation of the line of waves was 175° and wind speed estimated by the appearance of the sea was 30 knots, state what would be the apparent wind direction & speed.
   (Answer 139.5° at 28.6 knots).

6. On a course of North at 11 knots, find the apparent wind direction and speed if a true Easterly wind of 14 knots was blowing.
   (Answer 052° at 17.8 knots).

7. Course 308° speed 14.5 knots. Direction of wind by observing line of waves - NNE. Speed of wind by shipborne anemometer - 18 knots. State what direction and speed of wind is to be entered in the logbook. State also, the direction towards which the funnel smoke will blow. (Answer NNE - 7.5 knots, force 3. Funnel smoke will blow towards 151.5°).

8. On a course of 154° at 13 knots, an anemometer on the bridge showed a wind speed of 32 knots. The direction of true wind was observed to be WSW. What entry is to be made in the weather report with respect to wind direction and speed? If an observer on the vessel threw up a piece of paper, in which direction would it fly off? (True wind = WSW @ 29.6 knots. Weather logbook entry: dd = 25, ff = 30. Piece of paper will blow towards 043.5°).

9. Out in open sea, a vessel estimated the wind to be the upper limit of force 7 (33 knots), by the appearance of the sea surface. Her course was 076° and speed, 17 knots. The funnel smoke was blowing towards 352°. State what entry is to be made in the logbook regarding wind. (Answer 203° force 7 [33 knots]).

10. A vessel steaming due East at 19 knots in open sea, observes the sea surface and estimates the wind force to be the lower limit of force 6 (22 knots). A handkerchief held up was observed to blow towards South. State what entry is to be made in the weather report regarding wind direction and speed.
(Answer 300° at 22 knots).

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CHAPTER 9

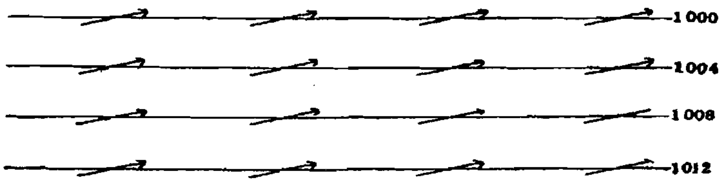
THE SEVEN BASIC

ISOBARIC PATTERNS

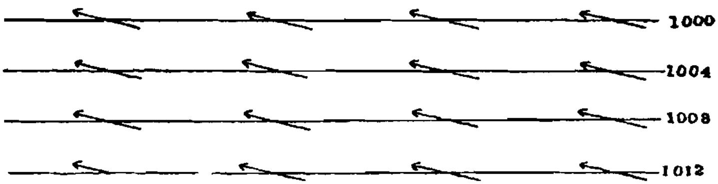
1. Straight isobars

Straight isobars are said to exist when the isobars run straight and nearly parallel for a few hundred miles. The pressure gradient is usually low, resulting in low wind speeds. Wind direction and force remain constant so long as the isobars remain unchanged. The weather associated with straight isobars cannot be defined as it depends on the properties of the air mass in which these isobars exist.

NORTHERN HEMISPHERE

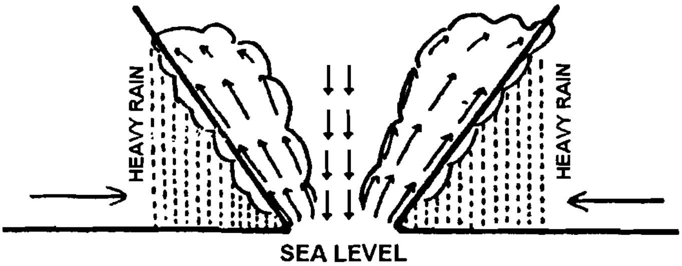


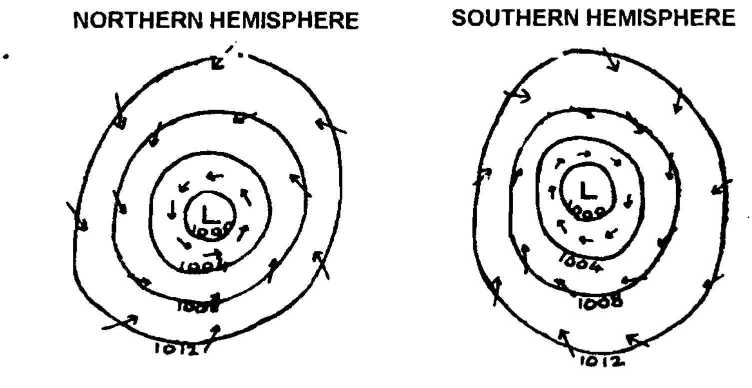
SOUTHERN HEMISPHERE

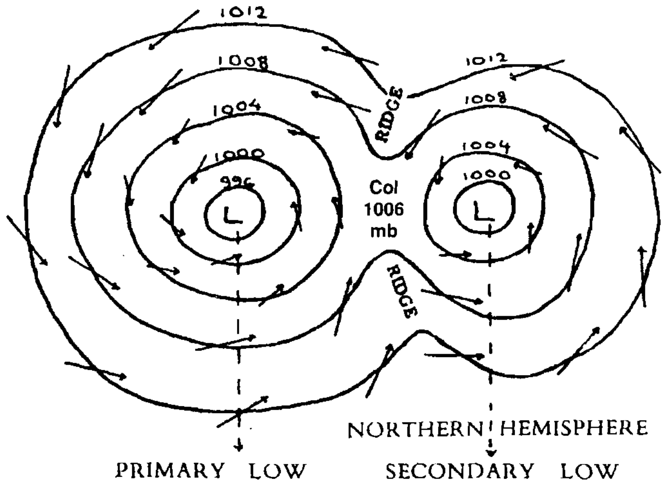


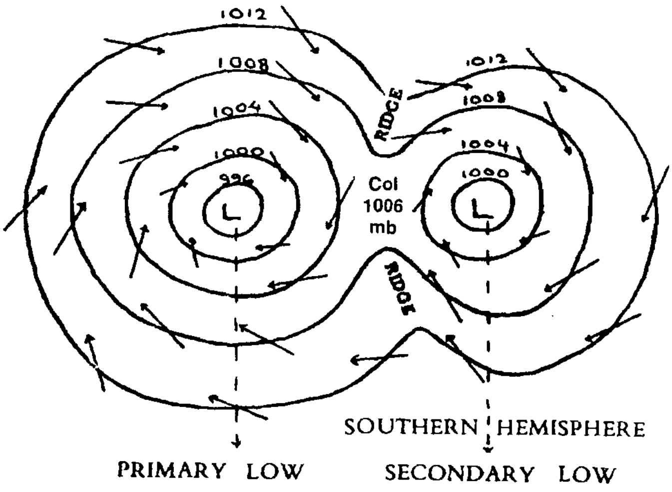
2. Cyclone or low

Cyclone or low is an area of low pressure surrounded by areas of high pressure. The isobars form closed shapes. The winds blow spirally inwards, anti-clockwise in the northern hemisphere and clockwise in the southern hemisphere. The pressure gradient is usually high, resulting in strong winds. A low is an area of convergence of air. On reaching the centre, the air moves up as a strong upward current, resulting in cumulus or cumulonimbus clouds of very high vertical extent and heavy precipitation. Over the actual centre of the low, a thin downward stream of air exists, where a patch of blue sky may be seen.









A cyclonic pattern of isobars is called a **low** or depression if the wind speed is 33 knots or less, a **cyclonic storm** if the wind speed is from 34 to 47 knots and a **severe cyclonic storm** if the wind speed is 48 knots or over. For further details, see Chapter titled 'Tropical Revolving Storms'.

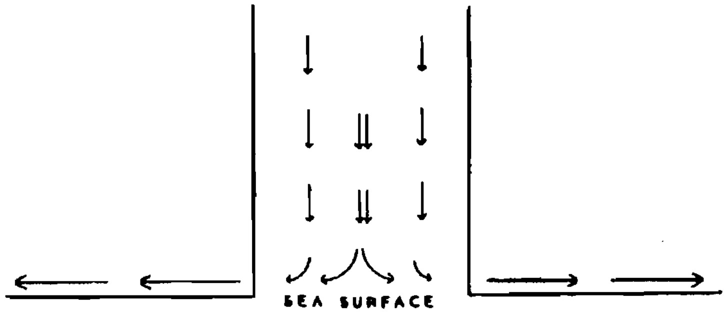
As mentioned above, a low is a sign of bad weather - strong winds, clouds, precipitation, etc.

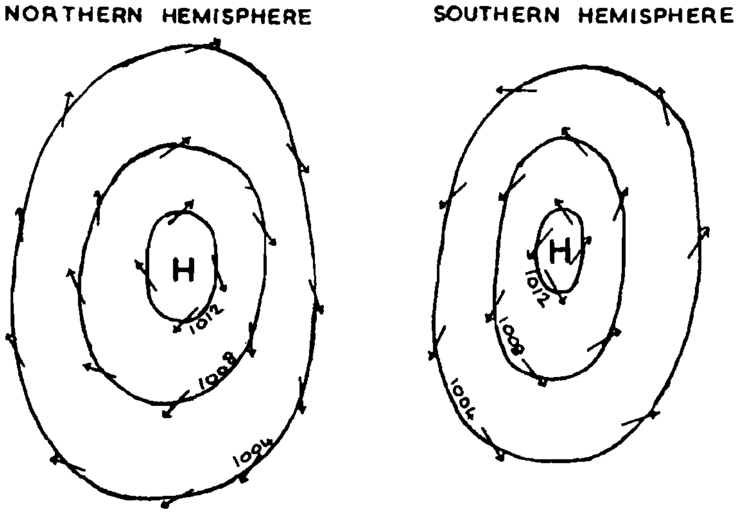
3. Secondary cyclone or secondary low

Sometimes a low is closely followed by another, within its pattern of isobars (see accompanying figure). The first one is called the primary and the second one, the secondary. The latter is so named only because it formed later but it possesses all the qualities of the primary and may either fill up and disappear or it may intensify and swallow up the primary.

4. Anticyclone or high

Anticyclone or high is an area of high pressure surrounded by areas of low pressure. The isobars form closed shapes. The winds blow spirally outwards, clockwise in the northern hemisphere and anti-clockwise in the southern hemisphere. The pressure gradient is usually low resulting in low wind speeds. An anticyclone is an area of divergence of air at sea level. This outflow of air is balanced by a downward current of air at the centre. This descending column of air warms up adiabatically and becomes relatively drier and drier as it descends (see under the heading of 'Relative humidity' in chapter 3). There is a total absence of any cloud or precipitation over the anticyclone. An anticyclone is, therefore, a sign of good weather - light winds, no clouds (blue sky), no precipitation, good visibility, etc. However, as the subsiding dry air reaches sea level and blows spirally outwards, quick evaporation takes place and, if the temperature of the sea surface is quite low, mist or fog may form on the outer fringes of the anticyclone. Even in such cases, visibility at the centre will be good.





Warm and cold anticyclone: If the descending air originally came from a very cold source, it would be colder than the surrounding air, level for level, and also at sea level - it is then called a cold anticyclone.

One example of a cold anticyclone is the high over Siberia during northern winter (see map in chapter titled 'General pressure and wind distribution').

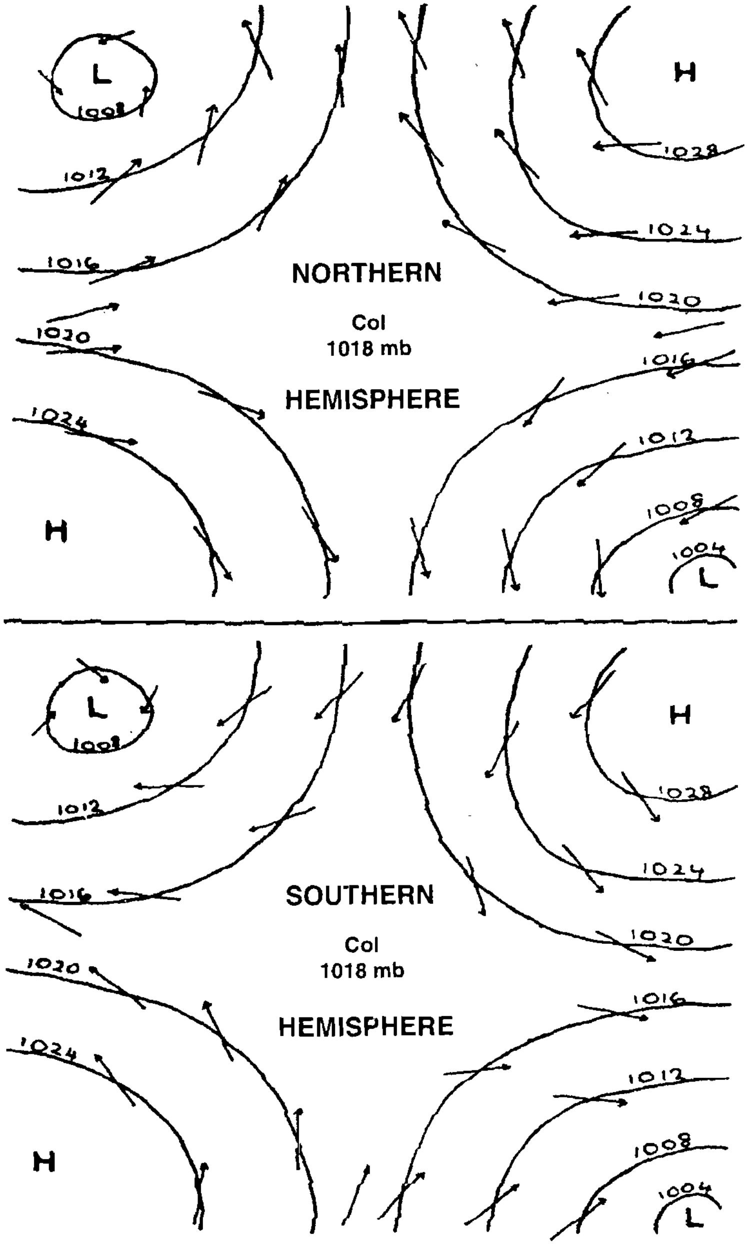
If the descending air originally came from a warm source, it would be warmer than the surrounding air, level for level, and also at sea level - it is then called a warm anticyclone. Examples of warm anticyclones are the permanent highs of 30°N and 30°S at the centres of large oceans (see map in chapter titled 'General pressure and wind distribution').

5. Col

A Col is an area between two highs and two lows situated alternately (see accompanying figure). Light variable winds are experienced but not for long. Sudden change of weather is likely. Relative humidity is fairly high and lightning may be seen. A Col may be situated between a primary low and secondary low as shown in the figure under 'Secondary Low' or it may be situated at the boundary between two different air masses. In the latter case, the change of weather, especially temperature, will be even more drastic. No definite pattern of weather is associated with a Col. Fog may be experienced in autumn. In summer over land, thunderstorms are frequently experienced.

6. Ridge or wedge

A ridge or wedge is an area of high pressure jutting into areas of low pressure. The isobars are curved, with the high pressure inside, and are generally far apart. They do not necessarily form closed shapes. A ridge may form by itself or it may be the outer fringes of an anticyclone far away.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Col
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HEMISPHERE
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1012
1016
1020
1024
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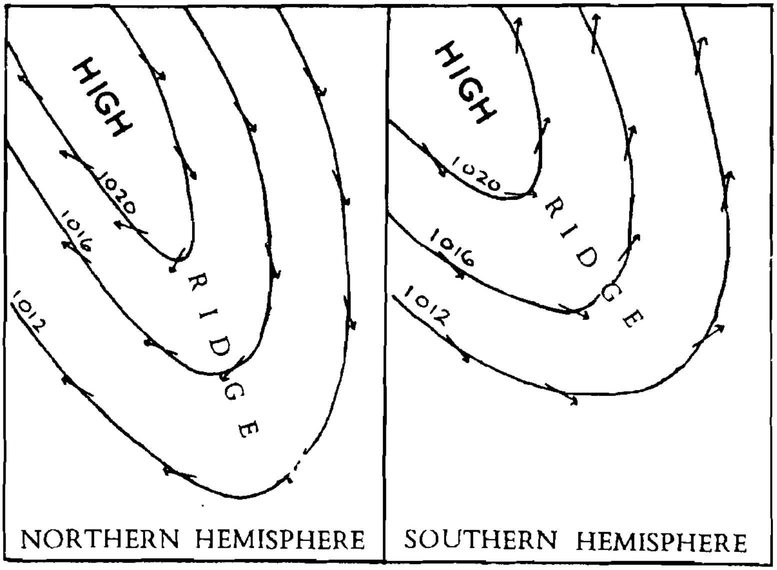
H
1028
1024
1020
1016
1012
1008
1004
L
SOUTHERN
Col
1018 mb
HEMISPHERE

The weather associated with a ridge is like that of an anticyclone - no precipitation, light winds, no clouds.

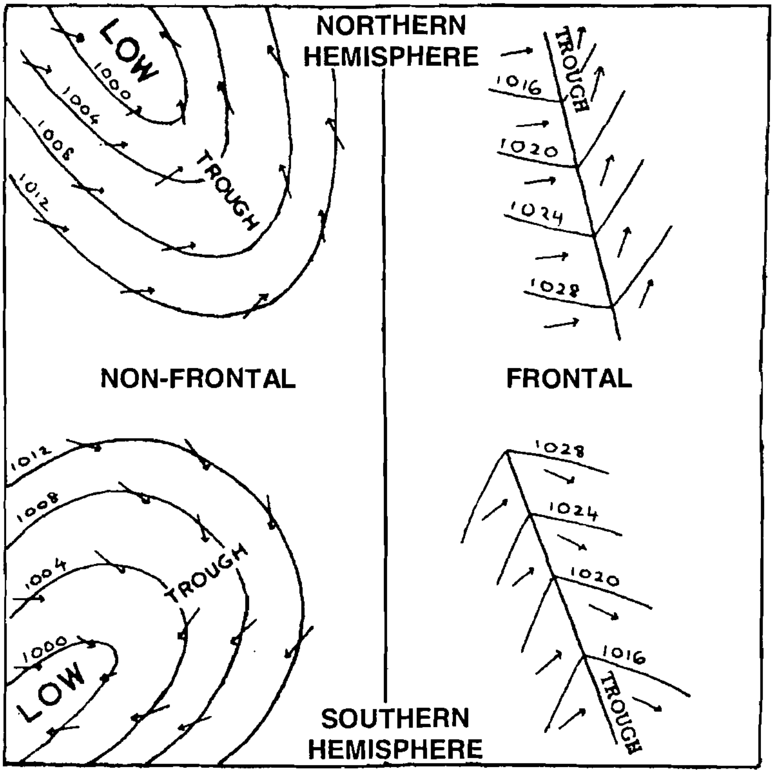
A ridge is also experienced between a primary low and its secondary as shown in the figure under the heading of 'Secondary low'. In such a case, the good weather associated with it will be very short lived - a couple of hours only.



7. Trough

A trough is an area of low pressure jutting into areas of high pressure. The isobars are curved, with the low pressure inside, but they do not form closed shapes. The pressure gradient is fairly high resulting in strong winds. The winds blow from the high pressure areas towards the areas of low pressure, being deflected to the right in the NH, and left in the

SH, by Coriolis force. Bad weather is associated with a trough. Before the trough, pressure falls and weather deteriorates. After the passage of a trough, pressure rises and weather improves.



There are two forms of trough:

Non-frontal trough: In this case, the isobars curve gently (change direction gradually). When a non-frontal trough passes over an observer, the wind veers gradually in the NH and backs gradually in the

SH. The "U" of the non-frontal trough always points towards the equator.

Frontal trough: A frontal trough exists at the boundary between two different air-masses. The 'V' formed by the isobars always points towards the equator. On crossing a frontal trough, the isobars change direction suddenly by about 90° - veers in the NH and backs in SH. Squalls may be experienced, accompanied by lightning and heavy precipitation. Since one air-mass is replaced by another, a sudden change of temperature also is experienced on its passage. For further details see chapters titled 'Air-masses and fronts' and 'Frontal depressions'.

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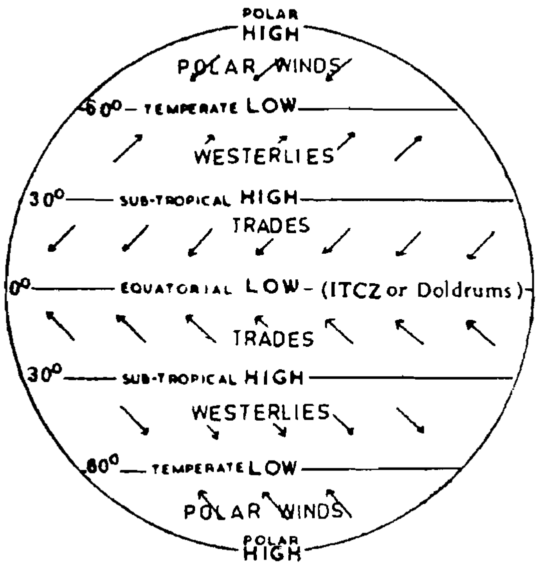
CHAPTER 10

GENERAL PRESSURE AND WIND DISTRIBUTION

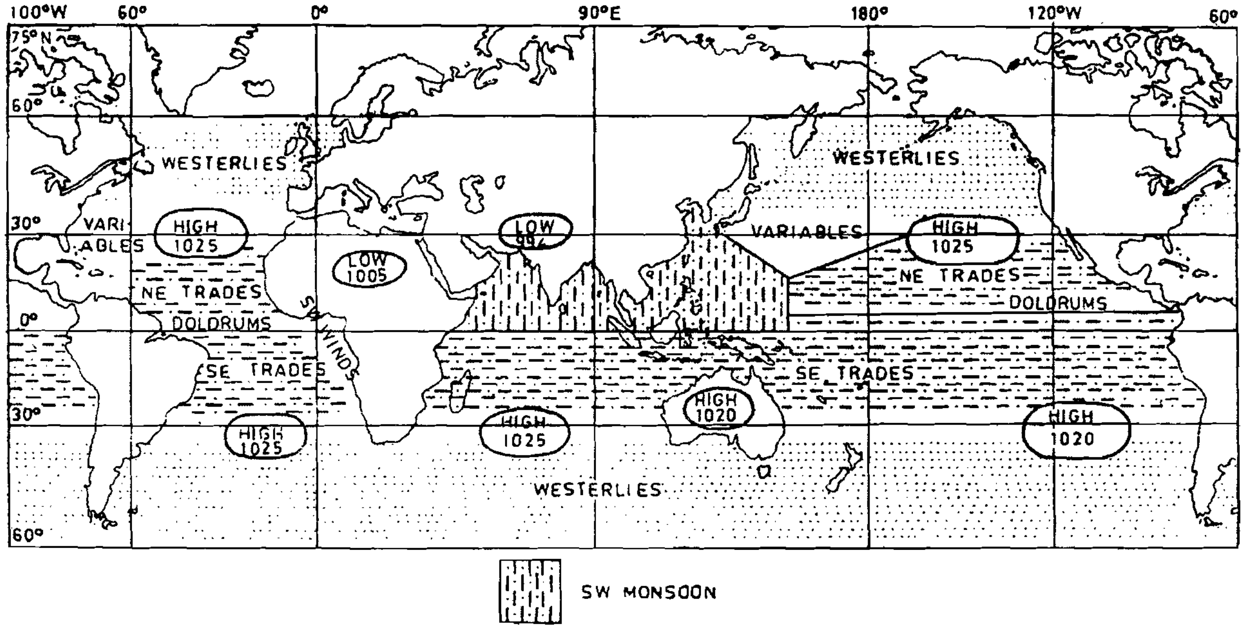
The ideal condition



The above figure gives the general pressure and wind systems which would exist if the entire surface of the earth was water only. Since such is not the case, variation of the above conditions occur over large areas of land.

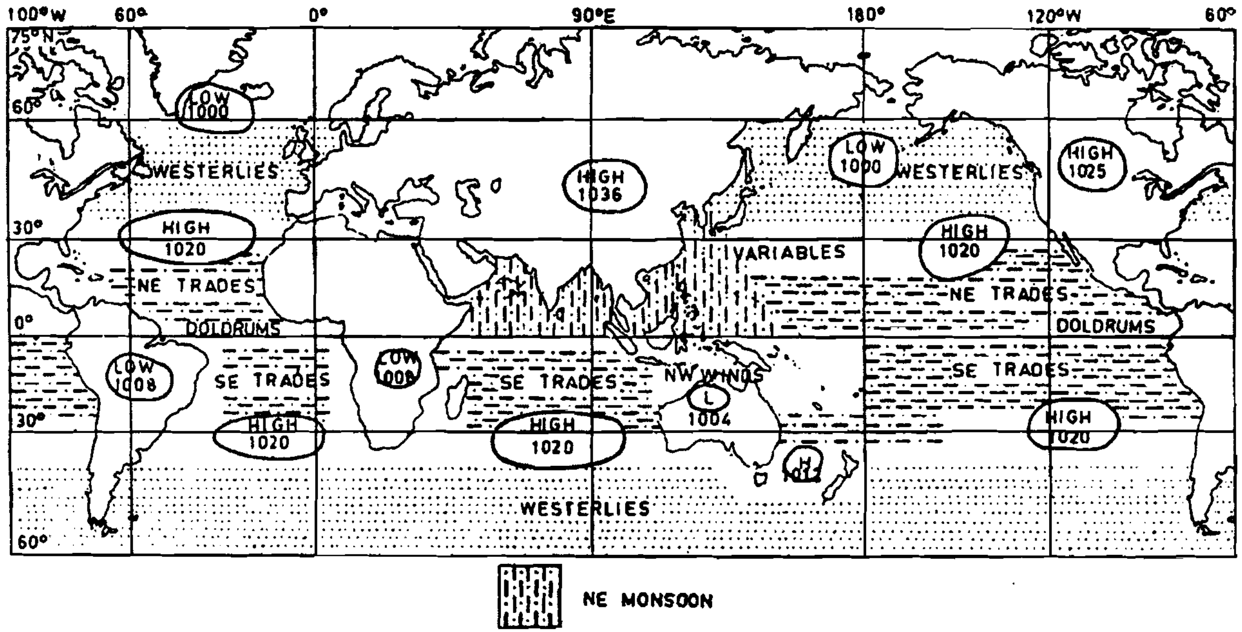
PRESSURE CENTRES & PREVAILING WINDS

NORTHERN SUMMER (JUNE to OCTOBER)



PRESSURE CENTRES & PREVAILING WINDS

NORTHERN WINTER (DECEMBER to APRIL)



The actual situation

During summer, the temperature of the land masses is high and hence the temperature of air in contact with them is also high, resulting in low pressure over them. During winter, the temperature of the landmasses is low and the temperature of the air in contact with them is also low, resulting in high pressure over them.

In short, over large landmasses there is low pressure in summer and high pressure in winter (see the foregoing weather maps). The wind direction and force thus become modified accordingly.

Over large oceans, however, there is not much change in the temperature between summer and winter and there is:

- A permanent low over the equator called the doldrums or Inter-Tropical Convergence Zone (ITCZ);
- Permanent highs at about 30°N & 30°S;
- Permanent lows at about 60°N & 60°S.

The foregoing statements can easily be confirmed and understood by a glance at the foregoing seasonal pressure and wind maps, one for Northern Summer (Southern Winter) and the other for Northern Winter (Southern Summer).

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CHAPTER 11

PERIODIC AND LOCAL WINDS

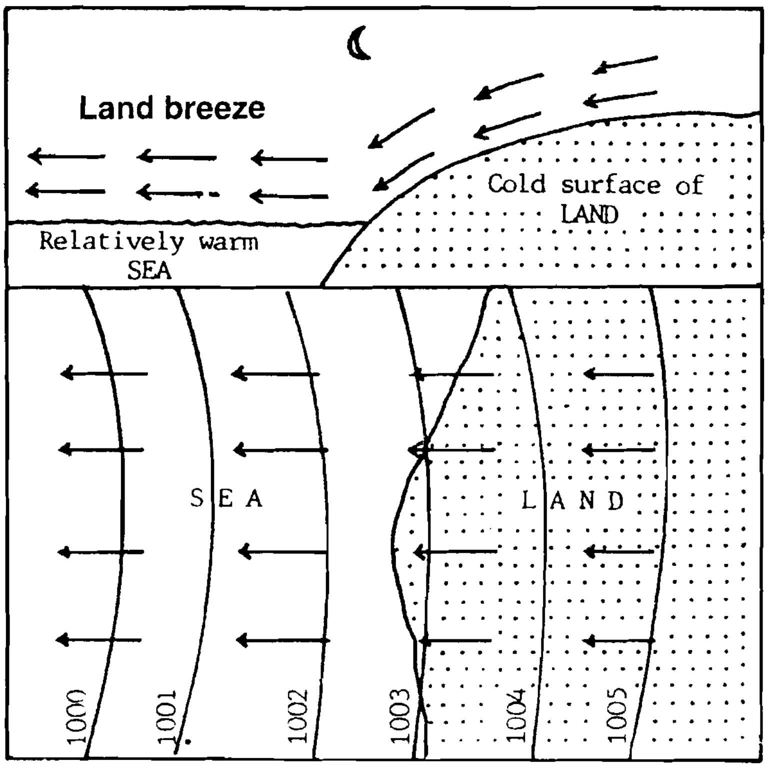
1. Land and sea breezes

Land and sea breezes are the result of the large difference in diurnal range of atmosphere temperature over land and over sea (see chapter1).

Over land, the diurnal range may be as high as 20°C whereas over sea, it is less than 1°C. Land and sea breezes are experienced only where large expanses of both water and land meet. It is because of land and sea breezes that coastal regions do not experience great heat or extreme cold. The effect of land and sea breezes may be felt upto about 20 miles away from the coast. If the hinterland is steep and high, their effect may be felt even beyond 20 miles. The sea breeze is much stronger than the land breeze. Ideal conditions for strong land and sea breezes are a high, dry, rocky or desert coast with no swamps or trees, a weak prevailing wind and a partly cloudy sky.

1.1. Land breeze:

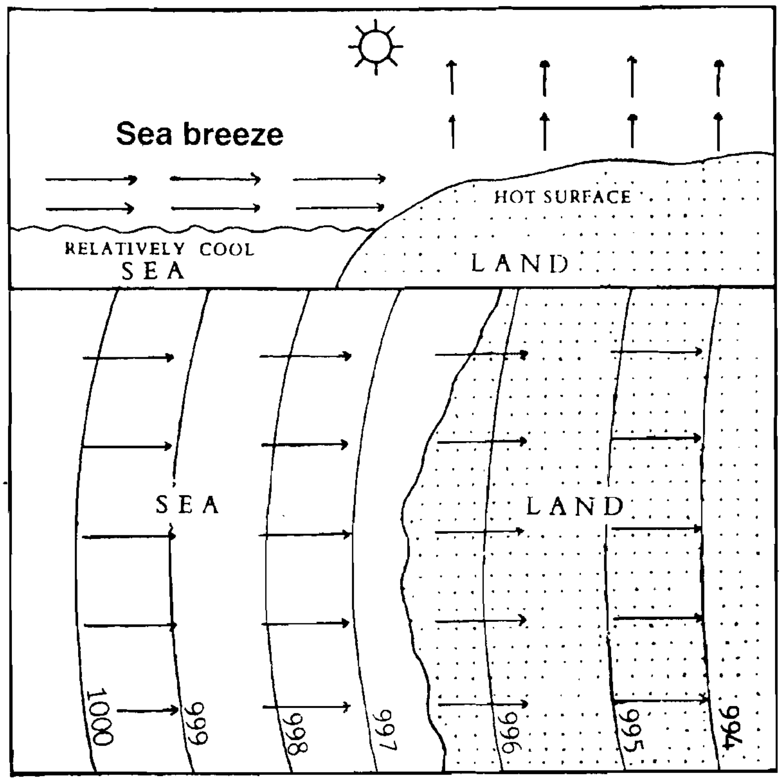
During the night, the land gives off its heat very quickly and the air in contact with it also cools rapidly resulting in a high pressure over the land. The temperature of the sea surface, and hence the temperature of the air in contact with it, remains fairly constant resulting in a relatively low pressure over the sea. The isobars run roughly parallel to the coast.



Since the distance between the HP over land and the LP over sea is small, the wind blows directly across the isobars from the land towards the sea. The land breeze sets in a couple of hours after sunset and blows until about half-hour after sunrise.

1.2. Sea breeze:

During the day, the land gets extremely hot and the air in contact with it gets heated, resulting in a low pressure over land. The temperature of the sea surface, and hence the temperature of the air over it, remains fairly constant resulting in a relatively high pressure over sea. The isobars run roughly parallel to the coast. Since the distance between the high and the low pressure areas is quite small and the pressure gradient is fairly high, the wind blows directly across the isobars from the HP over the sea, towards the LP over land. The sea breeze usually sets in by about 1000 or 1100 hours local time, reaches a maximum force of 3 to 4 by about 1400 hours and dies down about sunset. In rare cases, sea breezes have been detected as far away as 100 miles from the coast.



2. The Monsoons of the Indian Ocean

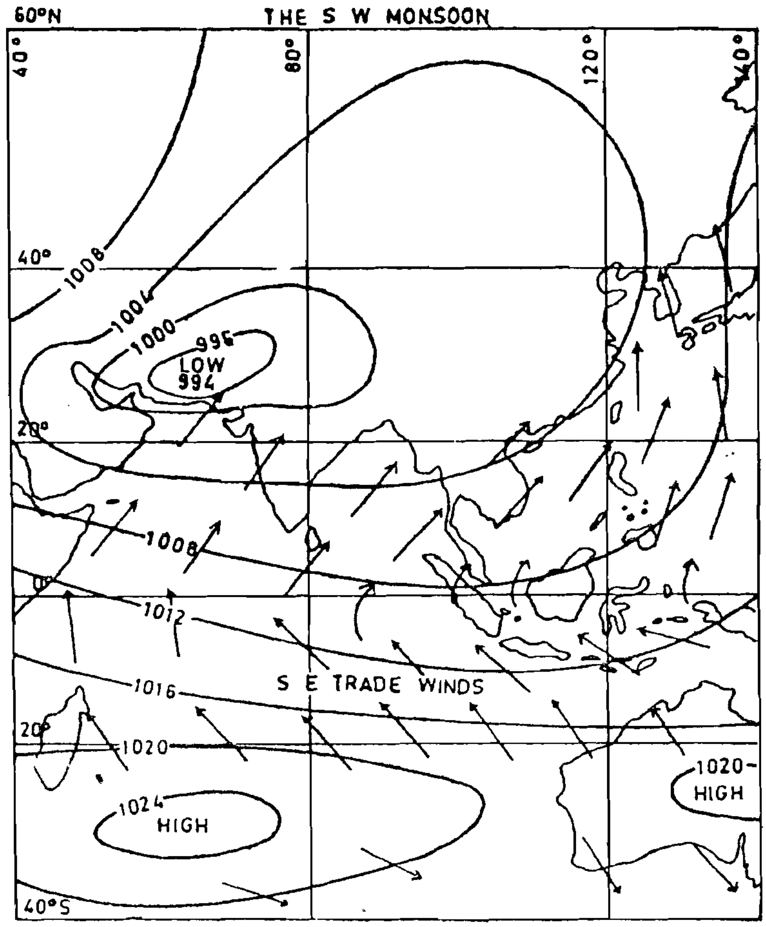
Over the centres of large oceans, there is a permanent low over the equator called the doldrums (around 1012 mb) and a permanent high at about 30°N and 30°S called the sub-tropical high or oceanic high (about 1020 to 1025 mb). As shown in the earlier chapter, the trade winds blow from the oceanic highs, of 30°N & 30°S, towards the doldrums, being deflected by Coriolis force. They are thus NE trade winds in the Northern Hemisphere and SE trade winds in the Southern Hemisphere.

Over large landmasses, the atmospheric pressure is low during summer and high during winter. This seasonal change of atmospheric pressure over large landmasses results in seasonal winds, of which the Monsoons of the Indian Ocean are a classic example.

In weather bulletins, the India Meteorological Department describes the monsoon as weak (Force 3 & less - less than 11 knots), moderate (Force 4 & 5 - 11 to 22 knots), strong (Force 6 & 7 - 22 to 33 knots) and vigorous (Force 8 and over - 34 knots and over).

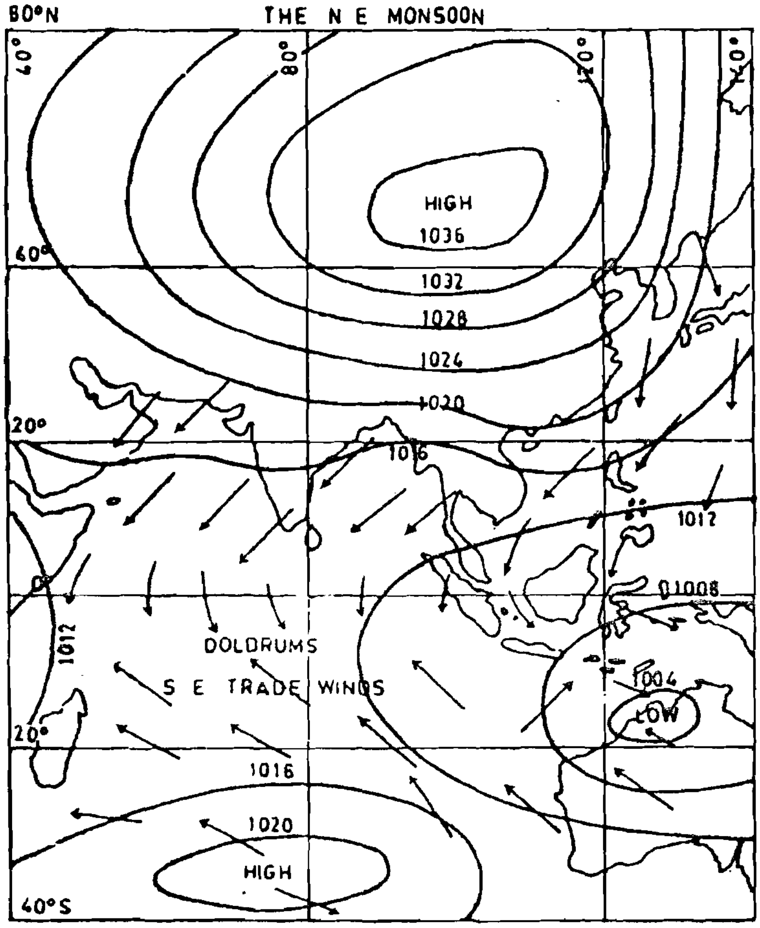
2.1. South West Monsoon:

During northern summer, the continent of Asia gets very warm and the resultant low pressure over it centres over the Thar Desert (NW part of the Indian sub-continent) with a pressure of about 994 mb. This low is considerably lower than the equatorial low of 1012 mb and hence a pressure gradient exists from the equator towards NW India. The SE Trade winds, blowing from the oceanic high of 30°S towards the equatorial low, cross over the equator and blow, as a strong SW wind called the SW Monsoon, towards the low over NW India. The SW direction is the result of gradient force and Coriolis force. The SW Monsoon blows from June to October and brings heavy rain to the West Coast of India, West Bengal, Bangladesh and Myanmar. The wind force is about 7 or 8 in the Arabian Sea and about 6 or 7 in the Bay of Bengal. The same SW Monsoon is also experienced in the China Sea.



2.2. The North East Monsoon:

During northern winter, the continent of Asia gets cold and the resultant high pressure over it centres over Siberia with a pressure of about 1036 mb. The equatorial low of 1012 mb, being oceanic, remains practically unaffected by the change of season.



The anticyclonic winds, around the Siberian high, reach the Bay of Bengal and Arabian Sea as the NE Monsoon with a force of 3 to 4. Heavy rain falls on the East Coast of India. The NE Monsoon blows from December to April.

In the China Sea the pressure gradient is larger, resulting in wind force between 5 and 7. The wind direction in this region is between north and north-east.

3. Katabatic and Anabatic winds

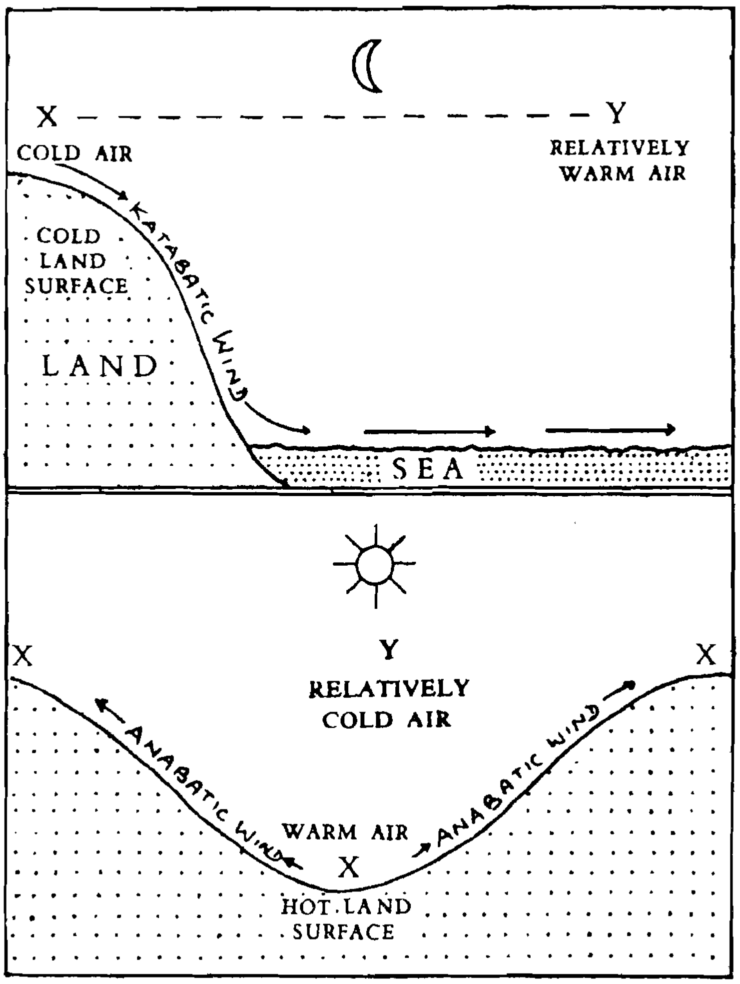
These two types of winds are opposites. Katabatic winds blow downhill, at night, whereas Anabatic winds blow up-hill, during daytime (see accompanying sketches).

3.1. Katabatic wind:

On clear nights, the land surface radiates its heat into space very quickly resulting in a cold layer of air next to the land surface. If the ground is sloping, the air at point X in the figure is colder and hence denser than at point Y, which is at the same horizontal level. Air from point X at the top of the hill starts sliding down due to gravitational force and is called a 'Katabatic wind' (in Greek 'Kata' means 'down' and 'Biano' means 'to move'). If the mountain is high and the slope is steep, Katabatic winds can reach sea level with force 7 or more in a very short while. Because of their sudden onset and great force, they are a menace to small craft and vessels at anchor.

The onset of Katabatic winds cannot be predicted because they have no relationship with isobars - they are caused more by gravitational force than by pressure gradient.

They are frequently experienced in the Adriatic Sea (e.g., Bora, Mistral), off Greenland, in the fjords of Norway and many other places having a high hinterland.



3.2. Anabatic wind:

During daytime, the land surface gets heated quickly, resulting in a layer of warm air next to the land surface. The air at points X in the figure is warmer than at point Y. The relatively colder air at Y subsides into the valley and the warm air, thus displaced from the valley, slides gently up the mountain side. This is called an Anabatic wind (in Greek 'Ana' means 'up' and 'Biano' means 'to move'). Anabatic winds are much weaker than Katabatic winds. They are of no importance to the mariner (navigation in valleys is a landlubber's problem!) but are mentioned here only because they are the direct opposite of Katabatic winds.

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CHAPTER 12

TROPICAL REVOLVING STORMS

A tropical revolving storm is a small area of very low pressure, around which winds of gale force (34 knots or force 8) or more blow spirally inwards, anticlockwise in the Northern Hemisphere (NH) and clockwise in the Southern Hemisphere (SH). In the case of violent tropical revolving storms, wind speeds up to 130 knots have been experienced with occasional gusts up to 150 knots.

1. Terminology (as per India Meteorological Dept.)

Wind speed Kn	*Wind force*	*Term used*
33 or less	7 or less	Depression
34 to 47	8 and 9	Moderate cyclone
48 to 63	10 and 11	Severe cyclone
64 to 119	12 & over	Very severe cyclone
120 and over	Over 12	Super cyclone

2. Great danger to shipping

TRSs in the Atlantic and Pacific are generally more violent than in the Arabian Sea and the Bay of Bengal. In the latter areas, only on rare occasions do wind speeds reach 100 knots.

Nevertheless, TRSs are a great danger to shipping regardless of where they are encountered and require a special study.

The terrible experience of a fleet of ships of the U.S. Navy, over which the eye of a violent TRS passed in December 1944 in the China Sea, is mentioned here briefly:

2.1. Visibility between 0 and 1 kilometre due to spray and torrential rain.
2.2. Inability of vessels to respond to rudder, due to force of wind.
2.3. All deck structures and equipment such as masts, aerials, funnels, davits, boats, ventilators, etc. carried away by wind and sea.
2.4. Loss of all wireless communication facilities. Even verbal communication between people on board nearly impossible due to roaring noise of wind and hammering noise of rain.
2.5. Vessels rolling over 70°, causing large quantities of water to be shipped through various openings, flooding of compartments including the engine rooms, resulting in short circuits, fires and failure of electric power and failure of main engines.
2.6. Loss of 3 destroyers which capsized and sank within a few minutes, taking all hands.
2.7. Loss of about 800 lives.
2.8. Damage to about 29 vessels, of which 10 were serious.
2.9. Irreparable damage/loss to about 150 aircraft with resultant fires.

Considering that naval vessels, being expected to survive the severe punishment of war, are constructed much stronger and more stable than merchant ships, and that they are not subjected to the vagaries of stowage of different types of cargo, one can well imagine the fate of a merchant ship in the above circumstances.

Whenever a vessel is in an area where TRSs are likely to be encountered, careful watch should be kept for the warning signs of an approaching TRS (given at the end of this chapter) and take early evasive action.

3. Local names and seasons

Local names of TRSs in various places, and their likely seasons, are given below. For more detailed information regarding their seasons, frequency of occurrence etc., the appropriate 'Sailing Directions' (also called the 'Pilot Book') of that area should be consulted.

Area	**Name**	**Season**
North Atlantic:		
Western side	Hurricane	June to November
Easter side	Do not occur	
South Atlantic:	Do not occur	
North Pacific:		
Western side	Typhoon or Baguios	All the year round. Worst period is from June to November.
Eastern Side	Hurricane or Cordonazo	June to November.
South Pacific:		
Western side	Hurricane	December to April.
Eastern side	Do not occur	
South Indian Ocean:		
Western side	Cyclone	December to April.
Eastern side	Willy-Willy	December to April.

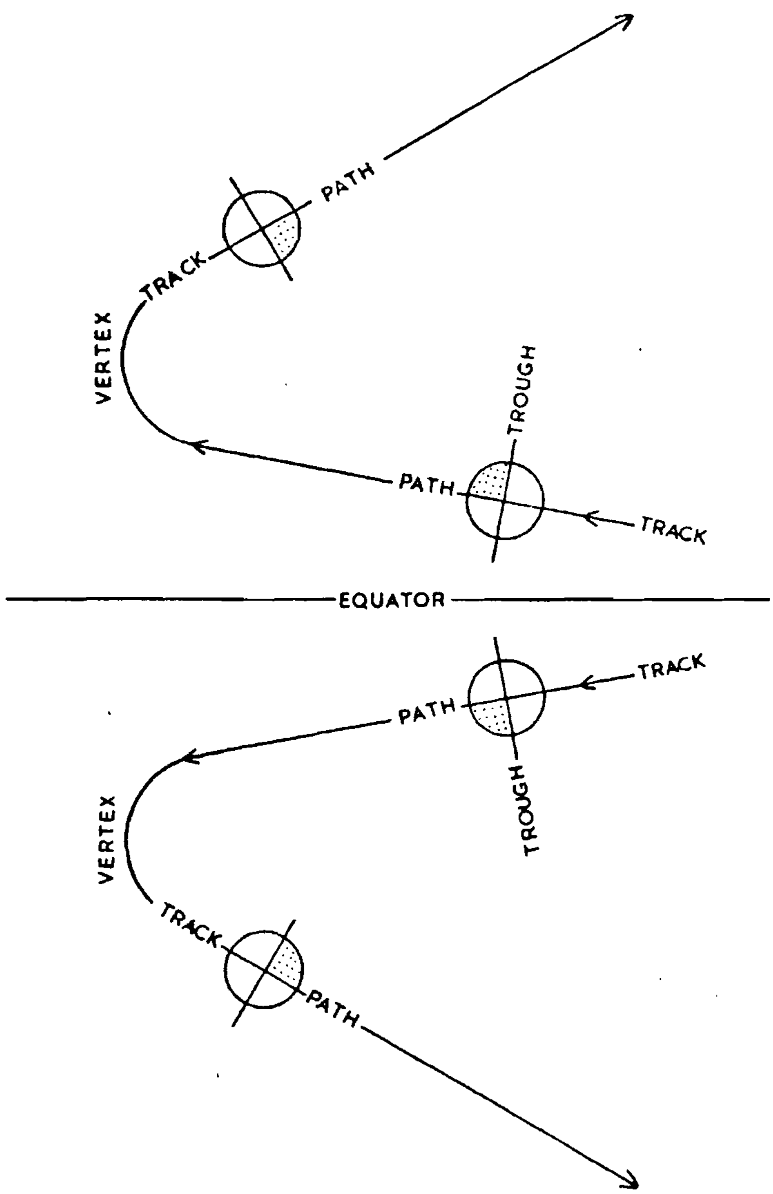
Arabian Sea:	Cyclone	*During change of Monsoon*: Mid April to mid June, October & November. Worst months are May, October & November.
Bay of Bengal:	Cyclone	May to December. Worst months are May, October, November and December.

4. Origin, movement and life span

TRS originate in latitudes between 5° & 20° and travel between W and WNW in the NH and between W and WSW in the SH, at a speed of about 12 knots. Somewhere along their track, they curve away from the equator – curve to N and then recurve to NE in the NH; curve to S and then recurve to SE in the SH (see following diagram).

The recurving is such that the storm travels around the oceanic high (which is situated at about 30°N and 30°S in the middle of large oceans). After recurving, the speed of travel increases to about 15 to 20 knots. Sometimes, a TRS does not curve or recurve at all, but continues on its original path, crosses the coast and dissipates quickly thereafter due to friction and lack of moisture.

It is important to note that all TRSs do not follow such definite paths and speeds. In their initial stages, occasional storms have remained practically stationary or made small loops for as long as four days.


PATH
TRACK
VERTEX
TROUGH
PATH
TRACK
EQUATOR
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PATH
TROUGH
VERTEX
TRACK
PATH

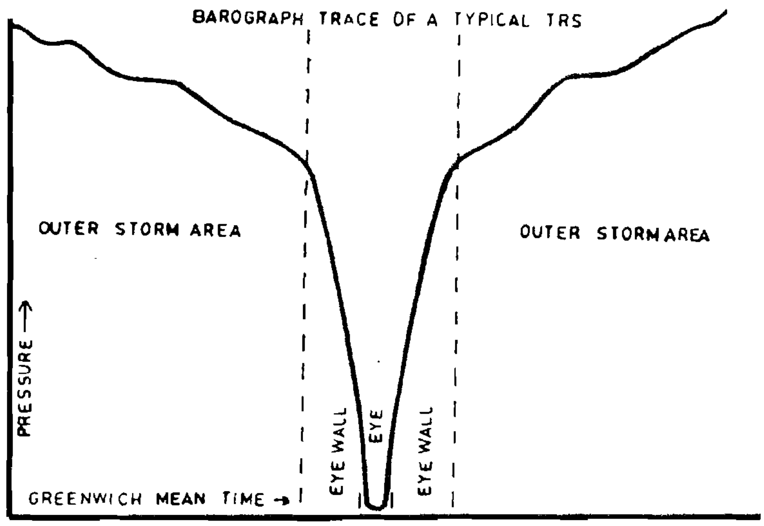
The life span of a TRS in anything from one to nineteen days, the average being about six days.

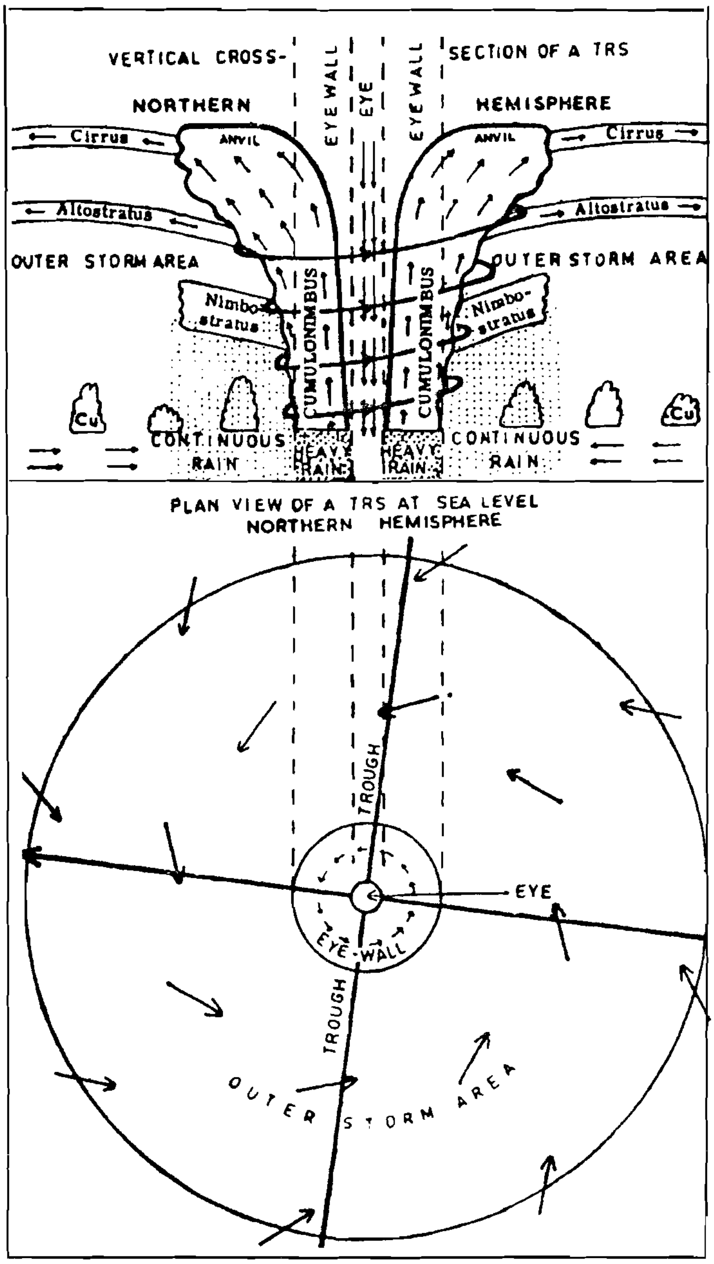
5. **Structure**

A well-developed TRS has three distinct parts:

5.1. **The eye or vortex**: A calm central area of lowest pressure, having a diameter between 4 miles and 30 miles, the average being about 10 miles.

5.2. **The eye-wall**: An inner ring of hurricane force winds having a width usually between 4 miles and 30 miles. The winds in the eye-wall blow in a perfectly circular path with a speed as high as 130 knots with occasional gusts up to 150 knots. The pressure gradient in the eye-wall is very steep and, therefore, the barograph would register a near vertical trend, downward before the eye and upward behind it, as shown in the accompanying figure.




VERTICAL CROSS-SECTION OF A TRS
NORTHERN HEMISPHERE
EYE WALL
EYE
EYE WALL
Cirrus
ANVIL
ANVIL
Cirrus
Altostratus
Altostratus
OUTER STORM AREA
OUTER STORM AREA
Nimbo-stratus
Nimbo-stratus
CUMULONIMBUS
CUMULONIMBUS
Cu
Cu
CONTINUOUS RAIN
HEAVY RAIN
HEAVY RAIN
CONTINUOUS RAIN
PLAN VIEW OF A TRS AT SEA LEVEL
NORTHERN HEMISPHERE
TROUGH
EYE
EYE-WALL
TROUGH
OUTER STORM AREA

5.3. **The Outer storm area**: The area surrounding the eye-wall, having a diameter between 50 miles and 800 miles, the average being about 500 miles. Winds in this region are strong (about force 6 or 7) and the pressure gradient is much less than in the eye-wall.

6. Definitions

Track: The route over which the storm centre has already passed.

Path: Predicted route over which the storm centre is likely to travel.

Trough: The line drawn through the centre of the storm, at right angles to the track. Ahead of the trough, pressure falls whereas behind it, pressure rises.

Vertex or Cod: The westernmost longitude reached by the storm centre when recurving takes place.

Right hand semicircle (RHSC): That half of the storm centre that lies to the right of the observer who faces along the path of the storm.

Left hand semicircle (LHSC): That half of the storm centre that lies to the left of the observer who faces along the path of the storm.

Dangerous semicircle: RHSC in the NH and LHSC in the SH.

Navigable semicircle: LHSC in the NH and RHSC in the SH.

Dangerous quadrant: The advance quadrant of the RHSC in the NH and LHSC in the SH. When the existence of a TRS in the vicinity has been established, evasive action has to be taken to keep the vessel out of this quadrant.

7. Weather

7.1. **Atmospheric pressure**: The barograph trace, typical of a well-developed TRS whose centre passes over a stationary observer, is as shown earlier in this chapter.

In the outer storm area, the fall of pressure ahead of the trough, and the rise of pressure behind it, is slow. The semi-diurnal variation of pressure may still be visible on the trace of a barograph.

In the eye-wall, the fall of pressure ahead of the trough, and the rise of pressure behind it, is very sharp. The trace of the barograph is very steep, nearly vertical. Semi-diurnal variation is not visible on it. The pressure gradient in this region can be as high as 11 mb in 15 miles.

In the eye, the lowest pressure is reached. This may be as low as 60 mb below normal. The lowest recorded pressure at the eye of a TRS was on 24th September 1958, about 600 miles East of Guam (13°27'N 144°35'E), in the Western Pacific Ocean. The pressure, reduced to sea level, was 877 mb, whereas the normal there should have been about 1010 mb. In the case of the Gopnath (Gulf of Cambay) cyclone of June 1976, the pressure at the eye was 980 mb, whereas the normal there should have been about 1006 mb, resulting in wind speeds of over 100 knots in the eye-wall. A pressure drop of 20 mb is sufficient to cause a well developed TRS.

If the storm centre passes *near* a stationary observer but not over him, the barograph trace would have similar characteristics but the pressure will not fall as low as it does at the eye.

7.2. Wind

Wind direction: If a ***stationary*** observer is in the RHSC, the wind will veer steadily and if he is in the LHSC, it will back steadily. This holds good for both NH and SH. If he is in the direct path of the storm, wind direction will remain fairly steady.

Angle of indraft: The angle of indraft, in the outer fringes of the storm, is about 45° and this gradually decreases until it is 0° in the eye-wall. The application of Buys Ballot's law, therefore, is appropriate.

Wind force: The wind force will increase as the atmospheric pressure falls and after the trough, or eye as the case may be, has passed, the wind force will gradually decrease as the atmospheric pressure increases.

The wind force in the outer storm area may be force 6 to 7, whereas in the eye-wall of a violent TRS it may be force 12 or over (see 'Terminology' on the first page of this chapter). In the eye-wall, the strongest winds usually lie in the rear quadrant on the polar side of the storm. In Indian waters, the strongest winds lie in that quadrant of the eye, whose wind direction coincides with the direction of the monsoon winds.

Wind direction & force in the eye: As soon as a vessel passes from the eye-wall into the eye, the wind dies down into light airs but the swell is mountainous and confused. It must not be presumed that a vessel in the eye of a TRS is in a comfortable and safe position. On the contrary, she is in a most dangerous situation. After a short while, as the vessel passes into the eye-wall behind the trough, the sudden hurricane force wind from the opposite direction as before, strikes the vessel and may cause it to heel over by as much as 80° or more and would hold it like that, leaving practically no margin for rolling further. Over and above possible extensive wind-damage described earlier, cargo may break loose and many openings may go below water causing the vessel to capsize.

7.3. **Atmospheric temperature**: Since a TRS exists in one air-mass only, no drastic changes of atmospheric temperature are experienced on its passage. However, atmospheric temperature would decrease during rain. In the eye, a slight increase may be registered due to adiabatic heating of the subsiding air.

7.4. **Clouds & precipitation**: The cloud sequence of a typical TRS is as follows:

In the outer fringes of the storm, cirrus in the form of strands or filaments generally so aligned, that they may be said to point towards the storm centre. Then cirrostratus followed by altostratus. Around the eye-wall, thick nimbostratus (giving continuous rain) and small patches of cumulus, may be seen. At the eye-wall, towering anvil-shaped cumulonimbus gives torrential rain.

Directly above the eye, a small circular patch of blue sky may be seen, indicating an absence of cloud therein and consequent cessation of precipitation.

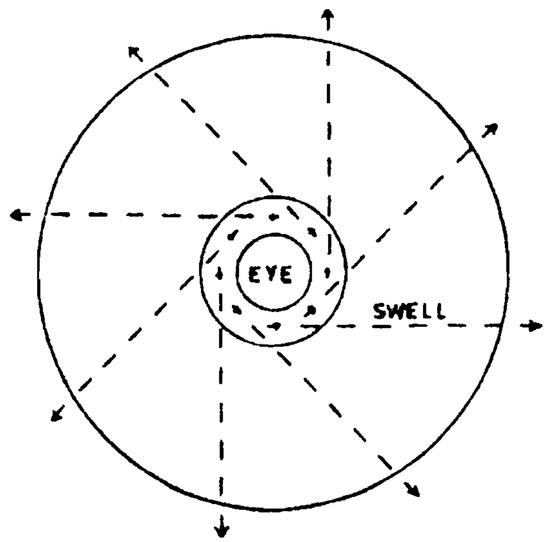
7.5. **Visibility**: In the outer fringes of a TRS, visibility is usually excellent. In the middle of the outer storm area, it becomes good except in occasional showers. Around the eye-wall, under the nimbostratus clouds, it becomes poor due to rain. In the eye-wall, it is poor due to driving rain and spray. In the eye, it is poor due to mist or fog.

7.6. **Storm surge or tidal wave**: The very violent winds of the eye-wall stir up mountainous waves, as high as 20 metres (from crest to trough). Since the TRS moves comparatively slowly, the winds act for a long time on the same area, setting up strong currents of water as deep as 25 metres below the surface. As these strong currents approach the shallow water near the coast, the water level suddenly rises well above the usual level (as much as 5 metres) and floods coastal areas. Such sudden rises of water level, caused by TRSs, are called "storm surges" or "tidal waves". If these storm surges happen to occur at the time of the usual high water, the havoc created is much more. The storm surge may be experienced from about 300 to 400 miles ahead of the storm and may last until the storm passes.

Around 30th May 1961, a severe cyclone struck the port of Chittagong. The storm surge flooded local areas and the hurricane force winds pushed a fairly large British general cargo vessel, the 'Clan Alpine', well inland. Soon afterwards, the water receded as the storm abated, leaving the vessel high and dry in a paddy field, a couple of miles inland. The vessel could not be refloated and was subsequently scrapped.

8. Warning signs of an approaching TRS

8.1. **Swell**: The very violent winds of the eye-wall send swell out in a radial direction. Swell can be experienced as much as a thousand miles away. Swell travels much faster than the speed of travel of the storm. Swell, therefore, approaches from the direction of the storm centre. Swell is usually the first indication of an approaching TRS.



8.2. **Atmospheric pressure**: Falls steadily.

The approach of a TRS should be suspected if:

- The ship is in an area where TRSs generally occur;
- If the time of the year is within the season when TRSs generally occur;
- The aneroid barometric pressure (corrected for index error & height above sea level), with due allowance for semi-diurnal variation time (for the time of the day), is >3 mb below normal.

The presence of a TRS is confirmed if the foregoing conditions are met and the fall of barometric pressure is more than 5 mb below normal.

Note: A pressure drop of 20 mb is sufficient to cause a well developed TRS.

8.3. **Weather**:

8.3.1. Cirrus clouds in bands or filaments aligned towards the direction of the storm centre.

8.3.2. Unusually clear visibility may occur.

8.3.3. Sometimes peculiar dark red/copper colour of sky is seen at sunset before a TRS.

8.3.4. Increase of wind force as the pressure falls.

8.3.5. Threatening appearance of dense, heavy clouds on the horizon.

8.3.6. Frequent lightning may be seen.

8.3.7. Succession of squalls, with or without rain.

8.4. **Storm warnings**: Weather reports based on satellite pictures and observations from other vessels may contain storm warnings which give the position and pressure of the storm centre and also probable direction of movement of the storm. However, it should be noted that satellite pictures are restricted to only a few per day and also that observations from ships in that vicinity may be few or even totally absent. Furthermore, a satellite picture cannot indicate the atmospheric pressure at the storm centre. It may thus happen that a vessel which notices the warning signs of a TRS, is the first and only one to do so and must warn others about it. She should first send out a safety message containing the storm warning and thence increase the frequency of its weather reports.

9. Action when approach of a TRS is confirmed

9.1. Obtain the bearing of the storm centre.

9.2. Ascertain in which semi-circle the vessel lies.

9.3. Take avoiding action.

9.1. Obtain the bearing of the storm centre.

'Face the wind, and according to Buys Ballot's law, the storm centre will lie 8 to 12 points on your right in the NH, left in the SH'.

If the pressure has fallen 5 mb below normal, allow 12 points as it means that either the vessel is in the outer fringes of a well developed TRS, or that a new TRS is forming in the vicinity.

If the pressure has fallen 20 mb or more below normal, allow 8 points as it means that the vessel is near the eye of a well developed TRS.

9.2. To ascertain in which semicircle vessel lies:

For a ***stationary observer***, if the wind veers, vessel is in the RHSC and if it backs, LHSC. This holds good for both NH and SH. While determining the semicircle, the following points should be noted:

9.2.1. **Wind observations**, though logged every hour during bad weather, should be compared with that 2 hours earlier. This is to give time for significant veering or backing and hence weed out errors that may be caused by irregular gusts of wind.

9.2.2. **Veering or backing**, once detected, should be continuous while the observer remains stationary, i.e. a veering wind should continue to veer and a backing wind should continue to back. If the wind veers at first and then backs, or if it backs at first and then veers, the vessel must have passed from one semicircle into another, due to change of path of the storm.

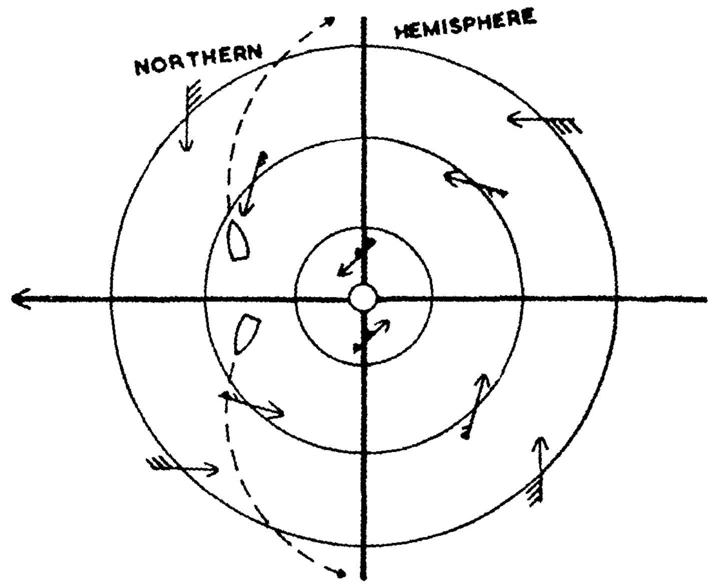
9.2.3. During the two-hour interval between observations, while veering or backing of wind is being decided, the observer must be ***stationary*** i.e., vessel ***should remain hove to.*** If not, the conclusion arrived at regarding RHSC or LHSC may be wrong and disastrous consequences may result as explained below:

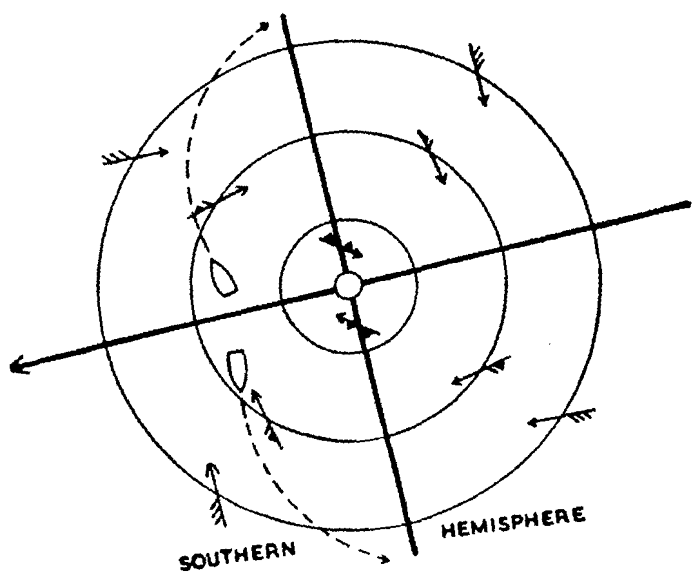
If a vessel was overtaking a TRS or it if was approaching a stationary TRS from its rear, the wind would veer in the LHSC and back in the RHSC. An unwary navigator would then arrive at a wrong conclusion regarding semi-circle and take the avoiding action mentioned later in this chapter, which action, instead of taking him away from the storm centre, would lead him right into it.

9.3. Avoiding action:

Any avoiding action should aim to keep the vessel well out of the storm centre. If a vessel is in port when a storm warning is received, it may be advisable to proceed well out to sea so that the vessel will have plenty of sea room and sufficient depth of water (to prevent the vessel from pounding on the seabed during pitching and heaving).

If proceeding out to sea is not possible, it would be advisable for the vessel to anchor outside the port, in whatever shelter she can find, drop both anchors with several shackles of cable out on each. The engines should be ready - bursts of engine movement may be necessary to prevent dragging of anchors.


NORTHERN
HEMISPHERE


SOUTHERN
HEMISPHERE

Out in open sea, the following action is recommended to keep the vessel out of eye/eye-wall:

9.3.1. **If vessel is in the dangerous quadrant**:
Proceed as fast as practicable with the wind 1 to 4 points on the *stbd* bow (*port* bow in SH) - 1 point for slow vessels (less than 12 knots) and 4 points for fast vessels (more than 12 knots) altering course as the wind *veers* (*backs* in SH). This action should be kept up until the pressure rises back to normal i.e., until vessel is outside the outer storm area.
If there is insufficient sea room, the vessel should heave to with the wind on the *stbd* bow (*port* bow in SH) until the storm passes over.

9.3.2. **If vessel is in the path of the storm or if in the navigable semi-circle**:
Proceed as fast as practicable with the wind about 4 points on the *stbd* quarter (*port* quarter in SH), altering course as the wind *backs* (*veers* in SH). This action should be kept up until the pressure rises back to normal i.e., until vessel is outside the outer storm area.

9. Ideal conditions for the formation of a TRS:

9.1. High relative humidity (open sea).
9.2. High temperature (Tropical areas).
9.3. LP area surrounded by areas of HP (daytime over large islands).
9.4. Convection current (daytime over large islands).

9.5. Fair amount of Coriolis force (latitude more than 5° N or S).
9.6. Weak prevailing winds (during change of season).

Foregoing points 9.1 & 9.2 ensure that a large quantity of water vapour is present in the air.

Points 9.3 & 9.4 ensure that air rises continuously so that adiabatic cooling results in condensation that liberates latent heat. This latent heat provides the energy for the TRS.

Point 9.5 ensues that when the winds blow, from surrounding areas of HP to the LP area inside, they get deflected sufficiently to blow spirally inwards (cyclonic).

Point 9.6 is important – if the prevailing winds are strong, the air would not rise vertically. It would be carried off horizontally, thereby not allowing a TRS to form.

To summarise the foregoing, the ideal conditions for the formation of a TRS exist during day time over large Tropical islands, in mid-ocean, between latitudes 5° & 20°, during the change of monsoon - in Indian waters, mid April to mid June and from October to December.

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CHAPTER 13

THE WEATHER

REPORTING SYSTEM

Efficient weather service to shipping depends on the timely location and accurate tracking of weather systems over the open sea, which covers three-quarters of the surface of the earth.

Overland it is easily possible to establish weather observation stations (observatories) but over sea, the establishment of ocean weather ships is a very major operation involving very great capital and recurring expense. Because of this, it is necessary for merchant ships, on the high seas, to spend a few minutes per day in sending out reports of the weather experienced. Even if the weather is normal, a report to that effect is very important.

Reporting system

As recommended by the World Meteorological Organisation (WMO), each government recruits a number of merchant ships called the Voluntary Observing Fleet (VOF).

The Indian VOF consists of Indian ships and also such foreign vessels that frequently and regularly call at Indian ports and hence treat an Indian port as their homeport.

Each vessel of the VOF makes weather observations at fixed UTC (GMT) hours (called synoptic hours), codes these observations and transmits them using the ship's terrestrial or space radio communications facilities as soon as possible. These are sent to any of the designated coast radio stations listed in the Admiralty List of Radio Signals Volume 3 (ALRS 3) which forwards them to the Regional Meteorological Data Collection Centre, on a priority basis. The ship does not incur any expense at all. The respective National Weather Authority pays all relevant charges and also provides for all necessary equipment, publications and stationery used by the VOF.

The codes have been devised in such a manner that the messages can easily be electronically processed and stored to enable better forecasts to be made.

The Regional Meteorological Centre (RMC) collates all the reports of that area and makes weather forecasts, which are transmitted to ships of that area, as weather bulletins (described later in this chapter), through selected stations, at fixed times, using terrestrial or space radio communications facilities.

Times of observations

Under normal conditions of weather, the hours of observation, called synoptic hours, are 00, 06, 12 and 18 UTC. In cases where there is disturbed weather, additional synoptic hours are 03, 09, 15 and 21 UTC.

The coded weather messages should be transmitted as soon as possible. In case of any genuine delays, a message may be transmitted up to four hours after the time of observation. In the case of ships, the time of observation is always the time when the barometer reading is taken.

In case any unusual but urgent weather phenomena are seen, a special message, in code or in plain language, may be sent out at any time. Examples of such messages are given later in this chapter.

In rare cases, as during a TRS, the RMC may request a ship in a particular area for special observations. The Master should regard such observations as urgent.

Meteorological log books

Each ship of the VOF is given a meteorological or weather logbook. All weather observations at synoptic hours and any special message must be recorded neatly and legibly in the weather logbook, whether they were transmitted or not.

When each logbook is completed, it is to be returned to the regional meteorological office. The messages received from the vessel will be compared with the logbook to eliminate errors during transmission. The logbook may contain additional remarks that were not transmitted in the coded messages. The data from logbooks are fed into computers for future use.

Classification of ships

In accordance with the recommendation of the WMO, vessels of the VOF are divided into three categories:-

Selected ship: A mobile ship which is equipped with *sufficient* certified meteorological instruments for making observations and which transmits the required observations in the full code consisting of eighteen to twenty one groups. *
Supplementary ship: A mobile ship which is equipped with a *limited number* of certified meteorological instruments for making observations and which transmits the observations in the abbreviated form of the code consisting of twelve or more groups. *
Auxiliary ship: A mobile ship normally not provided with certified meteorological instruments which transmits weather reports in disturbed weather or under a special request, in the reduced form of the code consisting of eleven or more groups * or in plain language.

Ships not recruited in any of the categories are requested to transmit weather reports on their own initiative in case of disturbed weather.

*For details of the Code see supplement to this book, titled 'Ships Weather Code'.

Equipment supplied by IMD

The following equipment is manufactured and supplied, free of charge, by the India Meteorological Department:-

Selected ship:

1. Barometer
2. Whirling psychrometer
3. Weekly barograph
4. Sea-thermometer$
5. Marine bucket$

Supplementary ship:

1. Barometer
2. Whirling psychrometer

$ Most ships of the VOF decline to accept these two instruments as they do not want to undertake the tedious method of obtaining samples of seawater and measuring sea temperature four times a day, every day. Instead, they prefer to phone down to the engine room and obtain the temperature of the seawater at the cooling water intake from the sea.

Publications supplied by IMD

The India Meteorological Department supplies the following publications, free of charge, to Selected and Supplementary ships:

1. Monthly meteorological charts of the Indian Ocean.
2. Indian Ocean Currents.
3. Marine Observer's Handbook.
4. International Cloud Atlas.
5. Ship's Weather Code.
6. Weather Services to Shipping, Fishing Vessels and Marine Interests.
7. Code of Storm Warning Signals.
8. Handbook of Cyclonic Storms in the Bay of Bengal.
9. Winds, Weather and Currents on the Coasts of India.
10. State of Sea Card.

Meteorological services and warnings

Regulation 5 of Chapter V, titled 'Meteorological services and warnings', of the International Convention for the Safety of Life at Sea 1974 (SOLAS 74), as amended in 2000, states as follows:

1. Contracting Governments undertake to encourage the collection of meteorological data by ships at sea and to arrange for their examination, dissemination and exchange in the manner most suitable for the purpose of aiding navigation. Administrations shall encourage the use of meteorological instruments of a high degree of accuracy, and shall facilitate the checking of such instruments upon request. Arrangements may be made by appropriate national meteorological services for this checking to be undertaken, free of charge to the ship.
2. In particular, Contracting Governments undertake to carry out, in co-operation, the following meteorological arrangements:
   - 2.1. To warn ships of gales, storms and tropical cyclones by the issue of information in text and, as far as practicable, graphic form, using the appropriate shore-based facilities for terrestrial and space radio communications services.
   - 2.2. To issue, at least twice daily, by terrestrial and space radio communication services, as appropriate, weather information suitable for shipping containing data, analyses, warnings and forecasts of weather, waves and ice. Such information shall be transmitted in text and, as far as practicable, graphic form, including

meteorological analysis and prognosis charts transmitted by facsimile or in digital form for reconstitution on board the ship's data processing system.

2.3. To prepare and issue publications as may be necessary for the efficient conduct of meteorological work at sea and to arrange, if practicable, for the publication and making available of daily weather charts for the information of departing ships.

2.4. To arrange for a selection of ships to be equipped with tested marine meteorological instruments (such as a barometer, a barograph, a psychrometer and suitable apparatus for measuring sea temperature) for use in this service, and to take, record and transmit meteorological observations at main standard times for surface synoptic observations (i.e. at least four times daily, whenever circumstances permit) and to encourage other ships to take, record and transmit observations in a modified form, particularly when in areas where shipping is sparse.

2.5. To encourage companies to involve as many of their ships as practicable in the making and recording of weather observations; these observations to be transmitted using the ship's terrestrial or space radio communications facilities for the benefit of the various national meteorological services.

2.6. The transmission of these weather observations is free of charge to the ships concerned.

2.7. When in the vicinity of a tropical cyclone, or of a suspected tropical cyclone, ships should be encouraged to take and transmit their observations at more frequent intervals whenever practicable, bearing in mind navigational preoccupations of ships' officers during storm conditions.

2.8. To arrange for the reception and transmission of weather messages from and to ships, using the appropriate shore-based facilities for terrestrial and space radio communications services.

2.9. To encourage Masters to inform ships in the vicinity and also shore stations whenever they experience a wind speed of 50 knots or more (force 10 on the Beaufort scale)

2.10. To endeavour to obtain a uniform procedure in regard to the international meteorological services already specified, and, as far as is practicable, to conform to the technical regulations and recommendations made by the World Meteorological Organisation, to which Contracting Governments may refer, for study and advice, any meteorological question which may arise in carrying out the present Convention.

3. The information provided for in this regulation shall be furnished in a form for transmission and be transmitted in the order of priority prescribed by the Radio Regulations. During transmission "to all stations" of meteorological information, forecasts and warnings, all ships must conform to the provisions of the Radio Regulations.

4. Forecasts, warnings, synoptic and other meteorological data intended for ships shall be issued and disseminated by the national meteorological service in the best position to serve various coastal and high seas areas, in accordance with mutual arrangements made by the Contracting Governments, in particular as defined by the World Meteorological Organisation's system for the preparation and dissemination of meteorological forecasts and warnings for the high seas under the Global Maritime Distress and Safety System (GMDSS).

Danger messages

Regulation 31 of Chapter V of SOLAS 74, titled 'Danger messages', as amended in 2000, states:

1. The Master of every ship which meets with dangerous ice, a dangerous derelict, or any other direct danger to navigation, or a tropical storm, or encounters sub-freezing air temperatures associated with gale force winds causing severe ice accretion on superstructures, or winds force 10 or above on the Beaufort scale for which no storm warning has been received, is bound to communicate the information by all the means at his disposal to ships in the vicinity, and also to the competent authorities. The form in which the information is sent is not obligatory. It may be transmitted either in plain language (preferably English) or by means of the International Code of Signals.
2. Each Contracting Government will take all steps necessary to ensure that when intelligence of any

of the dangers specified in paragraph 1 is received, it will be promptly brought to the knowledge of those concerned and communicated to other interested Governments.

3. The transmission of messages regarding the dangers specified is free of cost to the ships concerned.
4. All radio messages issued under paragraph 1 shall be preceded by the safety signal, using the procedure as prescribed by the Radio Regulations as defined in Regulation IV/2.

Information required in danger messages

Regulation 32 of Chapter V, titled 'Information required in danger messages', of SOLAS 74, as amended in 2000, states:

The following information is required in danger messages:

1. Ice, derelicts and other direct dangers to navigation:
   1.1. The kind of ice, derelict or other danger observed.
   1.2. The position of the ice, derelict or danger when last observed.
   1.3. The time and date (UTC) when the danger was last observed.
2. Tropical cyclones (storms):
   2.1. A statement that a tropical cyclone has been encountered. This obligation should be interpreted in a broad spirit, and information transmitted whenever the Master has good reason to believe that a tropical cyclone is developing or exists in the neighbourhood.

2.2. Time, date (UTC) and position of ship when the observation was taken.

2.3. As much of the following information as is practicable should be included in the message:

- Barometric pressure, preferably corrected (stating millibars, millimetres, or inches, and whether corrected or uncorrected);
- Barometric tendency (the change in barometric pressure during the past three hours);
- True wind direction;
- Wind force (Beaufort scale);
- State of the sea (smooth, moderate, rough, high);
- Swell (slight, moderate, heavy) and the true direction from which it comes. Period or length of swell (short, average, long) would also be of value;
- True course and speed of ship.

Subsequent observations

3. When a Master has reported a tropical cyclone or other dangerous storm, it is desirable, but not obligatory, that further observations be made and transmitted hourly, if practicable, but in any case at intervals of not more than 3 hours, so long as the ship remains under the influence of the storm.
4. Winds of force 10 or above on the Beaufort scale for which no storm warning has been received. This is intended to deal with storms other than the tropical cyclones referred to in paragraph 2; when such a storm is encountered, the message should

contain similar information to that listed under the paragraph but excluding the details concerning sea and swell.

5. Sub-freezing air temperatures associated with gale force winds causing severe ice accretion on superstructures:
   5.1. Time and date (UTC).
   5.2. Air temperature.
   5.3. Sea temperature (if practicable).
   5.4. Wind force and direction.

Examples of messages
(given at the end of Regulation 32 of SOLAS 74)

Ice

1. TTT ICE. Large berg sighted in 4506 N, 4410W, at 0800 UTC. May 15.

Derelicts

2. TTT DERELICT. Observed derelict almost submerged in 4006 N, 1243 W, at 1630 UTC, April 21.

Danger to navigation

3. TTT NAVIGATION. Alpha lightship not on station. 1800 UTC. January 3.

Tropical cyclone

4. TTT STORM. 0030 UTC. August 18. 2004 N, 11354 E. Barometer corrected 994 mb, tendency down 6 mb. Wind NW, force 9, heavy squalls. Heavy easterly swell. Course 067, 5 Knots.
5. TTT STORM. Appearances indicate approach of hurricane. 1300 UTC. September 14. 2200 N, 7236 W. Barometer corrected 29.64 inches, tendency down 0.015 inches. Wind NE, force 8, frequent rain squalls. Course 035, 9 knots.

6. TTT STORM. Conditions indicate intense cyclone has formed. 0200 UTC. May 4. 1620 N, 9203 E. Barometer uncorrected 753 millimetres, tendency down 5 millimetres. Wind S by W, Force 5. Course 300, 8 Knots.
7. TTT STORM. Typhoon to SE. 0300 UTC. June 12. 1812 N, 12605 E. Barometer falling rapidly. Wind increasing from N.
8. TTT STORM. Wind force 11, no storm warning received. 0300 UTC. May 4. 4830 N, 30 W. Barometer corrected 983 mb, tendency down 4 mb. Wind SW, force 11 veering. Course 260, 6 Knots.

Icing

9. TTT EXPERIENCING SEVERE INCING. 1400 UTC. March 2. 69 N, 10 W. Air temperature -7.8°C. Sea temperature -1.7°C. Wind NE, Force 8.

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Weather Bulletins

Details of weather bulletins sent out in each area - call signs of stations, radio frequencies and timings - are given in the Admiralty List of Radio Signals Volume 3 (ALRS 3).

A weather bulletin would consist of five parts:

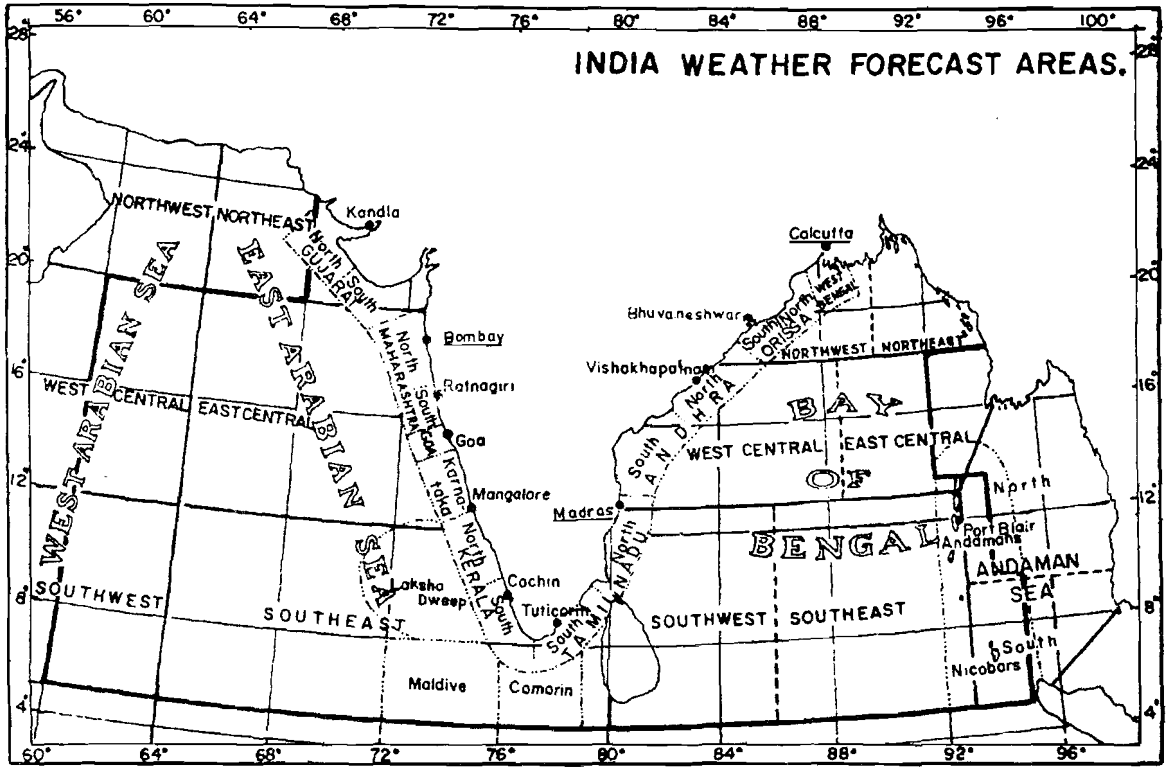
Part I Storm warning in plain language.

Part II Synopsis of weather conditions in the forecast area, in plain language.

Part III Forecast in plain language.

Part IV Surface weather analysis synoptic chart in the International Analysis Code (Fleet).

Part V Data of surface observations from ships and selected land stations and upper-air reports, all in WMO codes.


INDIA WEATHER FORECAST AREAS.
NORTHWEST
NORTHEAST
WEST ARABIAN SEA
EAST ARABIAN SEA
WEST
CENTRAL
EASTCENTRAL
SOUTHWEST
SOUTHEAST
Kandla
GUJARAT
MAHARASHTRA
Bombay
Ratnagiri
Goa
Karnataka
Mangalore
KERALA
Cochin
Laksha Dweep
Maldive
Comorin
Tuticorin
TAMILNADU
Madras
ANDHRA
Vishakhapatnam
Bhuvaneshwar
ORISSA
WEST BENGAL
Calcutta
BAY OF BENGAL
WEST CENTRAL
EAST CENTRAL
SOUTHWEST
SOUTHEAST
Port Blair
Andamans
ANDAMAN SEA
North
South
Nicobars

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CHAPTER 14

THE WEATHER CODES

A brief description of the four weather codes that are of interest to mariners is given here. For easy identification purposes, the World Meteorological Organisation (WMO) has, in its 'Manual of Codes – WMO 306', allotted each code with a distinct Roman Number. Such Roman Number is preceded by the letters FM (which is an abbreviation for 'Form'), a number and a hyphen thus: FM 13 - X. For further details, Admiralty List of Radio Signals Volume 3 - ALRS 3 – 'Maritime Safety Information (broadcasts) Services' – should be consulted.

1. Ship reports (FM 13 – X)

Ships should make weather reports in Code FM 13 - X, referred to as the Ships Weather Code. This code is described in detail in ALRS 3 and is included as a separate supplement to this book to enable the student to study them at his convenience.

2. Land station reports (FM 12 - X)

Land stations send out weather reports in the SYNOP code (FM 12 - X), full details of which are given in ALRS 3. This code is mentioned here in case a ship, in disturbed weather, intercepts such a weather message and wants to predict the weather on her own, until a proper weather forecast is received. Most weather bulletins, like the Atlantic

Weather Bulletin, Arabian Sea Bulletin, Bay of Bengal Bulletin, etc., include ship reports and selected station reports in their Part V.

The SYNOP Code is very similar to the Ships Weather Code with minor differences only:

(1) BBXX is replaced by AAXX.
(2) Group D.......D is omitted.
(3) Group $222D_sv_s$ is coded as 222/ /.
(4) Position groups $99L_aL_aL_a$ & $Q_cL_oL_oL_oL_o$ are replaced by one group IIiii, wherein:
II Indicates the region of the world in which the station is situated. e.g., Europe and Asia = 00 to 49, India, north of 20°N = 42, India, south of 20°N = 43, North and Central America = 70 to 79, etc.
iii Indicates the identity of the land station that made the report. On weather maps, the regional block number and the corresponding three-digit identity group of each station is already printed, each in its correct place.
For example, on the weather map of India, Mumbai (Colaba) is indicated as 43057 - the regional block number II of South India is 43, and Mumbai (Colaba) is 057. The names of various stations are not given on the map, so as to avoid unnecessary hassles of spelling and pronunciation. A complete list of regions and stations is given in the Admiralty List of Radio Signals Volume 4 - ALRS 4 - 'List of Meteorological Stations'.

3. The MAFOR Code (FM 61- IV)

Some countries that experience difficulty in sending out weather bulletins in plain English, use the Maritime Forecast Code (MAFOR Code) given below: MAFOR $YYG_1G_1/$ $0AAAa_m$ $1GDF_mW_1$ and two optional groups.

Detailed explanations of each of the various letters of this code are given in the ALRS 3. The information given by a MAFOR Code bulletin should be treated as approximate only.

4. The International Analysis Code (FM 46 - IV)

The International Analysis Code (IAC Fleet) is used to transmit surface weather conditions in the form of a ready weather map, covering an entire ocean. The bulletin gives the positions of pressure systems, frontal systems, isobars, tropical weather, etc. The bulletin may be an analysis (actual existing conditions) or a prognosis (prediction). The details of the IAC (Fleet) are given ALRS 3. In the IAC (Fleet), Part IV may consist of over 150 groups, and may require two to three hours to decode and plot on a map.

The invention of the facsimile recorder (explained later in this book), which automatically receives an entire weather map, without the necessity of a code, has made the IAC (Fleet) practically obsolete from the mariner's point of view.

More about ships reports

In the Ships Weather Code, each group consists of five characters and the total number of groups may be as many as 20. After many years, it was discovered that communication charges incurred by Meteorological Departments in receiving weather reports relayed through land lines could be reduced as much as 40% by a simple strategy. Charges for landline telegrams and telexes were levied per word. Internationally, one word could consist of up to 10 characters. So it was decided, by some National Weather Authorities, to join the first two groups, then the third and fourth groups, then the fifth and sixth groups, and so on, and transmit them as a series of 10-character strings.

However, this strategy has now become obsolete since Wireless Telegraphy has itself become redundant. The messages should be sent with groups of only five alpha-numeric characters each.

Some important points – ships' weather reports

GG	30 minutes is to be rounded off to the earlier hour. For example, 0530 is to be coded as 05 not 06. The time denoted here is the time at which the barometer is read. The barometer should be read as close to the synoptic hour as possible.
$99L_aL_aL_a$ $Q_cL_oL_oL_oL_o$	The last numeral of each of these groups should be the number of minutes divided by six, omitting the remainder. For example, latitude 38° 41' is to be coded as 386 not 387 and longitude 86° 58' as 0869 not 0870.
h	If the height of the base of the lowest cloud, above sea level, has a value that

	is the boundary between two code numbers, the <u>higher</u> code number should be reported. For example, 600 metres should be coded as 5 not 4.
VV	Ships should code VV between 90 and 99 only. The words 'less than', or the symbol <, is only meant for code number 90 - visibility less than 50 metres. For code numbers 91 to 98, the distances shown mean 'Objects visible at'. For example, if an object is visible at 2000 metres, VV = 95 and if visible only at 1500 metres, VV = 94.
N	Overcast with a few blue patches is to be coded as 7 not 8.
dd	Wind direction from <u>North</u> is to be coded as <u>36</u> not 00. dd = 00 only if ff = 00.
ff	Wind speed is reported in knots or in metres per second only, as indicated by i_w, <u>not</u> in Beaufort Scale numbers.
$T_dT_dT_d$	The dew point <u>not</u> the wet bulb temperature is to be reported, squared off to the first decimal place. For example 20.45 = 205, 18.75 = 188.
W_1W_2	The higher number should be reported first - for example, 94 not 49.
H_WH_W, $H_{W1}H_{W1}$, $H_{W2}H_{W2}$	Height of sea and swell should be in half-metre units - number of metres multiplied by 2, <u>not</u> divided by 2. For example 2 metres is to be coded as 04 <u>not</u> 01 or 02.

Examples in coding and decoding

1. Decode the following report:

BBXX	ATVH	10123	99408	30492	41398
62828	10143	20082	40084	56028	76364
84364	22234	00175	20808	302 //	41006

First copy down the groups carefully and then insert their code groups above them, seeing that the indicator figures suit the groups, and then decode:

BBXX	Surface report from a ship.
ATVH	Signal letters of ship.
$YYGGi_W$ 1 0 1 2 3	GMT 10d 12h. Wind speed reported by ff is estimated in knots.
$99L_aL_aL_a$ 994 0 8	Position of ship Latitude: 40.8° South
$Q_cL_oL_oL_oL_o$ 3 0 4 9 2	Longitude: 049.2° East.
i_Ri_xhVV 41 398	Precipitation group not sent. Manned station. Group $7wwW_1W_2$ is included in this report. Cloud base 200 - 300 metres above sea. Visibility 20 km.
Nddff 62828	Total cloud 6/8 of sky. Wind direction 280°, wind speed estimated at 28 km.
$1S_nTTT$ 10 1 4 3	Air temperature + 14.3°C.
$2S_nT_dT_dT_d$ 20 0 8 2	Dew point temperature + 08.2°C.

4PPPP 40084	Atmospheric pressure 1008.4 mb.
5appp 56028	Barograph trace ; Tendency (-) 02.8 mb.
$7wwW_1W_2$ 7 63 6 4	Present weather: moderate, non-freezing, continuous rain. Past weather: Rain, fog or haze.
$8N_hC_LC_MC_H$ 84 3 6 4	Low cloud 4/8 of sky. Low clouds: Cb, the summits of which lack sharp outlines, but are neither fibrous nor in the shape of an anvil. Medium clouds: Ac resulting from the spreading out of Cu or Cb. High clouds: Ci in the form of hooks or filaments, or both, progressively invading sky.
$222D_Sv_S$ 2223 4	Course made good last three hours: SE @ 16 to 20 knots.
$0S_nT_WT_WT_W$ 00 1 7 5	Sea temperature + 17.5°C.
$2P_WP_WH_WH_W$ 20 8 0 8	Sea period: 08 seconds; sea height: 04 metres.
$3d_{W1}d_{W1}d_{W2}d_{W2}$ 30 2 / /	First swell from 020°. No second swell.
$4P_{W1}P_{W1}H_{W1}H_{W1}$ 41 0 0 6	First swell: period 10 seconds, height 03 metres.

2. Decode the following report:

AAXX	06183	43057	41798	53628	10324
20208	40069	51042	71682	83262	222//
00282	20606	324//	41008		

AAXX	Report from a land station.
$YYGGi_w$ 0 6 1 8 3	GMT 06d 18h. Wind speed estimated In knots
I I i i i 43057	II-43 means India, south of latitude 20°N. iii-057 means Bombay (Colaba). In cases where a student does not know which particular area or station is indicated by IIiii, he may state as follows: II 43 - Regional block number. iii 057 - Station number (ALRS 4).
i_Ri_XhVV 41 798	Precipitation group not sent. Manned station. Group $7wwW_1W_2$ is included. Base of lowest cloud 1500 - 2000 metres above sea. Visibility 20 km.
Nddff 53628	Total cloud 5/8 of sky. Wind direction from North, estimated at 28 knots.
$1S_nTTT$ 10 324	Air temperature + 32.4°C.
$2S_nT_dT_dT_d$ 20 2 0 8	Dew point temperature + 20.8°C.
4PPPP 40069	Atmospheric pressure 1006.9 mb.
5appp 51042	Barograph trace ; Tendency (+) 04.2 mb.
$7wwW_1W_2$ 716 8 2	Present weather: Rain in sight near, but not on, ship. Past weather: Showers of rain; cloud covering more than half sky throughout the appropriate period.

$8N_hC_LC_MC_H$ 83 2 6 2	Low cloud 3/8 of sky. Cu of moderate or strong vertical extent. Medium cloud: Ac formed by the spreading out of Cu or Cb. High cloud: Dense Ci.
$222D_Sv_S$ 222 / /	No course or speed – land station.
$0S_nT_WT_WT_W$ 00 2 8 2	Sea temperature + 28.2°C.
$2P_WP_WH_WH_W$ 20 6 0 6	Sea period: 06 seconds; Height: 03 metres.
$3d_{W1}d_{W1}d_{W2}d_{W2}$ 32 4 / /	First swell from 240°. No second swell.
$4P_{W1}P_{W1}H_{W1}H_{W1}$ 41 0 0 8	First swell: period 10 seconds, Height 04 metres.

3. Code the following ship's report:

Ship: 3FRK, Position: 27° 35'N 98° 29'W, Course made good last three hours: 320° at 15 knots, Visibility: 20km, Wind: 240° estimated at 16 knots, Pressure: 1026.8 rnb, Tendency: +6.4 mb, Barograph trace: GMT: 08d 06h 10m.
Temperature: Dry 28.5°C, Wet 23.0°C, Sea 20.6°C.
Clouds: Total 6/8 of sky, low clouds 4/8 of sky, base 1000 metres above sea, Sc not resulting from Cu, Dense Ns, Ci in hooks progressively invading sky.
Weather: present - precipitation near but not at station. Past - Cloud covering more than 1/2 sky throughout and intermittent drizzle.
Sea: Period 08 seconds, height 01 metre.
Swell: From 050°, period 10 seconds, height 02 metres.

First copy down the groups from the Weather Code book. Then fill in the numbers under each code letter as appropriate.

BBXX	D........D	$YYGGi_W$	$99L_aL_aL_a$	$Q_CL_OL_OL_OL_O$
BBXX	3FRK	0 8 0 63	99 2 7 5	7 0 9 8 4

i_Ri_xhVV	Nddff	$1S_nTTT$	$2S_nT_dT_dT_d$	4PPPP
4 1698	62416	10 2 8 5	20 2 0 8	40268

5appp	$7wwW_1W_2$	$8N_hC_LC_MC_H$	$222D_SV_S$
52064	71 6 5 2	8 4 5 2 4	222 7 3

$0S_nT_WT_WT_W$	$2P_WP_WH_WH_W$	$3d_{W1}d_{W1}d_{W2}d_{W2}$
00 2 0 6	20 8 0 2	30 5 / /

$4P_{W1}P_{W1}H_{W1}H_{W1}$
41 0 0 4

4. Code the following ship's report:
Ship: VHAN, Position: 00° 05'N 46°58'E, Course made good past three hours: 170° at 10 knots, GMT: 16d 00h 20m, Wind: 052° estimated at 10 knots.
Visibility: 500 metres, Pressure 1008.8 mb, Tendency + 3.6 mb, Barograph trace: 
Temperature: Dry 28.5°C, Wet 23.0°C, Sea 20.6°C.
Clouds: Sky overcast with a few blue patches. Low clouds 4 oktas, base 600 metres above sea, Cu of strong vertical extent, Ac in a chaotic sky, Cc.
Present weather: Visibility poor due to dust in suspension in the air, **not** raised by wind at or near ship.
Past weather: Thick haze, thunderstorm.
Sea: Period 04 seconds, height 0.4 metres.
Swell: From 270°, Period 08 seconds, height 04m.

BBXX	D...D	$YYGGi_W$	$99L_aL_aL_a$	$Q_CL_OL_OL_OL_O$
BBXX	VHAN	1 6 0 03	99 0 0 0	1 0 4 6 9

i_Ri_XhVV	Nddff	$1S_nTTT$	$2S_nT_dT_dT_d$	4PPPP
41593	70510	10285	20208	40088

5appp	$7wwW_1W_2$	$8N_hC_LC_MC_H$
50306	7 06 94	84 2 9 9

$222D_Sv_S$	$0S_nT_WT_WT_W$	$2P_WP_WH_WH_W$
2224 2	00 2 0 6	20 4 0 1

$3d_{W1}d_{W1}d_{W2}d_{W2}$	$4P_{W1}P_{W1}H_{W1}H_{W1}$
32 7 / /	40 8 0 8

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CHAPTER 15

PRESSURE

MEASURING INSTRUMENTS

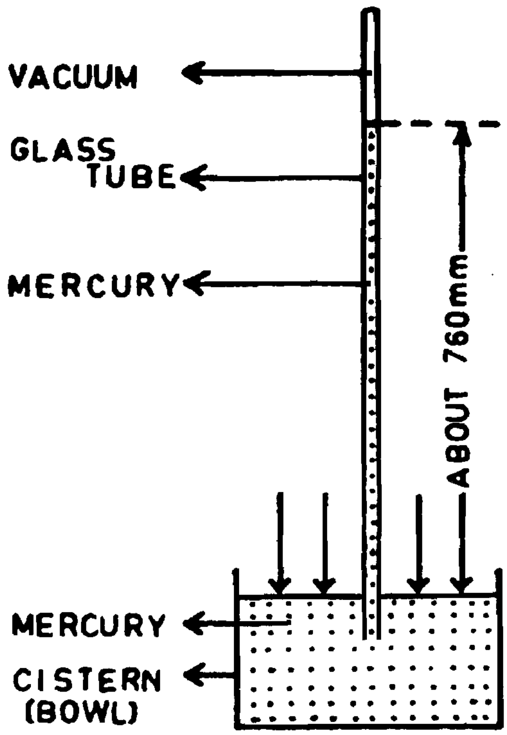
1. The mercury barometer

The mercury barometer is an instrument for measuring atmospheric pressure. It was invented by an Italian scientist named Torricelli in 1643.

Principle

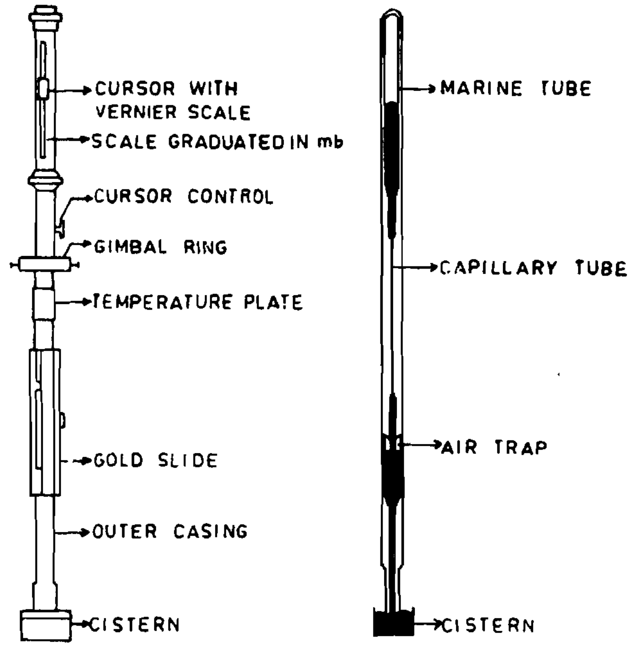
In its simplest form, the mercury barometer consists of a glass tube about one metre long, closed at one end, filled with mercury and inverted into a bowl containing mercury (see accompanying sketch). While inverting the tube, a finger should be placed over the open end and removed only after the end has been immersed in the mercury in the bowl. It will be noticed that the mercury level in the tube drops by a certain amount and then remains steady. This is because atmospheric pressure, acting on the surface of mercury in the bowl, balances the weight of mercury in the tube. Atmospheric pressure, therefore, is the weight of mercury above the level of mercury in the bowl (for further details of atmospheric pressure, please see chapter 1).

If any air is present in the top of the inverted tube, the barometer would show lower than correct readings. If air was allowed to freely enter the space on top, the level of mercury in the tube would drop until it became equal to the level of mercury in the bowl.



Construction of the marine barometer

The marine barometer, also called the Kew-pattern marine barometer, consists of a glass tube sealed at its upper end, with its lower end immersed in a bowl (cistern) of mercury. The bore of the tube is narrow for most of its length but is broader at the top. The narrowness, along most of its length, reduces the quantity of mercury required and thereby reduces the weight and cost of the barometer without loss of accuracy.



At its middle, the bore of the tube gets very narrow and is hence called a capillary tube. This is to reduce "pumping" which is described later in this chapter, under "Other sources of error in readings of the marine barometer".

The top part is broader to reduce error of capillarity (which is described latter), in order to ensure accurate observations.

An air-trap is provided to prevent any air from finding its way into the vacuum at the top.

The lower end of the glass tube is immersed in a bowl (cistern) of mercury. The top of the cistern has one or more holes to admit air into it. These holes are covered with a thin leather washer which is permeable to air (air can pass freely through it) but impermeable to mercury or dust.

The entire barometer is enclosed in a metal case to protect the glass interior from damage. The top part of this metal case has millibar makings on it. A sliding cursor, with a vernier scale on it, allows readings up to 0.1 of a millibar. The vertical movement of the cursor is controlled by a milled knob.

The barometer is attached to a horizontal, suspension arm by gimbal rings. The other end of the suspension arm fits into a socket that is screwed on to the bulkhead. The suspension arm keeps the barometer well away from the bulkhead and the gimbals allow the barometer to remain vertical during rolling and pitching.

An attachment called a Gold Slide (described later in this chapter) is fitted on all modern mercury barometers for easy and quick correction of barometric readings.

Reasons why mercury is used in barometers

1) Mercury has a high relative density - 13.6. Therefore, a mercury barometer is less than one metre high whereas a water barometer would have to be over 10 meters high.
2) Mercury does not wet the glass surface as other liquids would.
3) Mercury is easily visible.

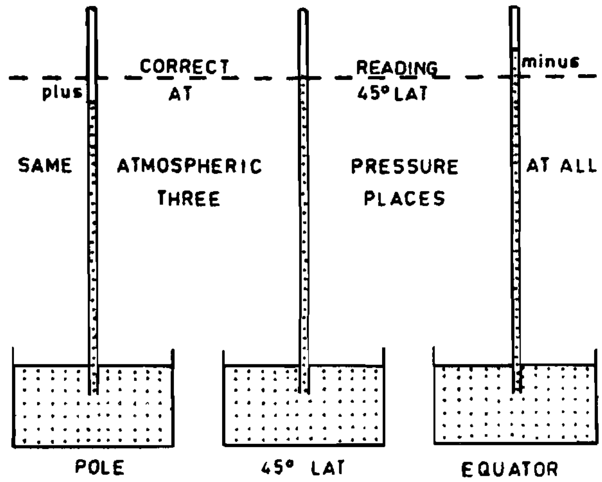
4) Mercury has a uniform coefficient of expansion so temperature correction can easily be applied accurately.
5) Mercury cannot escape easily through the leather washer on top of the cistern during transportation of the barometer, owing to its high viscosity (thick nature), whereas water or other such liquids would spill out easily.
6) Mercury has a low freezing point (about –39°C) and a very high boiling point (over 350°C) and hence is suitable for marine barometers.

Correction of barometric readings

For the sake of uniformity of climatic records and for forecasting purposes, all barometric readings should be reduced to a common datum - sea level in latitude 45° with no error due to temperature. All barometric readings should, therefore, be corrected for height, latitude, temperature and index error before making entries in the Mate's Logbook, Weather Logbook or weather reports.

(a) **Reason for height correction**: As explained in chapter 1, atmospheric pressure decreases as height increases. The reading on the bridge will, therefore, be lower than the reading at sea level. Since we have the reading on the bridge, but have to report the pressure at sea level, we have to **add** a correction for height to the bridge reading at the rate of 1 millibar for every 10 metres above sea level.

(b) **Reason for latitude correction**: Since the earth's polar radius is about 13 miles less than its equatorial radius, the gravitational force at the poles is greater than at the equator, One c.c. of mercury, therefore, weighs more at the poles than at the equator.



If, for example, we assume that the pressure at the equator, at 45° latitude and also at the pole was the same at a given instant, the height of the column of mercury at the pole would be less than that at latitude 45° whereas the height of the column at the equator would be more than that at latitude 45°, although the actual atmospheric pressures were equal. This means that the barometer readings in latitudes higher than 45° need a plus correction while those in latitudes lower than 45° need a minus correction to bring them to the uniform datum of 45° latitude. The rate of change is about 1 millibar for every 12° of latitude.

(c) **Reason for temperature correction**: Each mercury barometer is constructed to show correct readings at a particular temperature called the standard temperature or **fiducial temperature**, which is 0°C (273°K) for modern barometers and 12°C (285° K) for those constructed before 1st January 1955. The standard temperature of the barometer is mentioned on a brass plate attached to the metal case of the barometer, just below its gimbal ring.

If the temperature of the barometer is different from its standard temperature, the pressure indicated by the barometer has to be corrected at the approximate rate of 1 millibar for 6° difference. The correction is additive if the actual temperature is below the standard temperature and vice versa.

Temperature error is caused by the different coefficients of expansion of mercury, glass and the metal scale.

Adjusted fiducial temperature is the temperature at which the correction for temperature neutralises the correction for height and latitude. It is of no importance in modern meteorology.

(d) **Index error**: If a barometer does not give the correct pressure inspite of proper corrections being applied for height, latitude and temperature, the difference between the corrected barometric pressure and the actual atmospheric pressure is called the index error of the barometer, positive if the former is less and negative if the former is more e.g., if corrected barometric pressure is 1004.8 mb and the actual atmospheric pressure is 1005.2 mb, the index error is +0.4 mb. Index error should always be applied, as per sign, to the barometric reading.

On a request from a selected or supplementary ship, representatives of the National Weather Authority (in India, the India Meteorological Department) will came on board, free of charge, and compare the ship's barometer reading with the reading of a tested barometer that they bring with them. The index error is then entered on a card and attached to the barometer by a string.

Index error should be checked every three months as it may change slowly with time.

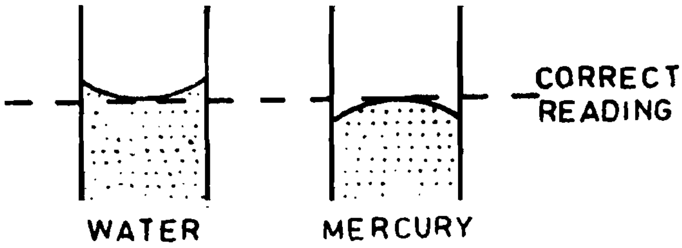
All the four corrections given earlier can be applied by a formula, where each correction is to be applied according to its sign:

Mercury barometer		**Correction**
Barometric reading	+	Height (in m) ÷ 10
	+	(Lat – 45°) ÷ 12
	+	(Std temp – actual temp) ÷ 6
	±	Index Error
	=	**Corrected reading**

However, the use of this formula is now a thing of the past as all modern mercury barometers come fitted with a Gold Slide which is accurate and quick to consult and which can be pre-set to include index error. If by a rare chance, a Gold Slide is not available, correction tables are given at the back of the "Marine Observer's Handbook" (usually supplied gratis by the National Weather Authority), for accurate results.

Others sources of error in barometric readings

1) **Capillarity**: Surface tension causes the surface of mercury in a tube to form a convex meniscus (upward curvature). A column of water will have a concave meniscus (downward curvature). The reading should always be taken at the centre of the meniscus. A piece of white paper held behind the barometer makes the observation easier.

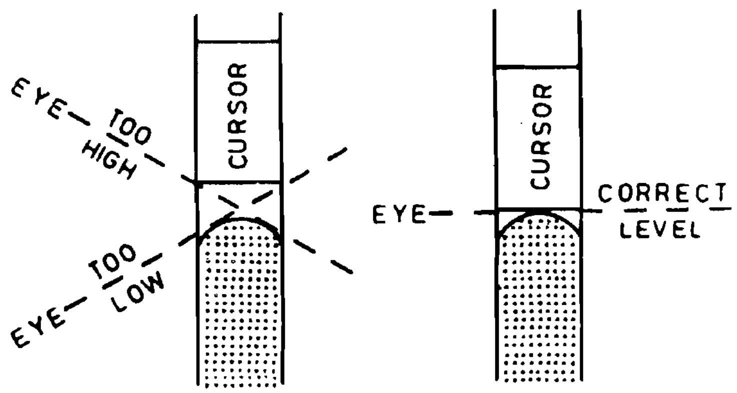


2) **Capacity**: The height of the mercury column should be measured from the level of mercury in the cistern. If the pressure rises, the mercury in the column rises but the level in the cistern falls, and vice versa. This means that the zero of the scale changes with pressure whereas the graduated part of the scale is fixed at the top. The error liable to be so caused is called error of capacity. Since the quantity of mercury in the whole barometer is a predetermined amount, manufacturers eliminate error of capacity by suitable permanent adjustment in the distance between graduations on the scale.

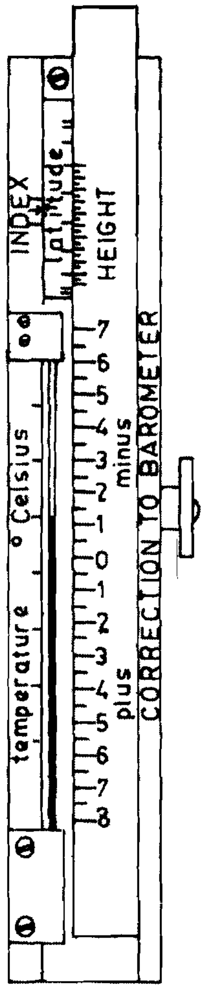
3) **Pumping**: is the oscillation (up and down movement) of the top of the mercury column, which causes inaccuracies during reading. Pumping is caused by gusts of wind, vessel's vertical movement (heaving) in a seaway, the pendulum-like swing of the barometer during rolling and pitching and due to vibration caused by ship's main engine, generators, etc.

   To minimise the error caused by pumping, three sets of readings should be taken - highest and lowest alternately - and the mean of all six readings should be taken.

4) **Error due to parallax**: is also called observational error. This is caused if the observer's eye is higher than or lower than the level of mercury during observation. This is eliminated by adjusting the level of the observer's eye such that the front edge and rear edge of the bottom of the cursor appear in transit during the observation.



The Gold Slide



FINER GRADUATIONS NOT SHOWN HERE

The Gold Slide was invented by Lieutenant Colonel E. Gold. It is an instrument for the quick computation of total correction (due to index error, height, latitude & temperature) which is to be applied to the reading of the barometer.

The latitude scale is fixed and not moved during normal use but it can be shifted up or down after slacking two screws at the back, in order to pre-set it to allow for the index error of the barometer.

The sliding scale on the right hand side can be moved up or down by the milled wheel provided. The height above sea level should be made to coincide with the latitude of the ship.

The total correction in millibars, is then read off from the lower part of the sliding scale, in line with the level of mercury in the attached thermometer. It is a good practice to first read the attached thermometer as soon as the barometer is approached. Otherwise, the body warmth of the observer could affect the reading of the thermometer and thereby cause an error in the total correction computed by the Gold Slide.

Location of a barometer on a ship

1) In the wheelhouse or chartroom for easy accessibility to the navigating officers.
2) As close to the centre line of the ship as practicable, to reduce pumping caused by rolling.
3) Reasonably out of the way so that people will not bump into it accidentally.
4) Away from direct gusts of wind, which will cause pumping.
5) Away from direct sunlight.
6) Away from draughts of air, blowers, heaters, etc., that could cause sudden or abnormal changes in temperature; on air-conditioned bridges, also away from access doors.
7) On a bulkhead not subjected to excessive vibration.
8) Top part of marine tube should be at eye-level or a little lower to allow easy reading.
9) Sufficient space should be available around the barometer so that the observer may rotate the barometer to face the light while setting the cursor, but face away from light while reading the scale.
10) Safe from tampering by unauthorised persons and secure from theft, especially in port.

Transporting a barometer

Gently lift the instrument and unship its bracket from its socket on the bulkhead. Very gently and slowly, tilt the instrument until it is horizontal so that the marine tube will gently get full of mercury. Any sudden movement during this tilting will either cause the mercury in the marine tube to bump against the top and break the glass, or let air get into the vacuum in the marine tube.

The instrument should then be gently placed in its box and carried in a horizontal position, preferably with the cistern a little higher than the marine tube, avoiding jerks and bumps. The mercury will not leak out of the holes in the cistern because of the leather washer which is permeable to air only.

When a barometer arrives on the ship (either new or after repair), it should be gently removed from its box and slowly brought upright and then its attached suspension arm should be shipped into its socket on the bulkhead. The mercury in the marine tube should flow back into the cistern to its correct level - if it does not, swing the barometer on its gimbals slowly or tap the cistern with gradually increasing force until it does. Unnecessary violence will only damage the barometer. Allow about two hours' time for the barometer to adjust itself to the surrounding temperature, before making observations.

After setting up a barometer (new or after repair) its index error should be checked (as explained earlier in this chapter).

Maintenance of the barometer

1) Keep barometer dry and free of dust by wiping with a soft cloth.
2) Keep glass cover of the graduated scale free of fingerprints.
3) Inspect the gimbal screws for wear and tear caused by swinging during rolling and pitching.

4) Avoid touching the graduated surfaces of the Gold Slide as fingerprints, perspiration or body oils create smudge marks on them.
5) Wipe the Gold Slide free of dust or dirt using a soft cloth.
6) Never apply metal polish of any kind on the Gold Slide as the abrasive action of the polish will first remove the paint in the graduations making it difficult to read and then it will wear down the face of the scale, making the graduations indistinguishable. Particles of metal polish will also clog moving parts. A little clock oil may be applied as a thin film to prevent corrosion by salt air.
7) A drop of clock oil should be applied now and then on all moving parts of the Gold Slide to ensure free movement.

Reading the mercury barometer

1) Note the temperature on the attached thermometer, set the Gold Slide and obtain the total correction to be applied, including index error.
2) Tap the barometer gently to ensure that the top of the mercury column has a smooth convex shape - if pumping is present, tapping is unnecessary.
3) Adjust cursor properly, avoiding error of parallax.
4) Allow for pumping, as explained earlier.
5) Read off the barometric pressure, apply total correction and obtain corrected barometric pressure.

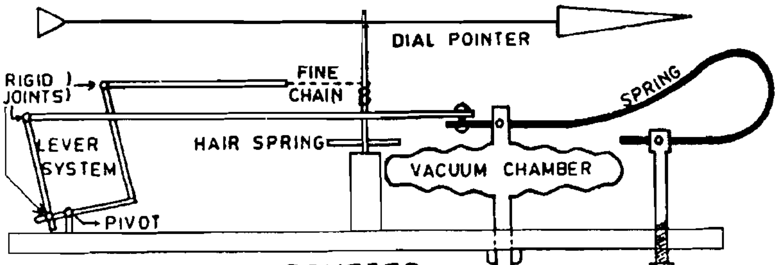
2. The aneroid barometer

Aneroid means without liquid. A sealed chamber made of very thin metal, having a partial vacuum inside it, is connected by a system of levers and springs to a pointer fitted over a circular, graduated scale. The thin metal has an elastic effect.

When the atmospheric pressure increases, the chamber gets compressed and the inward movement of its wall is transmitted mechanically to the pointer that then registers a higher reading on the scale.

When the atmospheric pressure decreases, the opposite happens. The expansion of the chamber is assisted by a spring.

The larger the chamber, the greater the accuracy of the aneroid barometer.



ANEROID BAROMETER

Errors of an aneroid barometer

For the sake of uniformity of climatic records, and for forecasting purposes, it is necessary to convert the reading to that at sea level. Hence readings of an aneroid barometer need two corrections — index error (instrumental error) and height above sea level.

(i) **Index error**: This is very likely and is caused by imperfect elasticity of the vacuum chamber. Index error is likely to change and should be obtained at least once in three months. This could be done by comparison with another aneroid barometer whose index error is known. Representatives of port meteorological offices in most ports usually bring their aneroid barometer on board for comparison, free of charge, on a request from the ship.

The index error should be entered on a special card hung near the instrument. If the index error becomes quite large, it can be reduced, if not eliminated, by a small adjustment on the back of the instrument, with the use of a screwdriver.

(ii) **Height correction**: Since atmospheric pressure near sea level falls at the rate of one millibar for every 10 metres increase of height, the correction may be calculated as follows:

Correction (in mb) = Height above sea level in metres ÷ 10 (always additive)

There is no correction to be applied for variation in atmospheric temperature as the manufacturers allow for it during construction.

Location of an aneroid barometer:

The instrument should be so positioned as to be:

(i) Away from undue vibration or sudden jerks (which would cause changes in its index error).

(ii) Away from draughts of air.

(iii) Away from places liable to experience abnormal or sudden changes of temperature.

(iv) As close to the centre line of the ship as practicable. This would minimise fluctuations caused by change of height above sea level during rolling.
(v) At eye level for ease of observation.

Precautions when using an aneroid barometer

Tap the face of the instrument lightly to release any sticking of levers or pointer due to friction.

Advantages of aneroid barometer

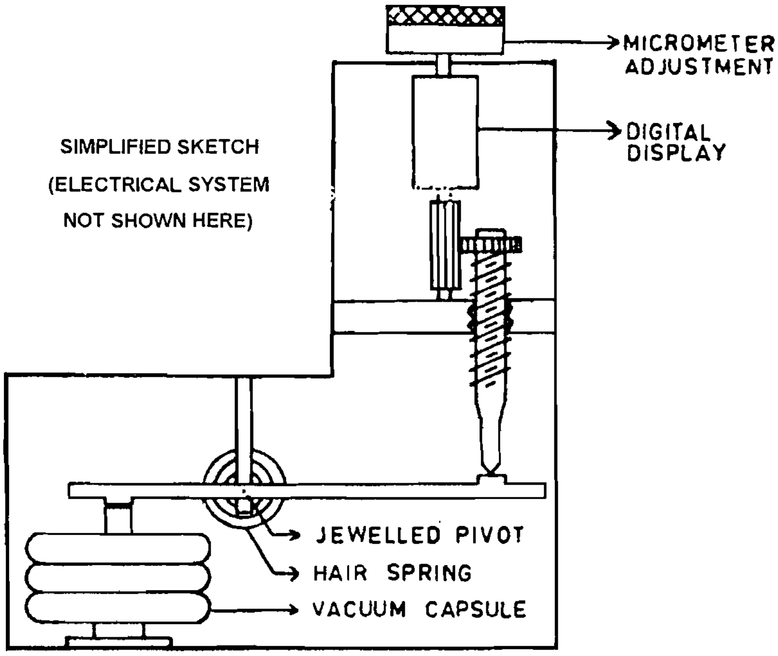
It is a robust and compact instrument. . Changes of pressure are easily detectable. For this purpose, a fixed pointer is provided, attached to the glass face of the instrument. After tapping the instrument, the fixed pointer is aligned with the dial pointer, taking care to avoid error of parallax. After some time (about half an hour or more) the instrument is tapped gently again. If the dial pointer now lies to the right of the fixed pointer, the pressure has risen and vice versa. The amount of rise or fall can also be noted.

Barometric tendency

Where a barograph is not working, or is not provided on board, barometric tendency can easily be obtained by the aneroid barometer - align the fixed pointer to the dial pointer every three hours, starting from 00 UTC, and note the change each time.

3. The precision aneroid barometer

This is a compact (small), robust (strong), accurate, aneroid barometer that has replaced the large, delicate, mercury barometer that was fitted on ships in the earlier days. It has a micrometer arrangement for reading to 0.1 of a millibar.



PRECISION ANEROID BAROMETER

Construction

The vacuum capsule consists of three metal chambers attached together like the bellows of an accordion. The shorter end of a pivoted lever rests lightly on the top of the vacuum capsule with the help of a hairspring. The pivot is jewelled to eliminate sticking due to friction. Increase or decrease of atmospheric pressure causes the top of the capsule to move in or out and the longer end of the lever to move up or down. This movement can be measured by a micrometer arrangement with a digital display showing the reading in millibars and decimal of a millibar.

To obtain the correct reading, the bottom of the micrometer arrangement should just touch the end of the lever. To assist in achieving this, a small cathode ray tube (magic eye) and a small battery are provided. A continuous line on the magic eye indicates contact and a broken line indicates a break in contact. To prolong the life of the battery, a spring-loaded switch is provided. When the switch is depressed, the magic eye is energized. When finger-pressure on the switch is released, the latter automatically switches off.

Reading the precision aneroid barometer

(i) Depress the switch and hold it there.

(ii) Increase the reading (by slowly rotating the micrometer-head) until the magic eye shows a continuous line.

(iii) Decrease the reading very slowly until the magic eye just about shows a broken line.

(iv) Release the switch and read off the pressure in millibars and decimal of a millibar.

Corrections to be applied.

(i) **Index error** can creep in due to the imperfect elasticity of the metal chamber and has to be applied to the digital reading each time. Index error should be checked once every three months or so. A card, placed conspicuously near the instrument, should state the date of comparison for index error, by whom and with what other instrument the comparison was made and the value of the index error so found.

(ii) **Height correction** is necessary, as in the case of the ordinary aneroid barometer, to convert the reading at bridge level to that at sea level, at the rate of +0.1 mb per metre height above sea-level.

Damping minor fluctuations due to gusts

To make the instrument insensitive to sudden, small changes of pressure caused by gusts of wind, rolling, pitching, heaving, etc., the outer casing is airtight except for one small air-inlet that is fitted with a damping device.

4. The barograph

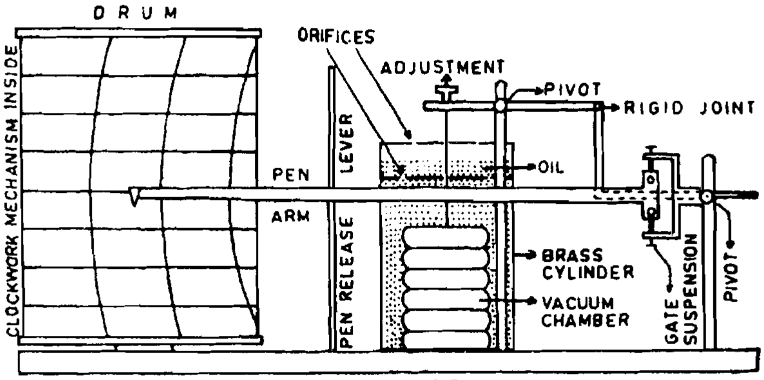
The barograph is an aneroid barometer that gives a continuous record of pressure on a paper chart. Such a chart, with a continuous barograph trace on it, is called a barogram. The barograph is so adjusted as to allow for index error and also error due to height above sea level. Comparison should be done once a week, when the paper is changed and, if necessary, adjustment of error made.

For climatic record purposes, the barograph is always set to UTC (GMT) not to ship's time.

Construction of the barograph

The vacuum chamber consists of a series of metal boxes arranged vertically, resembling the bellows of an accordion. Change of atmospheric pressure causes the top of the chamber to ascend or descend and this movement is conveyed by a lever system to a stylus (pen) that moves up or down on the chart.

The chart is fixed on a cylindrical drum that rotates at a uniform speed of one rotation per week. The rotation is effected by an eight-day clock mechanism. The clock is, therefore, wound whenever the chart is changed. The key of the clockwork mechanism can be reached by removing the lid of the drum.



THE BAROGRAPH

The tip of the stylus has a detachable pen that contains one drop of slow drying ink, specially supplied for this purpose. The ink needs to be replenished once a week and this is done by a dropper and inkbottle provided. The pen should be washed with water or cleaned with methylated spirit about once a month to ensure that the trace is thin, clear and even. Excess of ink should be avoided as the ink will not only corrode the pen arm but also cause the normally detachable pen to stick fast to the pen arm.

The entire barograph is provided with a hinged glass cover, to keep out gusts of wind and dust, and is mounted on springs and rubber pads to reduce vibration.

In modern barographs, the vacuum chamber is immersed in a brass cylinder of oil. As the chamber expands, oil is forced out of the top of the cylinder through small holes. When the chamber contracts, oil is sucked into the cylinder. This dampens the movement of the stylus (like the shock absorber of a motor car) and prevents small vibrations and gusts from making unwanted squiggles (embroidery) on the trace, without loss of accuracy of the barograph.

The chart or barogram

The vertical lines of the barogram that indicate UTC are at two-hour intervals and are curved, having the same radius of curvature as the length of the pen-arm, so that changes in pressure are recorded without creating an error in time.

The chart is fixed around the drum by means of two clips, one at the top and one at the bottom or one long clamp equal to the height of the drum.

The latter end of the chart should overlap its earlier end so that, in the event of the paper not being changed (due to oversight) at the end of a week, the pen will not catch on the edge of the paper and tear it.

Before handling the chart for renewal, the pen must be pulled clear of the chart by means of a pen release lever, provided for this purpose.

Time reference marks

Every day at 12 UTC, a button provided should be pressed a couple of times. This causes the pen-arm to move up and down slightly creating a time reference mark, for future reference by the meteorological department, in case the rate of rotation of the drum is slightly in error.

Completed barograms

As each barogram is completed, the entries on the back (latitude, longitude, dates, comparison with a barometer, etc.) should be filled up and the barogram handed over, along with completed weather logbooks, to the port meteorological office of the home port.

Location on board

(i) In the wheelhouse or chart-room, for easy accessibility to the navigating officers.
(ii) Out of the way to avoid being bumped into by people.
(iii) Away from direct sunlight or other sources of undue heat or cold.
(iv) Away from undue vibration.
(v) As close to centre line of vessel as practicable.
(vi) At eye-level.

Weekly schedule

(i) Renew chart
(ii) Wind the clockwork mechanism.
(iii) Replenish ink.
(iv) Compare and adjust reading to eliminate index error and error due to height above sea level.
(v) Wash pen at least once every month.

Advantage of barograph

The barograph gives a continuous record of pressure that can be matched by a barometer only if the latter is read and recorded every half hour!

The characteristic of the barometric tendency

This is a term used in the weather codes to denote the shape of the trace of the barograph during the three hours preceding the time of observation.

In the code group 5appp, 'a' stands for the characteristic of the barometric tendency (please see supplement to this book titled 'Ships Weather Code').

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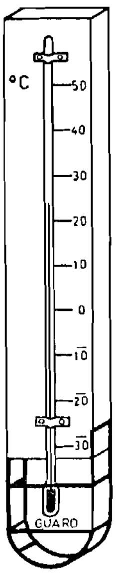
CHAPTER 16

OTHER METEOROLOGICAL INSTRUMENTS

1. The thermometer

The thermometer is an instrument for measuring temperature. Thermometers meant for normal use, to measure temperature of liquids and gases, contain mercury.



Description

A capillary tube of glass is attached to a bulb containing mercury, evacuated of air and sealed at its open end. When heated, the mercury in the bulb expands into the capillary tube. When the temperature increases, the mercury in the bulb expands and the length of mercury in the column gets more. When the temperature decreases, the mercury in the bulb contracts and the length of mercury in the column gets less.

The tube is graduated with two reference points - the freezing point and the boiling point of water. The graduation differs from type to type.

The World Meteorological Organisation has adopted the Celsius type where the freezing point of water is 0ºC and its boiling point, 100ºC. The length of the tube between 0 and 100 is divided into 100 equal parts. Since air temperature can fall below 0ºC, the thermometers on ships are usually graduated on the lower side of 0ºC, down to about –20ºC or so.

There are two other types of graduation and they are shown here for academic interest only.

	Celsius*	Kelvin#	Fahrenheit
Freezing point of water	0ºC	273ºK	32ºF
Boiling point of water	100ºC	373ºK	212ºF

* Formerly called Centigrade. # Formerly called Absolute.

Reasons why mercury is used

(i) Easily visible.
(ii) Large, uniform coefficient of expansion.
(iii) Does not wet the glass.
(iv) High boiling point (over 350ºC)
(v) Fairly low freezing point (about -39ºC).

Reading a thermometer

(i) Stand as far away as practicable so that body heat will not affect the thermometer.
(ii) Keep eye at same level as top of mercury column to avoid error of parallax.
(iii) Read the thermometer by judging it to the nearest tenth of a degree. If this is not possible, then read it to the nearest half of a degree.

2. The hygrometer (also called psychrometer)

The hygrometer is an instrument for obtaining the relative humidity and/or dew point temperature of air. The type in use at sea on merchant ships is called the Mason's hygrometer or *wet-and-dry-bulb* hygrometer or psychrometer.

Description

The hygrometer consists of two identical Celsius thermometers, one called the dry bulb thermometer and the other, the wet bulb thermometer. The wet bulb thermometer has a thin, single layer of muslin or cotton (starch free) tied around the bulb by a few strands of cotton wick. The extra length of the strands of wick is immersed in a bottle of distilled water. Both the thermometers are enclosed in a special, ventilated, wooden box called the Stevenson screen, described later. Both, the Mason's hygrometer and the Stevenson's screen are shown in a sketch under "Stevenson's screen".

Principle

Because of capillary action, the muslin always remains damp - water is drawn upwards, from the bottle through the strands of wick. If the atmosphere is dry, rapid evaporation takes place from the muslin. Since evaporation causes cooling, the wet bulb thermometer will show a much lower reading than the dry bulb thermometer. If the atmosphere is humid, evaporation from the muslin will be slow, and less cooling of the wet bulb will take place. The reading of the wet bulb thermometer will then be not much lower than that of the dry bulb thermometer.

In other words, the difference between the readings of the wet bulb and the dry bulb thermometers (called the depression of the wet bulb), gives an indication of the relative humidity of the air. The greater the difference, the lower the relative humidity and vice versa.

To find relative humidity and dew point

Meteorological tables, entered with dry bulb reading on one axis and the depression of the wet bulb on the other axis, give the relative humidity or the dew point of the air. Separate tables are provided for relative humidity and for dew point. Separate tables are provided for use with the hygrometer and with the whirling psychrometer.

Precautions when using a hygrometer

(i) The Stevenson's screen should be on the windward side, in open air, away from artificial sources of heat (heaters or blowers) and artificially heated draughts of air (from accommodation, funnel, hold ventilators, skylights, etc.,

(ii) It should be about 1.5 m above the deck for the convenience of the observer.

(iii) Sunlight falling on the Stevenson's screen is permitted but not directly on the thermometers.

(iv) It should be far away from metal bulkheads, etc., which will cause heat radiations that can affect the readings.

(v) The muslin should be clean - free of dust or salt particles carried by spray. If not, the wet bulb thermometer will give a higher than correct reading.

(vi) In any case, the muslin and strands of wick must be changed once a week. This is because solid particles are left behind by the evaporating water. These particles subsequently prevent free evaporation and the wet bulb reading will be higher than the correct reading. That is why distilled water is used. Even then, the distilled water available is rarely as pure as we would like it to be.

An entry should be made in the weather logbook every time the muslin is changed.

(vii) The muslin should be only just damp. Too much water on it, or too little, will cause the wet bulb reading to show higher than correct. This can easily be rectified by adjusting the number of strands of wick leading into the water bottle.

(viii) The water bottle should be washed and the distilled water in it renewed once a week.

(ix) Whenever distilled water has been added or changed, or the muslin has been renewed, or the Stevenson's screen has been shifted to the windward side, at least half an hour must elapse before reading the wet bulb thermometer, so as to allow sufficient time for evaporation.

(x) The dry bulb should be clean and clear of drops of condensed water.

(xi) Reading of a wet bulb thermometer inside a Stevenson's screen, when the wind speed is less than seven knots, are not accurate enough, as described later in this chapter under "Advantages of a whirling psychrometer".

Wet bulb reading higher than dry bulb

This can happen only under the following circumstances:

(i) Insufficient evaporation taking place from the wet bulb due to dust, salt or other impurities on the muslin, or due to no water on the muslin.

(ii) Insufficient time interval allowed after shifting of Stevenson's screen to windward, addition of distilled water, renewal of wick or water, etc.

(iii) Difference in the sensitivity of the thermometers whereby one of them is slow in recording sudden changes of temperature.

(iv) Faculty or broken thermometers.

Hygrometer readings below 0ºC

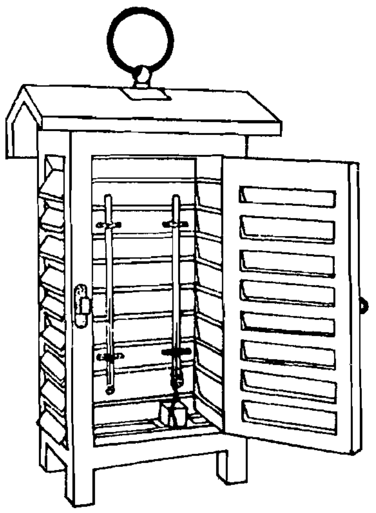
When the dry bulb reading is below 0ºC, the film of water on the wet bulb freezes into a thin layer of ice called frost. Once this has formed, the reading of the wet bulb thermometer will be below the reading of the dry bulb thermometer because evaporation takes place from ice as freely as from water. If the muslin dries up, distilled water should be dropped on it and, after this has frozen, readings may be taken.

In rare cases, drops of water may be seen on the wet bulb even though the temperature of the dry bulb is well below 0ºC. Such drops of water are said to be super-cooled and great error in reading will result. In such a case, the wet bulb should be touched by a snow crystal, the back of a pencil or other cold object and freezing will start. The reading should be taken only after about fifteen minutes or so, after freezing of the drops on the wet bulb is complete.

3. The Stevenson screen

This is a wooden box specially constructed to house a hygrometer. It was invented by Thomas Stevenson (father of Robert Louis Stevenson).

It is a wooden cupboard with a hinged door. The door, the back and the two sides, are all fitted with "louvers" or slats which let air circulate freely without letting in direct solar radiation or re-radiated heat from ship's structure. The louvers also keep out rain and spray. There are various types of Stevenson's screens. The type found on ships is the portable type.



THE STEVENSON SCREEN

If sunlight is allowed to fall directly on the thermometer it will get very hot and the reading shown by it will be the temperature of the instrument itself, not that of the atmosphere. Inside the screen, the thermometer will show the temperature of the atmosphere because of the shade and the free circulation of air.

During the night, if the thermometer was out in the open, its bulb would radiate out its heat very quickly, much quicker than the air and would thus show a lower-than-true reading of atmospheric temperature. The thermometer will then show the temperature of the instrument itself, not that of the atmosphere.

While using the screen, the heat radiated by the mercury is partially retained inside the screen and the reading shown by the thermometer will be closer to the true reading than when in the open.

Positioning of Stevenson screen

This has already been described earlier in this chapter under 'Precautions when using a hygrometer'.

4. The whirling psychrometer

This is a very efficient type of hygrometer. Hence its basic principle is the same as that described, earlier in this chapter, under "Hygrometer".

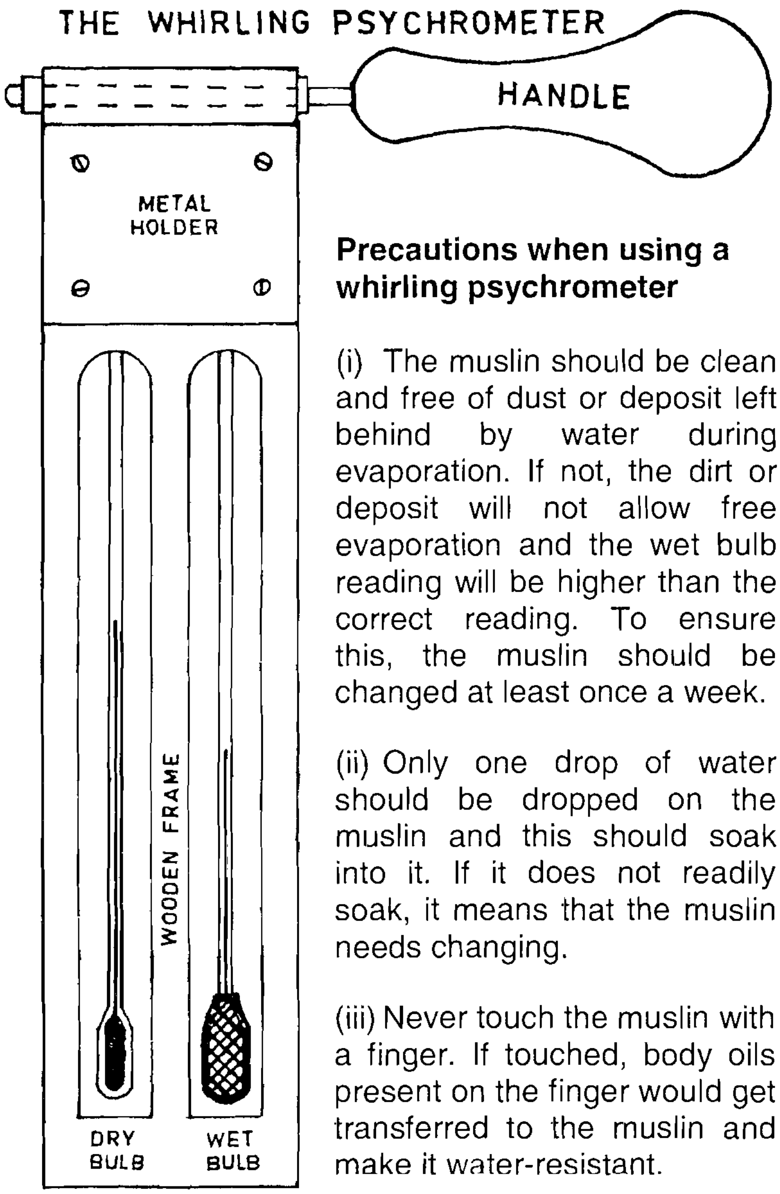
Description and use

It consists of a light wooden frame, pivoted to revolve smoothly around a handle. The frame has two identical Celsius thermometers mounted on it. One of them has a single layer of thin muslin tied firmly around its bulb, with string, and is called the wet bulb thermometer.

When required, the frame is held horizontal and, using a dropper, one drop of distilled water is made to fall on the muslin to make it damp.

The frame is then whirled in open air for at least two minutes before reading off the wet and dry bulb temperatures. By entering meteorological tables with the dry bulb reading on one axis and the depression of the wet bulb on the other axis, the dew point and/ or the relative humidity is obtained.

Different tables are used for the whirling psychrometer and for the hygrometer in the Stevenson's screen because of their different rates of evaporation.



Precautions when using a whirling psychrometer

(i) The muslin should be clean and free of dust or deposit left behind by water during evaporation. If not, the dirt or deposit will not allow free evaporation and the wet bulb reading will be higher than the correct reading. To ensure this, the muslin should be changed at least once a week.

(ii) Only one drop of water should be dropped on the muslin and this should soak into it. If it does not readily soak, it means that the muslin needs changing.

(iii) Never touch the muslin with a finger. If touched, body oils present on the finger would get transferred to the muslin and make it water-resistant.

(iv) When the muslin does not soak water readily, officers have been known to coax the water in by rubbing the muslin with a wet finger, instead of renewing the muslin. This is wrong and only makes the muslin more and more water-resistant and results in erroneous readings.

(v) Always swing the instrument in the open air on the windward side of the ship, away from direct sunlight.

(vi) While swinging the instrument care should be taken to ensure that it does not strike against any obstruction, resulting in broken thermometers. The whirling psychrometer is the most frequently damaged instrument on a ship's bridge, and that too, by carelessness.

(vii) The instrument should be swung for at least two minutes. The readings of the thermometers should be made soon thereafter, while out in the open air, using a torch if necessary. If was brought under the chart-room light for reading, the reading would have altered by then.

Advantages of a whirling psychrometer

(i) Very simple instrument.

(ii) Very quick readings.

(iii) Very accurate. It has been observed that the rate of evaporation, and hence the depression of the wet bulb, depends on the speed of air flowing past the bulb i.e., the greater the wind speed, the more the depression of the wet bulb and vice versa.

The rate of evaporation reaches a maximum at about seven knots wind speed and any further increase of wind speed does not make any appreciable change i.e., when the wind speed past the bulb is seven knots or more, the reading of the wet bulb can be relied upon.

In the case of hygrometer inside a Stevenson screen, the airflow depends entirely on the direction and force of the wind outside the screen. If such wind is less than seven knots, the wet bulb reading cannot be relied upon.

In the case of the whirling psychrometer, a speed of one rotation per second equals to a wind flow of more than seven knots past the bulb. Since the average person would rotate it at about 2 rotations or more per second, the reading of the wet bulb thermometer is accurate.

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CHAPTER 17

VISUAL STORM WARNING SIGNALS

The Meteorological Warning Centre sends, on high priority, storm warnings to Port Authorities whose ports are likely to be affected by adverse weather.

The Port Authorities display visual storm signals, on conspicuous masts specially meant for this purpose, for the benefit of vessels in port or in the vicinity of the port. The signals consist of black coloured cones and cylinders by day and of red and white lights by night. The Port Authorities also send word to fishing vessels and country craft in their respective ports.

VISUAL STORM WARNING SIGNALS IN USE

	SIGNAL		
	No:	**Day**	**Night**
DISTANT CAUTIONARY: There is a region of squally weather in which a storm may be forming.	I		OW OW
DISTANT WARNING: A storm has formed.	II		●R ●R
LOCAL CAUTIONARY: The port is threatened by squally weather (see note at the end).	III		OW ●R

LOCAL WARNING: The port is threatened by a storm but it does not appear that the danger is as yet sufficiently great to justify extreme measures of precaution.	IV		●R ○W
DANGER: Port will experience severe weather from a cyclone expected to move keeping the port to the left of its track.	V		○W ○W ●R
DANGER: Port will experience severe weather from a cyclone expected to move keeping the port to the right of its track.	VI		●R ○W ○W
DANGER: Port will experience severe weather from a cyclone expected to move over or close to the port.	VII		○W ●R ○W

GREAT DANGER: Port will experience severe weather from a severe cyclone expected to move keeping the port to the left of its track.

VIII

○W
●R
●R

GREAT DANGER: Port will experience severe weather from a severe cyclone expected to move keeping the port to the right of its track.

IX

●R
●R
○W

GREAT DANGER: Port will experience severe weather from a severe cyclone expected to move over or close to the port.

X

●R
○W
●R

FAILURE OF COMMUNICATIONS. Communications with the Meteorological Warning Centre have broken down and the local officer considers that there is danger of bad weather.

XI

●R

CHAPTER 18

SURFACE CURRENTS -

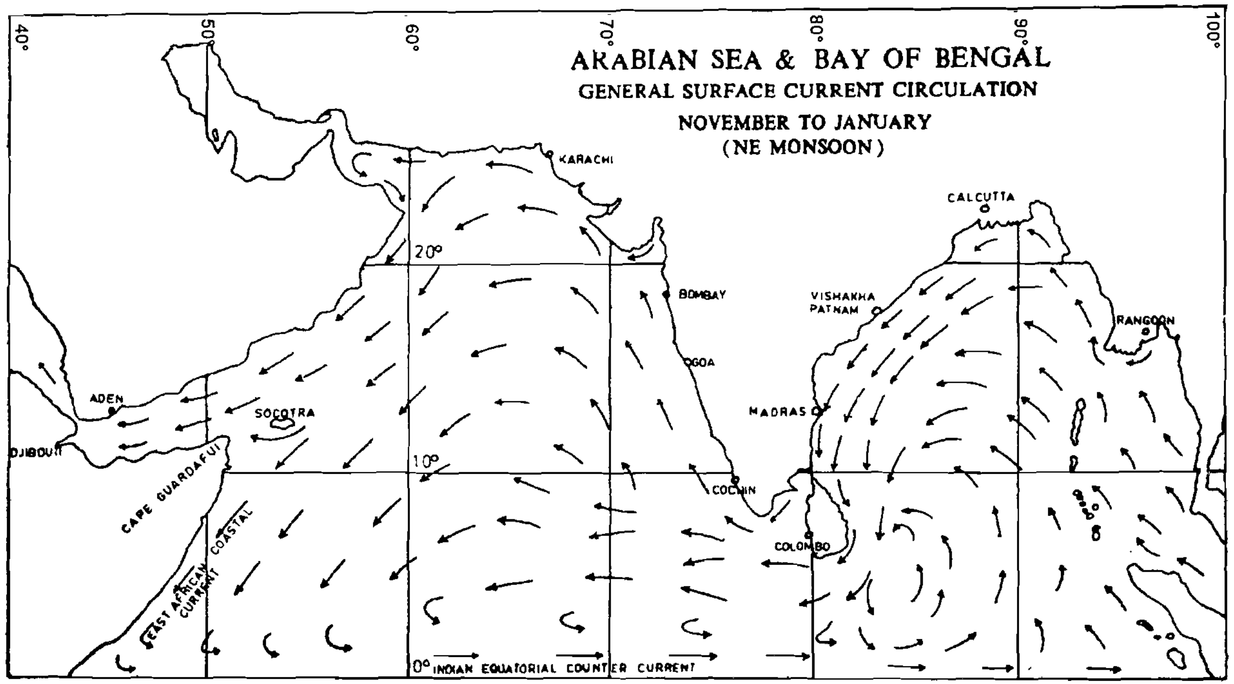
ARABIAN SEA & BAY OF BENGAL

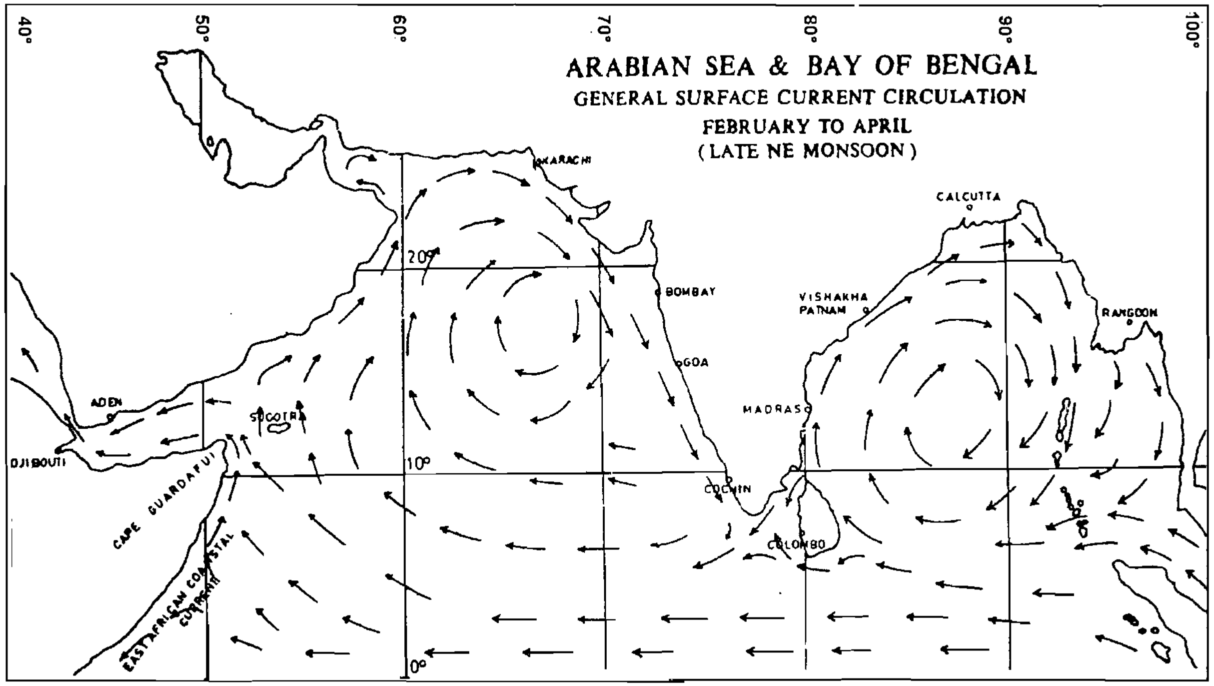
During the NE Monsoon

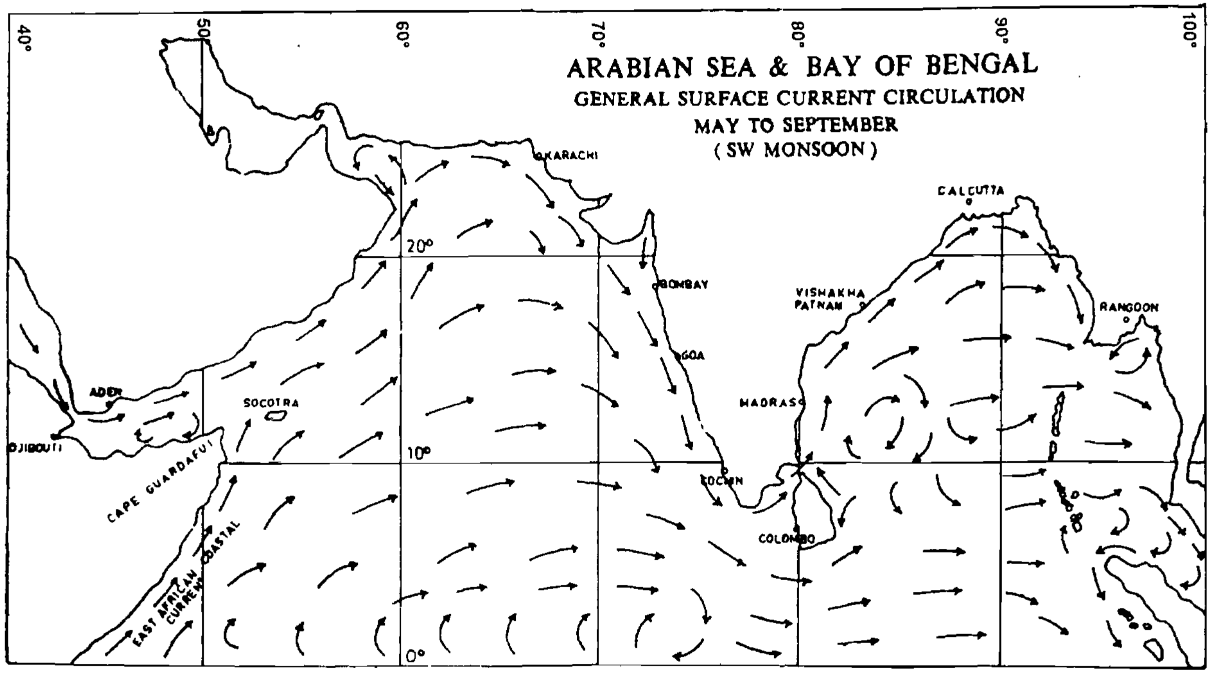
In open waters, the general movement is westward, being caused by the NE Monsoon and being deflected to the right by Coriolis force. Coastal effects cause an anticlockwise circulation, the easterly flow being provided by the Indian Equatorial Counter-current. The maximum rate of current is near Cape Guardafui, between 5º & 10º N, where it may be as high as 4 knots.

During late NE Monsoon

Although the main flow of water, in open waters, is westerly, the coastal circulation becomes clockwise. This is because the cool air, of the NE Monsoon, lowers the temperature of the sea-surface at the head of the Arabian Sea & Bay of Bengal by as much as 3ºC. A gradient current therefore flows northwards along the western shores of both waters, opposite to the wind direction. By the time this gradient is neutralized, the SW Monsoon arrives.


ARABIAN SEA & BAY OF BENGAL
GENERAL SURFACE CURRENT CIRCULATION
NOVEMBER TO JANUARY
(NE MONSOON)
40°
50°
60°
70°
80°
90°
100°
20°
10°
0°
KARACHI
BOMBAY
GOA
COCHIN
CALCUTTA
VISHAKHA PATNAM
MADRAS
COLOMBO
RANGOON
ADEN
DJIBOUTI
SOCOTRA
CAPE GUARDAFUI
EAST AFRICAN COASTAL CURRENT
INDIAN EQUATORIAL COUNTER CURRENT


ARABIAN SEA & BAY OF BENGAL
GENERAL SURFACE CURRENT CIRCULATION
FEBRUARY TO APRIL
(LATE NE MONSOON)
40°
50°
60°
70°
80°
90°
100°
20°
10°
0°
KARACHI
BOMBAY
GOA
COCHIN
MADRAS
COLOMBO
VISHAKHA PATNAM
CALCUTTA
RANGOON
ADEN
DJIBOUTI
SOCOTRA
CAPE GUARDAFUI
EAST AFRICAN COASTAL CURRENT


ARABIAN SEA & BAY OF BENGAL
GENERAL SURFACE CURRENT CIRCULATION
MAY TO SEPTEMBER
(SW MONSOON)
40°
50°
60°
70°
80°
90°
100°
20°
10°
0°
KARACHI
BOMBAY
GOA
COCHIN
MADRAS
COLOMBO
VISHAKHA PATNAM
CALCUTTA
RANGOON
ADEN
DJIBOUTI
SOCOTRA
CAPE GUARDAFUI
EAST AFRICAN COASTAL CURRENT

During the SW Monsoon

In open waters, the general movement is eastward, being caused by the SW Monsoon and being deflected to the right by Coriolis force. The SW Monsoon greatly strengthens the clockwise coastal circulation already existent just before its onset. During this period, the East African Coastal Current is very strong and in September, north-easterly tidal rips upto 168 miles per day (7 knots) have been recorded off the south-west coast of the island of Socotra.

Caution

The description and the current circulation charts given in this chapter are to give a general understanding of the situation. The currents are variable in various parts of the Arabian Sea and the Bay of Bengal. Even the monthly limits mentioned therein should not be constructed as rigidly and strictly correct.

For a detailed study of this topic (not usually required for merchant navy officers) and for navigational uses, publications such as "Indian Ocean Currents" and appropriate pilot books should be consulted.

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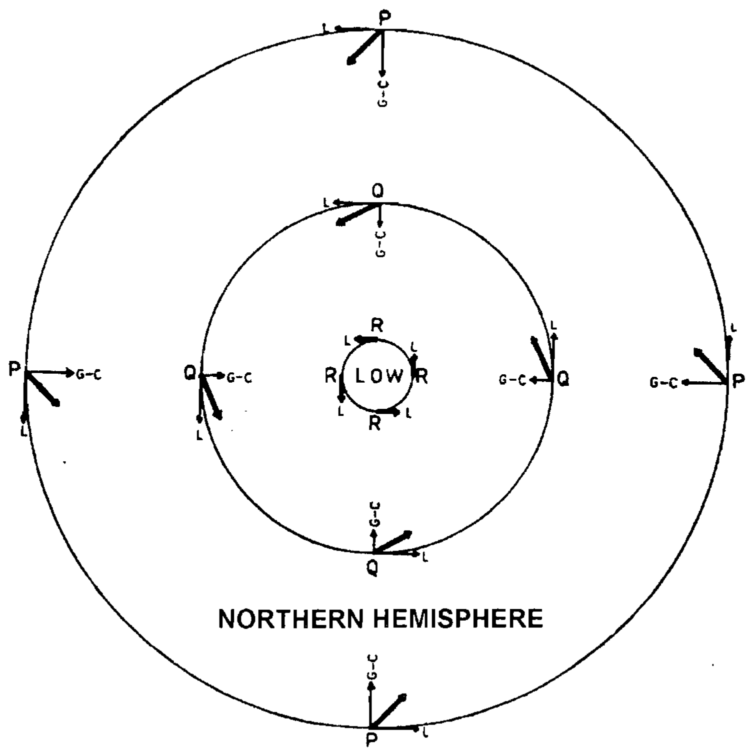
CHAPTER 19

CYCLOSTROPHIC FORCE

Explanation

If a stone was being swung in a circular path by a string and if the length of the string was suddenly decreased (radius of rotation of the stone suddenly decreased), it will be observed that the speed of rotation of the stone increases.



Similarly, as the radius of rotation of the winds in a TRS decreases, due to its spirally inward movement, the wind speed increases.

As the wind speed increases, a new force called "Centrifugal force" or "Cyclostrophic force" comes into being. This force acts radially outwards from the centre of rotation (low-pressure area). The greater the speed of rotation, the greater the Cyclostrophic force. Cyclostrophic force, therefore, increases steadily from practically nil at the outer fringes of the TRS to maximum in the eye-wall.

In the foregoing figure, P is a point on the outer fringes of a TRS, R a point in the eye-wall and Q, a point about midway between P and R.

At P, gradient force (G) acts radially inwards while Cyclostrophic force (C) acts radially outwards. The latter is negligible at the outer fringes of the TRS. The resultant of G and C is as shown in the figure. The wind that finally blows at P is the resultant of G-C and Coriolis force (L), and has an angle of indraft of about 45°.

At Q, cyclostrophic force has reached a certain amount and G-C is now less than before, as shown in the figure. The wind that blows at Q is the resultant of G-C and L and has an angle of indraft of about 22°.

At R, cyclostrophic force has increased to such an extent that it is now equal to gradient force (G-C = zero), and there is no inward force at all. The wind that blows, as a resultant of G-C and L, hence blows in a perfectly circular path (i.e., with an angle of indraft of 0°).

The foregoing explains why or how:

1. The winds in a TRS blow in a spirally inward path.
2. The winds reach maximum force in the eye-wall.
3. There is no wind in the eye.
4. Buys ballot's law was derived.

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CHAPTER 20

COMPARISON BETWEEN TRS & TLD

A tabulated comparison between tropical revolving storms and temperate latitude depressions is given below:

	TRS	TLD
1	Diameter between 50 and 800 miles average usually less than 500 miles.	1000 to 2000 miles across.
2	Only one single air-mass involved	Two different air masses involved.
3	Wind speeds can be as high as 130 knots, with gusts upto 150 knots.	Wind speeds rarely exceed 55 knots.
4	Wind speeds are maximum at lower levels and decrease with height.	Wind speeds increase with height. At a height of 1.5 km, jets of 100 to 200 knots may be experienced.
5	Travel East to West before recurring.	Always travel West to East.
6	No appreciable change in air temperature when it passes over an observer.	Drastic changes of air temperature, as much as 20°C, owing to the different air masses in contact.

7	Form in areas of constant winds (Trade Wind areas)	Usually form in an area of different wind directions.
8	Energy obtained from latent heat given off by enormous condensation	Energy obtained from lifting of warm air by cold air.
9	Similar pattern of isobars exist throughout life of storm.	Pattern of isobars vary and change very much during life of depression.
10	Clouds are mostly Cb with some stratiform type above outer storm area.	Clouds are mostly of the stratiform type except for a line of Cb above the cold front.

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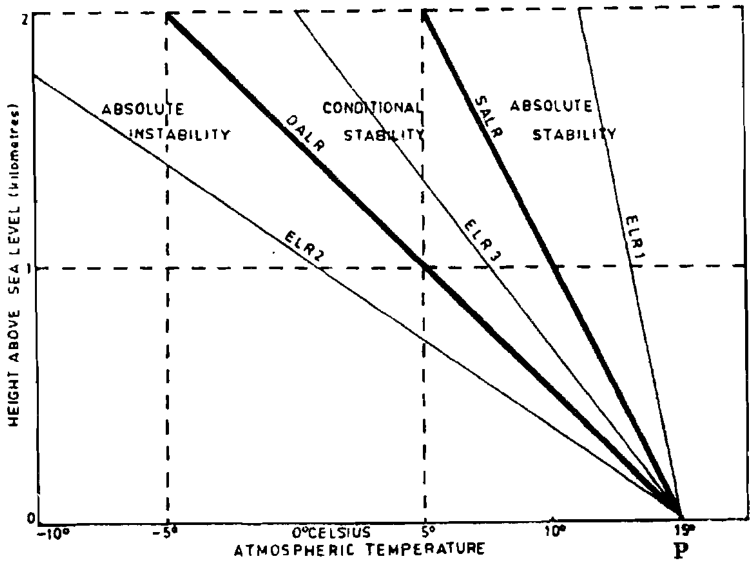
CHAPTER 21

STABILITY OF AIR

Equilibrium of a fluid (gas or liquid) is its tendency to return to its original position, when slightly displaced by an external force.

In the figure below, consider a point P at sea level, having an atmospheric temperature of 15°C. If a parcel of air at P was made to rise slightly by some disturbance, its temperature would fall by 10°C per km height (DALR) if the parcel was dry, and by about 5°C per km height (SALR) if it was saturated, shown by the DALR and SALR lines in the figure below.



Absolute Stability

If the surroundings (environment) are such that the actual lapse rate existent is less than DALR and SALR, absolute stability is said to exist (see ELR (1) in figure).

i.e., If dry temperature of parcel at 1 km height is 5°C

If wet, " " " " " " 10°C

Present temperature of surrounding air at 1 km height, as per ELR (1) in figure, is more than 10ºC.

This means that the parcel of air is colder (and hence denser) than the surrounding air at that level and would thus try to return below, to its original position. Because this happens regardless of whether the parcel was originally saturated or not, this condition is referred to as absolute stability.

Absolute Instability

If the environment is such that the actual lapse existent is more than SALR and DALR, absolute instability is said to exist (see ELR (2) in figure).

i.e., If dry, temperature of parcel at 1 km height is 5°C

If wet, " " " " " " 10°C

Present temperature of surrounding air at 1 km height as per ELR (2) in figure, is less than 5ºC.

This means that the parcel of air is warmer (and hence less dense) than the surrounding air at the same level and would thus try to continue upwards in the direction of the original disturbance. Because this happens regardless of whether the parcel was originally saturated or not, this condition is referred to as absolute instability.

Conditional Stability

If the environment is such that the actual lapse rate existent is less than DALR but more than SALR, conditional stability is said to exist (see ELR (3) in figure).

i.e., If dry temperature of parcel at 1 km height is 5°C
If wet, " " " " " " 10°C

Present temperature of surrounding air at 1 km height as per ELR (3) in figure, is between 5°C and 10°C.

This means that if the parcel of air is dry, it is colder (and hence denser) than the surrounding air at the same level, and would try to return below to its original position i.e., stable equilibrium.

If the parcel of air is saturated, it is warmer (and hence less dense) than the surrounding air at the same level, and would try to continue upwards, in the direction of the original disturbance i.e., unstable equilibrium.

Because stability or instability, in this case, depends on whether the parcel is dry or saturated, this condition is referred to as conditional stability.

Neutral equilibrium of air

If the ELR coincides with DALR when the parcel of air is dry or with SALR when the parcel is saturated, then the parcel of air which is displaced upwards, is the same temperature as that of the surrounding air at the same level and would have no tendency to return to its original position or to continue upwards in the line of original disturbance. This condition is called indifferent or neutral equilibrium.

CHAPTER 22

ICE AT SEA

Ice at sea in this chapter refers to floating ice encountered at sea and excludes ice accumulation on board ship. Ice at sea is of two types:

1. Sea-ice formed by the freezing of sea water and
2. Icebergs, which are huge masses of floating ice.

Sea-ice accounts for most of the ice met with at sea. Icebergs are important because they are dangerous to navigation but they are confined to limited areas.

Fresh water freezes at 0°C whereas salt water freezes at lower temperatures. The greater the salinity, the lower the freezing temperature. Average seawater is of salinity 35‰ (35 parts per thousand) and it freezes at about –2°C.

As the surface cools, the surface water becomes denser and sinks, creating convection currents. Water will not freeze until the entire body of water has cooled to freezing temperature. Hence the surface of deep-sea waters does not freeze, even if the air temperature is extremely low.

1. Sea-ice

In shallow waters, the convection currents have very little vertical distance to travel. The entire body of water is easily cooled to freezing temperature and sea-ice forms over shoal banks, over bays, inlets, straits and estuaries where there is no appreciable current/tide and where the salinity is low. Ice first forms on the surface because of contact with very cold air and spreads downwards, with the initial ice crystals on the surface acting as nuclei.

When the air temperature is very low and a few particles of ice are already present, these particles can cause more ice to form on the surface, even though the entire body of water has not yet cooled to freezing temperature.

Wave action hinders the formation of sea-ice. If sea-ice has already formed, wave action breaks it up into small pieces (brash-ice). Currents or tides carry away the ice particles and retard the growth of sea-ice. Sea-ice may grow about 7 to 10 cm thick during the first 24 hours and about 5 to 7 cm more in the next 24 hours. Thereafter, the growth is slower because the surface ice insulates the water from the cold air.

2. Icebergs

Icebergs are huge masses of floating ice, broken off from (i) glaciers and (ii) ice-shelves. Though the relative density of pure, solid, fresh water ice is 0.916, the relative density of icebergs is only about 0.9 because of pockets of air trapped in them.

2.1. Icebergs of glacier origin:

When persistent snow falls on a mountainside and freezes into ice, the weight of the ice makes the entire mass of ice slide down the mountainside. The ice, sliding down very slowly, about a few centimetres per day because of obstructions such as rocks, trees, etc., is called a glacier.

When the lower edge of a glacier reaches the sea, large chunks (as much as a few miles across) break off and are carried away as icebergs by ocean currents and winds.

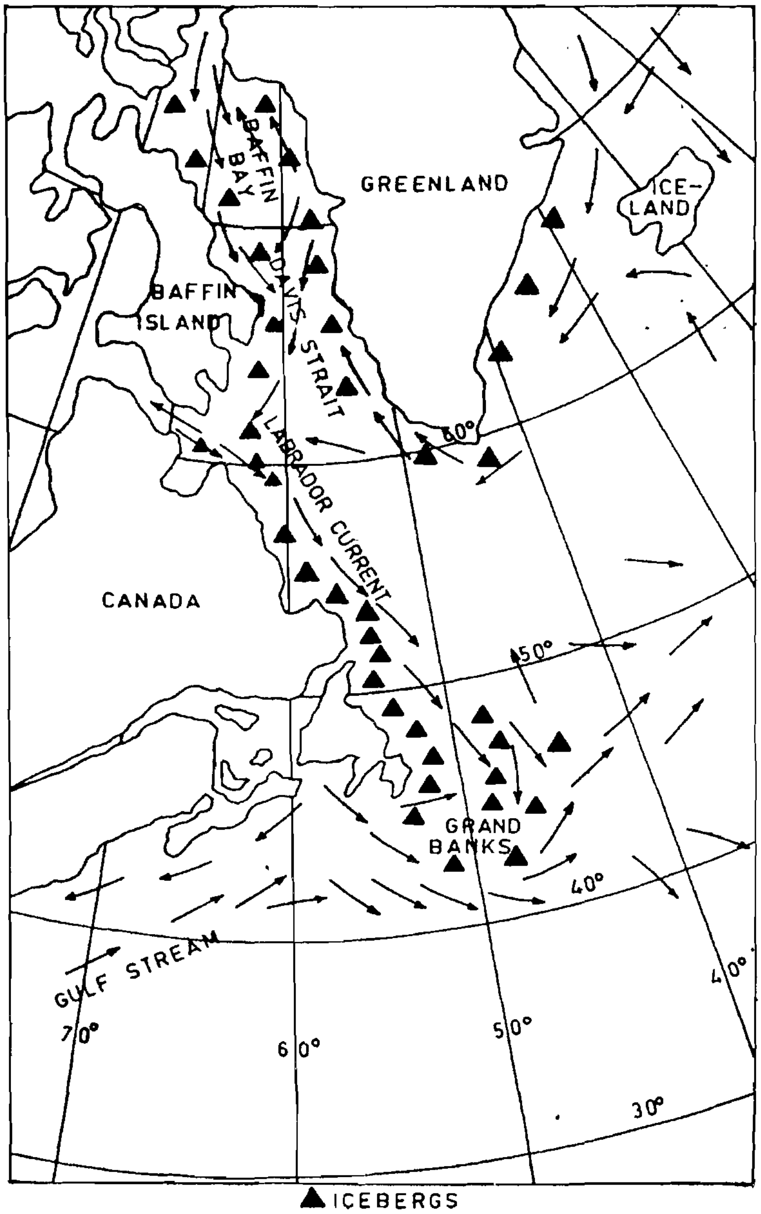
Icebergs of glacier origin have irregular shapes. Their tops are frequently pinnacle-shaped and their sides, sloping. They are hence not good radar targets, considering their size. Such icebergs have been known to suddenly disappear from the radar screen (owing to change of aspect) even when range had not increased.

Based on actual measurements made by the International Ice Patrol, the depth below water of an iceberg, of glacier origin, may be anything from one to five times its visible height above the sea surface (this refers to vertical distance not volume). Parts of icebergs may extend horizontally much further underwater than visible above water.

The tallest iceberg seen in the Grand Banks was 80 metres high and the longest, 517 metres. Icebergs over 900 metres long have been seen further north.

Most of the icebergs in the northern hemisphere are of glacier origin. 90% of the land ice in the north polar region is in Greenland. An estimated total of 15,000 to 30,000 icebergs break off from Greenland each year but only about 1% (150 to 300) of them make it to the Atlantic Ocean.

The icebergs born on the east coast of Greenland are carried south-westwards by the East Greenland Current (see accompanying map). After rounding the southern tip of Greenland, they join the icebergs born on Greenland's west coast. They are then carried northwards by the West Greenland Current.


GREENLAND
ICE-
LAND
BAFFIN
BAY
BAFFIN
ISLAND
DAVIS STRAIT
LABRADOR CURRENT
CANADA
60°
50°
40°
GRAND
BANKS
GULF STREAM
70°
60°
50°
40°
30°
ICEBERGS

From Baffin Bay (about 75°N), they are brought southwards by the Labrador Current. By the time they reach the Grand Banks, they are one to two years old.

The volume of an average-sized iceberg in this region is about 20,000 cubic metres. Its rate of drift is erratic, being between 10 & 70 nautical miles per day.

The International Ice Patrol advises shipmasters to keep at least 100 miles off from the last reported position of an iceberg. This may mean an eight-hour detour for a vessel bound for New York and a twenty-four-hour detour for a vessel bound for Canadian or Great Lakes ports.

On meeting the Gulf Stream, whose temperature is as high as 16°C, the average sized icebergs melt in one or two weeks. The larger ones may take as long as two months.

2.2. Icebergs of ice-shelf origin:

These are common in high latitudes of the Southern Hemisphere. They are huge chunks broken off from large ice-shelves. Some times, an entire shallow bay of water freezes and, later on, breaks off and floats free.

Icebergs of ice-shelf origin are called tabular bergs because of their vertical sides and smooth, horizontal tops. They are good radar targets. Many have been measured and found to be 20 to 30 miles long and 10 to 35 metres high. The longest on record was 90 miles long and 35 metres high, seen in 1927.

Diminution of icebergs

Icebergs becomes smaller in size due to the following reasons:

1. Calving (breaking off) into smaller pieces.
2. Melting caused by warm ocean currents. Such underwater melting will result in frequent toppling and calving.
3. Melting due to warm air and sunlight.
4. Erosive action of wind and waves.

Visibility of an iceberg

Day-time:

1. On days with clear skies, about 18 M off from the masthead and about 12 to 15 M off from the bridge.
2. On cloudy days with good visibility, about 2 M less than on clear days.
3. Light fog/haze/drizzle/rain - 2 to 3 M.
4. Dense fog - not detectable more than 100 metres.

Night-time:

1. On nights with clear skies and good visibility, about ¼ M to the naked eye. If bearing is known, then 1M using night glasses.
2. Difficult to detect in moderate or rough sea.
3. Moonlight has very strong but variable effect on visual detection range, depending on the azimuth and altitude of Moon, bearing of the iceberg, etc.

Probable indication of the proximity of an iceberg.

1. Possible detection by radar. It should be borne in mind that sub-refraction usually exists in the vicinity of icebergs. Icebergs may have smooth sloping sides making them poor radar targets.

The low profile growler* is the poorest form of ice target for radar - detection range not more than 4 M.

2. Thundering noises as growlers calve from icebergs.
3. Ice-blink (whitish glare on low clouds near horizon).
4. Presence of smaller pieces of ice which may have calved from the iceberg. The iceberg would probably be to windward.
5. Noise of sea breaking over edge of the iceberg.
6. A sudden drop of wind speed accompanied by a severe drop of air temperature. These are caused when the vessel comes into the lee of an iceberg.

Echoes of the ship's whistle from an iceberg or a drop of sea temperature are not considered reliable indications.

Classification of Icebergs

Icebergs have been classified by the International Ice Patrol as follows:

	Height above SL in metres	Length in metres
Growler	Under 1	Under 6
Bergy bit	1 to 6	6 to 15
Small berg	6 to 15	15 to 60
Medium berg	15 to 45	60 to 120
Large berg	45 to 80	120 to 215
Very large berg	Over 80	Over 215

*Description of growler is given under 'Classification of icebergs' at the bottom of this page.

In case the length of an iceberg and its height fall into different categories, the larger of the two classes is used. For example, if the length was 70 metres and height was 10 metres, the iceberg should be classed as a medium berg.

Some ice terms

Brash-Ice: Small pieces of floating ice, (each less than 2 m in length), broken off from larger pieces.

Fast-Ice: A large ice-field which remains stationary, being stuck to the shore, rock, shoals or other obstruction.

Field-Ice: or Ice-field is a large area of floating ice, whose boundaries are not visible even from the masthead. The floes in an ice-field can be of any size.

Floe: Or ice-floe is the name given to each single piece of floating sea-ice regardless of its size. Small floes may be as small as ten metres long, while a huge floe may be a few miles across (see also, ice-cake).

Hummock: An elevated part or ridge formed on a floe due to pressure. When a drifting ice-field comes across a small obstruction, the rest of the ice-field continues to drift but the obstructed part experiences the enormous pressure of the ice from behind and this results in the formation of vertical ridges or hummocks.

Iceberg: A large mass of floating ice, having a height of at least 5 metres above sea level. It could be of glacier or ice-shelf origin.

Ice-blink: A whitish glare on low clouds near the horizon caused by reflection of light from a distant iceberg or ice-field.

Ice-cake: The name given to a piece of floating sea-ice, which is less than 10 metres in length (see also brash-ice)
Ice-edge: The boundaries, of an ice-field, beyond which open sea exists.
Ice-limit: The estimated position of the ice-edge during any given month or period, based on past observations.
Land-Ice: Ice of land origin - formed either on land on attached to land.
Pack-Ice: Or drift-ice means an area of any kind of sea-ice except fast-ice.
Pancake-Ice: Circular pieces, of newly formed ice, having diameter's between 0.3 and 3 m. The edges of the pieces may be raised due to collision with adjacent pieces.
Rotten Ice: Pieces of ice in the final state of melting, whereby they appear riddled with holes.
Sludge or Slush: The name given to a grey, gummy appearance of the sea owing to the presence of freshly formed ice-crystals on the surface.

Approximate ice-limits

The approximate ice-limits are shown on the charts in the chapter titled "Ocean currents". After studying the map, the following thumb rule, for academic purposes only, may be convenient to remember:

1. Off the coast of Newfoundland, the easterly limit is 40°W and the southerly limit is 40°N.
2. In the North Pacific, a line drawn from the NE tip of Japan, passing just north of the Aleutian Islands, to approximately 60°N 160°W.

3. In the Southern Hemisphere, roughly the parallel of 50°S, except in longitude 20°W, where it is about 40°S. (Cape Horn, Tasmania and New Zealand are clear of the ice limits).

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CHAPTER 23

THE INTERNATIONAL ICE PATROL

The International Convention for the Safety of Life at Sea 1974 (SOLAS 74), as amended in 2000, states, in Chapter V Regulation 6, titled 'Ice Patrol Service', as follows:

1. "The Ice Patrol contributes to safety of life at sea, safety and efficiency of navigation and protection of the marine environment in the North Atlantic. Ship's transiting the region of icebergs guarded by the Ice Patrol during the ice season are required to make use of the services provided by the Ice Patrol.
2. The Contracting Governments undertake to continue an Ice Patrol and a service for study and observation of ice conditions in the North Atlantic. During the whole of the ice season, i.e., for the period from 15th February through 1st July of each year, the south-eastern, southern and south-western limits of the region of icebergs in the vicinity of the Grand Banks of New Foundland shall be guarded for the purpose of informing passing ships of the extent of this dangerous region; for the study of ice conditions in general; and for the purpose of affording assistance to

ships ands crews requiring aid within the limits of operation of the patrol ships and aircraft. During the rest of the year, the study and observation of ice conditions shall be maintained as advisable.

3. Ships and aircraft used for the Ice Patrol Service and the study and observation of ice conditions may be assigned other duties provided that such other duties do not interfere with the primary purpose or increase the cost of this service.
4. The Government of the USA agrees to continue the overall management of the Ice Patrol Service and the study and observation of ice conditions, including the dissemination of information therefrom.
5. The terms and conditions governing the management, operation and financing of the Ice Patrol are set forth in the 'Rules for the management, operation and financing of the North Atlantic Ice Patrol' appended to this chapter, which shall form an integral of this chapter.
6. If, at any time, the USA and/or Canadian Governments shall desire to discontinue providing these services, it may do so and the Contracting Governments shall settle the question of continuing these services in accordance with their mutual interests. The USA and/or Canadian Governments shall provide 18 months' written notice to all Contracting Governments whose ships are entitled to fly their flag and whose ships are registered in territories to which those Contracting Governments have extended this regulation benefit from these services before discontinuing providing these services".

Necessity

The cold Labrador Current carries some icebergs south to the vicinity of the Grand Banks and into the great circle shipping lanes between Europe and the major ports of the East Coast of the US and Canada. In this area the Labrador Current meets the warm Gulf Stream and the temperature differences between the two water masses of up to 20°C, produces dense fog. The combination of icebergs, fog, severe storms, fishing vessels and busy transatlantic shipping lanes makes this area most dangerous.

While traversing this area, ships try to make their voyage as short and as economical as possible. Therefore, ships in the vicinity of the "limit of all known ice" (abbreviated to **LAKI**) normally will pass just to the south of this boundary.

For vessels crossing the North Atlantic, the farther south the ice limits are, the farther the ship must travel to avoid the icebergs. For example, the difference between a route that cuts through the iceberg area and one that avoids it can be as great as 340 nautical miles for a vessel going from northern Europe to New York. At 14 knots, this would add 24 hours to the voyage.

A vessel passing through Ice Patrol's published ice limit, runs the risk of a collision with an iceberg. This fact was grimly brought to light with the sinking of the R.M.S. TITANIC in 1912, after it struck an iceberg.

R.M.S. Titanic

On her maiden voyage from Southampton to New York, the R.M.S. TITANIC collided with an iceberg just south of the tail of the Grand Banks and sank within two-and-a-half hours. Although the night was clear and seas were calm, the loss of life was enormous - more than 1,500 of the 2,224 passengers and crew perished. The TITANIC, brand new flagship of the White Star Line, was the largest passenger liner of its time displacing 66,000 tons and capable of sustained speed in excess of 22 knots. The vessel had been built with the latest safety design, featuring transverse subdivision and such innovations as automatically closing watertight doors. It is ironic that publicity regarding these features had given it the reputation of being unsinkable.

Objective

The objective of the International Ice Patrol (IIP) is to monitor the extent of the iceberg danger near the Grand Banks of Newfoundland and provide **LAKI** (limits of all known ice) to the maritime community.

Area of coverage

The area of coverage the Ice Patrol is clearly defined in the Appendix to chapter V of SOLAS 74, as amended in 2000, and does not extend North of 48°N in the North Atlantic Ocean. The total area of coverage is about 500,000 square nautical miles.

Contributors

In recent years, the cost share has been based on each participating nation's percentage of the total cargo tonnage transiting the patrol area during the ice season. As of 1998 the governments contributing to the Ice Patrol included Belgium, Canada, Denmark, Finland, France, Germany, Greece, Italy, Japan, Netherlands, Norway, Panama, Poland, Spain, Sweden, UK and the USA (17 in all).

Annual budget

IIP's annual budget averages around US $3.5 million (as in 1998).

Headquarters of the IIP

The United States Coast Guard (USCG) has been entrusted with the responsibility of the IIP service. Hence the headquarters of the IIP is at the Coast Guard Research and Development Centre, Avery Point, Groton, Connecticut, U.S.A.

Ice reconnaissance unit

During the ice season, an ice reconnaissance detachment (RECDET), usually comprising of 11 aircrew and 4 ice observers, is deployed at St. John's, Newfoundland so as be closer to the ice area.

The period of ice patrol

As per the Appendix to chapter V of SOLAS 74, as amended in 2000, the ice season is from 15th February to 1st July each year. The Grand Banks are normally free of icebergs from early August to end January.

Aircraft reconnaissance

A fixed wing Coast Guard aircraft conducts the primary reconnaissance work for the Ice Patrol on the average of five days every other week during the ice season. The Hercules HC-130 aircraft has been the mainstay of the IIP flights for the past 20 years.

A normal reconnaissance flight is about 1700 M long, lasts about 7 hours and covers an area of about 30,000 square nautical miles. The flights are at about 2000m height with a track spacing of 30 nautical miles. While using Forward Looking Airborne Radar (FLAR) and Side Looking Airborne Radar (SLAR), IIP flights allow for 200% coverage of the interior portion of a standard parallel track search pattern. Typically, it takes about four flight days to cover LAKI.

Source of ice information

Information concerning ice conditions is collected primarily from air surveillance flights and ships operating in or passing through the ice area. Ships are requested to report the position and time of all ice sighted and make sea surface temperature and weather reports to the IIP Operations Centre in Groton, Connecticut, every 6 hours when in the vicinity of the Grand Banks.

Data processing

All the iceberg data is fed into a computer model at the IIP Operations Centre along with ocean current and wind data. Using this information, the model predicts the drift of the icebergs.

Predictions

Every 12 hours, the predicted iceberg locations are used to estimate the limit of all known ice (LAKI). This limit, along with a few of the more critical predicted iceberg locations, is broadcast as an "Ice Bulletin" from radio stations around the U.S., Canada, Europe and over the World Wide Web. This is for the benefit of all vessels transiting the North Atlantic. In addition to the Ice Bulletin, a radio facsimile chart of the area, depicting the limits of all known ice, is also broadcast twice daily.

Continuous operations and proof of success

Except for the years of the two World Wars, the IIP has operated every ice season since 1913.

That the IIP has maintained broad-based international support for over eight decades despite changing operational and technological factors is proof of the soundness of the basic concept.

Since 1913, the IIP has amassed an enviable safety record with not a single reported ship-iceberg collision, or loss of life or property due to collision with an iceberg, outside the advertised limits of all known ice in the vicinity of the Grand Banks. However, the potential for a catastrophe still exists.

Artificial destruction of icebergs

The USCG has conducted numerous experiments for accelerating the disintegration of icebergs. These have included gunfire, mines, torpedoes, depth charges, and bombing. However, the use of conventional explosives or combustibles proves difficult. In addition to the operational hazards of approaching and boarding an iceberg in a seaway, it has proved uneconomical, as an average sized iceberg of 20,000 cubic metres would require about 1930 tonnes of TNT to break it up - a fantastic rate of about 1 tonne of TNT per 10 tonnes of ice.

Natural means are best

Natural processes of deterioration by melting, erosion, calving, etc., remain the best means for an iceberg to melt fully.

Tracking icebergs by marking them

It is not practical to track icebergs with special location markers. The IIP has done experiments with marking icebergs with dye and by placing electronic position beacons on them. Since icebergs are very dynamic, these markers or beacons either become washed away or dislodged from the iceberg. Icebergs are constantly breaking apart or changing mass. This often results in them completely changing their orientation in the water. Some may even flip over completely as the lower portion melts or breaks apart. These are the difficulties in placing special markers on icebergs. As a result, the IIP uses aerial reconnaissance as its primary method of monitoring icebergs in order to provide the mariner with iceberg limit information in the North Atlantic Ocean.

Towing for fresh water

Towing of icebergs to New York, to supplement fresh water supplies, was also considered but calculations showed that by the time the tugs reached New York through the warm Gulf Stream, the iceberg would, most probably, be only the size of an ice-cube!

Other ice patrols

There are other ice patrols also. The **Canadian Ice Services** which focuses its efforts on the waters of the Canadian Economic Zone and the **Danish Meteorological Institute** which reports on the ice conditions around Greenland.

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CHAPTER 24

AIR-MASSES AND FRONTS

Definition of an air-mass

An air-mass may be defined as a quantity of air with dimensions of about 500 nautical miles or so, with little or no horizontal variation of any of its properties, especially temperature.

The idea of air-masses was first introduced by a Norwegian scientist called Bergeron in 1928.

Because the temperature of air depends almost entirely on contact with the earth's surface, the air over polar regions will be cold, while that over the tropics will be warm. Air-masses are named by the sources from which they originate.

For an air-mass to change its temperature by 10° to 20°C, it may take weeks. That is why when wind from one air-mass region blows over an area outside its source, the weather of that area is very highly affected. The main air-masses over the earth are polar air-masses and tropical air-masses.

Factors affecting the properties of an air-mass

1. Its source region.
2. Its track over the earth's surface.
3. The extent of convergence and divergence.
4. Its age.
5. Its rate of travel.

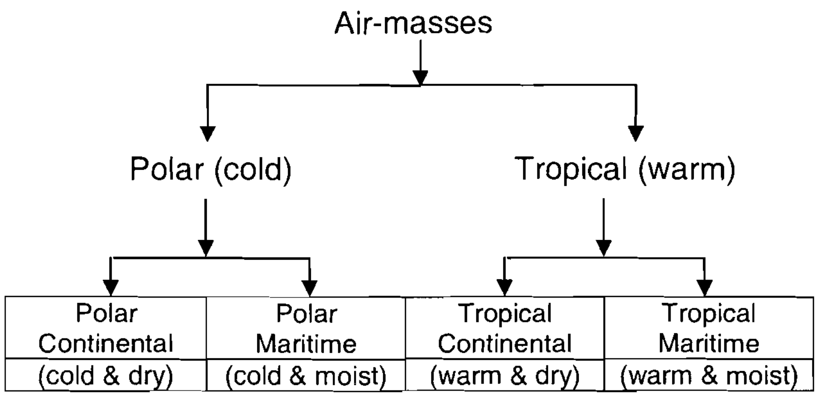
Each of the foregoing is discussed below:

1. **Its source region:** If it is of polar origin, the air-mass will be cold and if of tropical origin, warm.
2. **Its track over the earth's surface:** If it passes over large expanses of water, it will be moist and if it passes over land, it will be dry.
3. **The extent of convergence and divergence:** Convergence at lower levels (as in depressions) causes air at the centre to ascend. Divergence at lower levels (as in anticyclones) causes air from above to descend. Both convergence and divergence cause vertical movement of air resulting in proper mixing of the air of different levels and thus they influence the properties of the air-mass, especially relative humidity and temperature lapse rates.
4. **Its age:** The age of an air-mass is the number of days it has spent in its source region. The longer it has stayed there, the greater it is influenced by the climate of that place. For a tropical air-mass to get converted into a polar air-mass or vice-versa, it may take well over a month.
5. **Its rate of travel:** Consider an air-mass moving over an area outside its source region. If it moves quickly, the area over which it blows does not have sufficient time to significantly influence the properties of the air-mass. Hence a quick moving air-mass retains most of its original characteristics. If the air-mass moves slowly, the area over which it blows has sufficient time to influence the properties of the air-mass. Hence the characteristics of a slow moving air-mass may be somewhat different from its original characteristics.

Classification of air-masses

Based on their properties, air-masses are divided into four main classes:

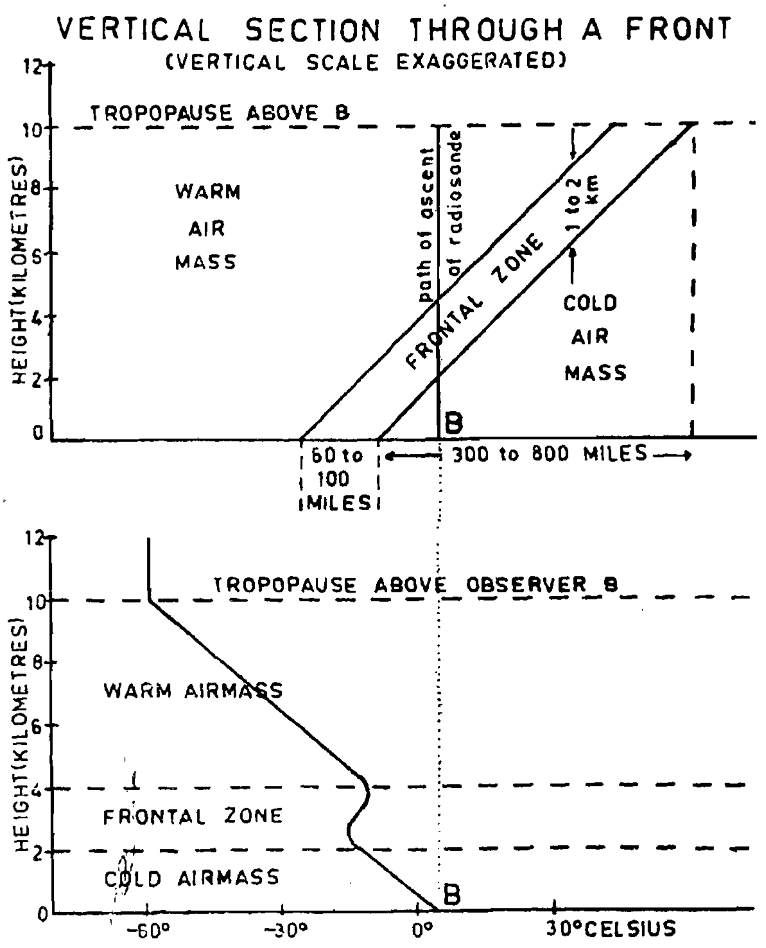
a) Polar Continental (PC): Polar air-mass coming over land - it will be cold and dry.
b) Polar Maritime (PM): Polar air-mass coming over the sea - it will be cold and moist.
c) Tropical Continental (TC): Tropical air-mass coming over land - it will be warm and dry.
d) Tropical Maritime (TM): Tropical air-mass coming over sea - it will be warm and moist.



Front

The boundary between two adjacent air masses is well defined by their different characteristics and is called a front.

Because tropical air is warmer and hence less dense than polar air, it will climb over the polar air at the front. The front will, therefore, not be vertical. It will always be inclined towards the colder air mass. The slope of the front may be around 1 in 150 (0.5°) for warm fronts and around 1 in 50 (1°) for cold fronts.



TEMPERATURE VERTICALLY ABOVE B MEASURED BY A RADIO-SONDE

The two figures above show how a front and its slope are detected by a meteorologist. The upper figure shows how a front would appear, to an observer at sea level, if such a front was visible. If an observer, at B in the upper sketch, was to send up a radio-sonde*, the height-temperature graph that he would obtain is shown in the lower sketch. He would notice from the graph that the cold air mass exists above him upto a height of 2 km and the warm air-mass from 4 km height to the tropopause. Between 2 km and 4 km height, an irregular and very steep temperature inversion exists and this must be the frontal zone where some mixing of the two air masses is taking place at their edges. If more radio-sondes were sent up from other places, the slope of the front would easily be deduced.

Warm and cold fronts

After a front passes over a place, if the atmospheric temperature is higher than it was before, the front is called a warm front; if the atmospheric temperature is lower than it was before, the front is called a cold front. In other words, a warm front occurs when warm air replaces cold air and a cold front occurs when cold air replaces warm air.

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*A radio-sonde is a gas filled balloon with meteorological instruments attached. When released, the radio-sonde ascends and transmits, by radio waves, the temperature, pressure, relative humidity, etc. at various heights.

On a weather map a red line is used to denote a warm front and a blue line to denote a cold front. Where colours cannot be used, such as in facsimile charts, the foregoing symbols are used. The symbol is inserted on that side of the line towards which the front is moving. In both the above cases, the fronts are moving towards east.

More information regarding the weather associated with warm and cold fronts, their cross-sectional view, etc., is given, in the next chapter, under the heading of "Frontal Depressions".

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CHAPTER 25

FRONTAL DEPRESSIONS

A frontal depression is a low pressure area formed at the boundary between two different air-masses. Frontal depressions occur in middle or high latitudes. Quite often, a series of them follow, one after another, and they are referred to as a family of frontal depressions.

Frontogenesis

The formation of a frontal depression is called frontogenesis. The warm air should be travelling faster than the cold air, or they should be travelling in opposite directions. The following description is for the northern hemisphere.

COLD AIR		COLD AIR
———→		←———
----------------------	Or	----------------------
———→		———→
WARM AIR		WARM AIR

The frontal depression begins as a small bulge of warm air in the cold air (see following figures 1 and 2).

The bulge increases in size and the isobars in the cold air bend accordingly (following figure 3). Since the density of warm air is less than that of cold air, the bulge is an area of low pressure, surrounded on three sides by areas of high pressure.

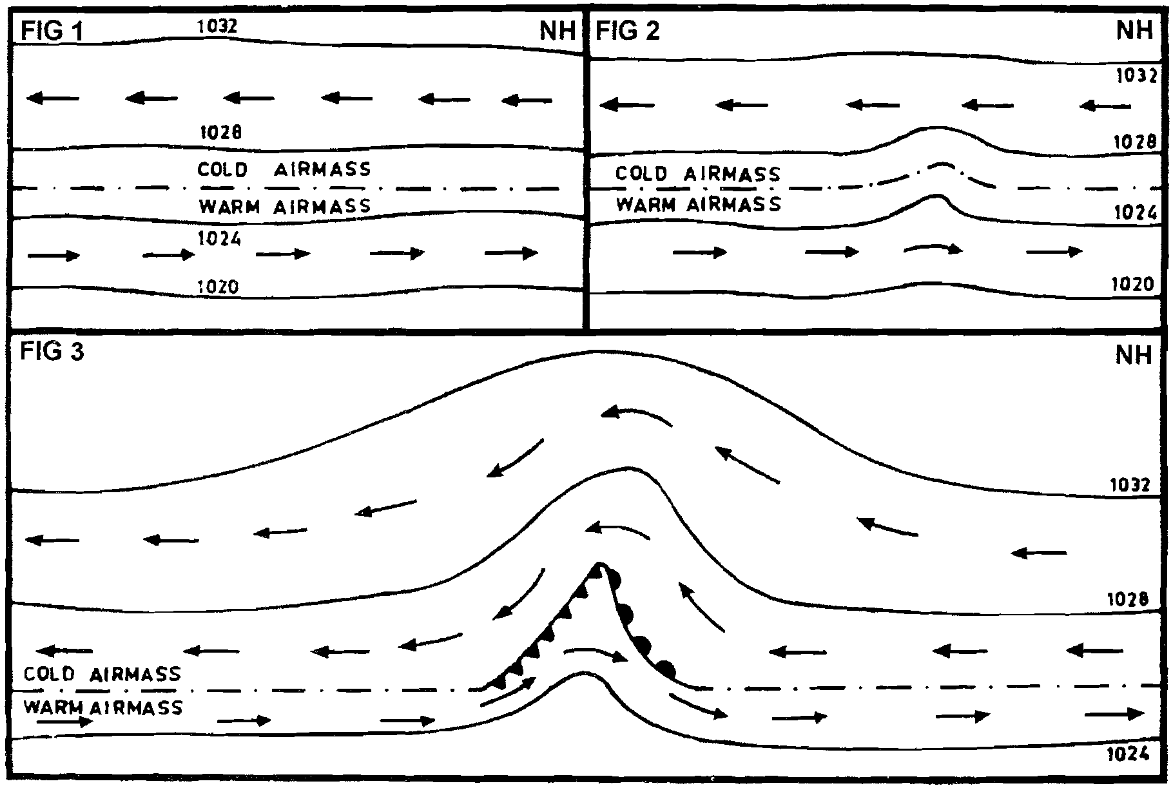


FIG 1
NH
1032
1028
COLD AIRMASS
WARM AIRMASS
1024
1020
FIG 2
NH
1032
1028
COLD AIRMASS
WARM AIRMASS
1024
1020
FIG 3
NH
1032
1028
COLD AIRMASS
WARM AIRMASS
1024

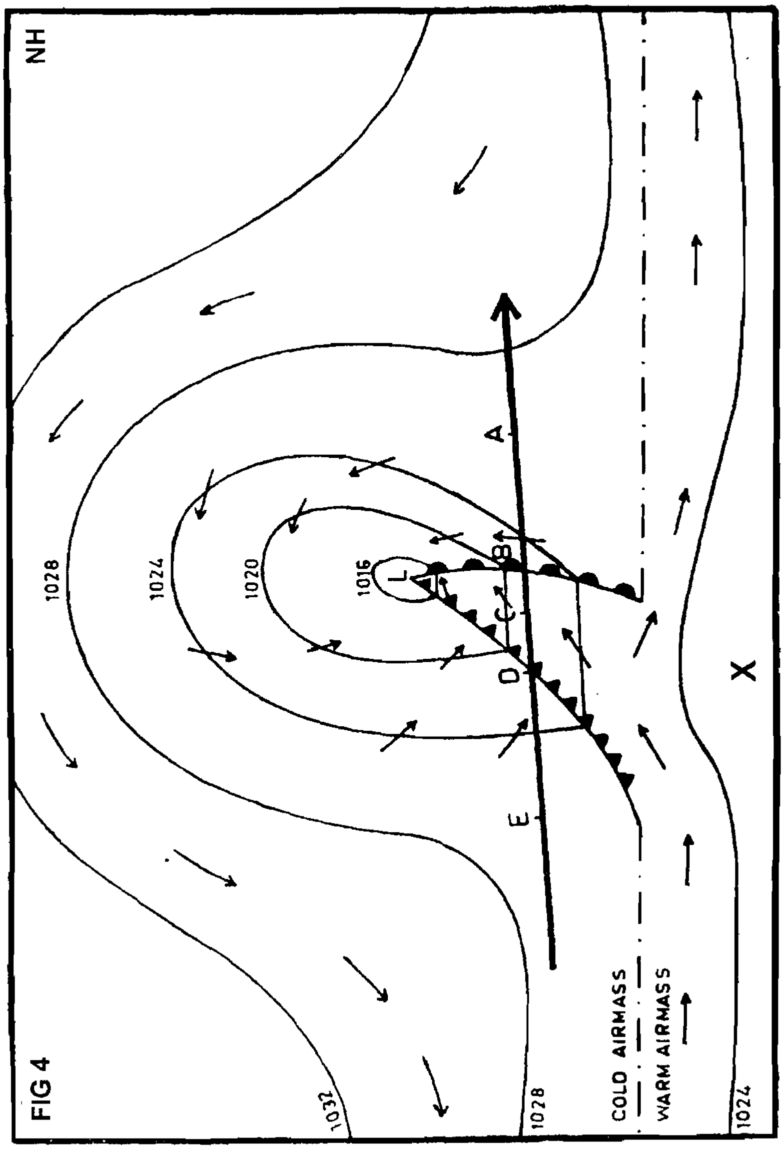
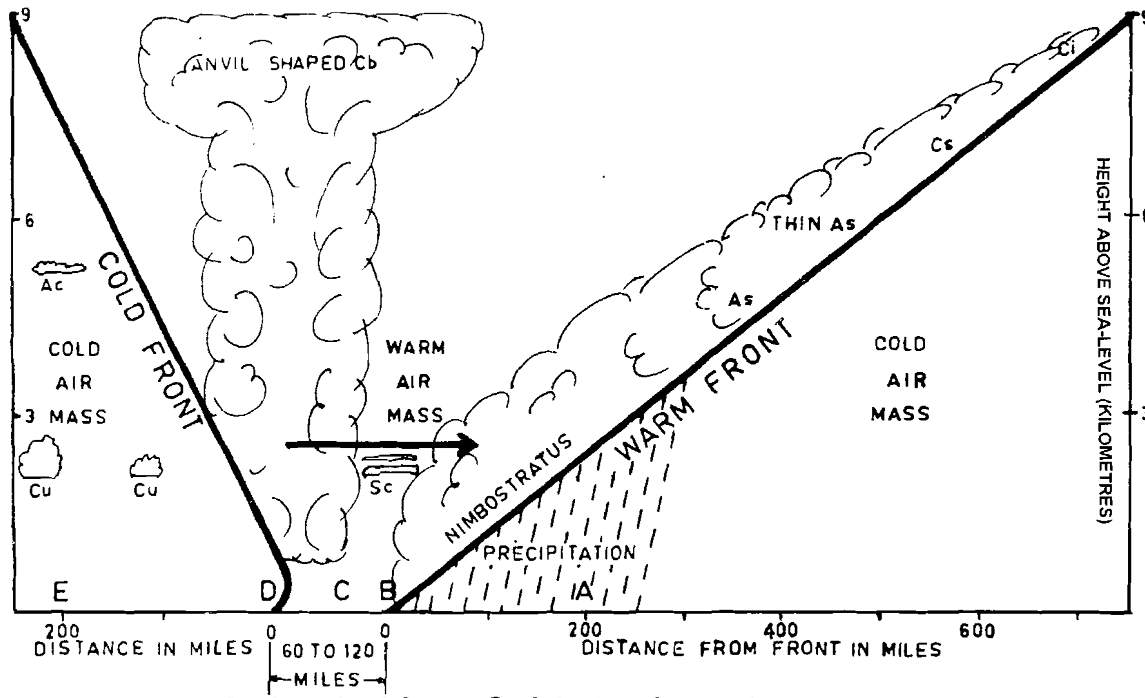


FIG 4
NH
1032
1028
1024
1020
1016
L
A
B
C
D
E
X
COLD AIRMASS
WARM AIRMASS
1028
1024

FIG 5

NH



VERTICAL CROSS SECTION THROUGH POINTS ABCDE OF FIGURE 4

VERTICAL SCALE EXAGGERATED

The bent isobars then take closed shapes (see accompanying figure 4) and the winds take on a spirally inward circulation, anticlockwise in the NH. The isobars inside the bulge are straight and roughly parallel to the original boundary between the two masses of air. On crossing the front, the isobars change direction by about 90°. Because of this, when a front passes over a place, the wind will suddenly veer in the NH (back in the SH) by about 90°.

The entire system will move in the same direction and at approximately the same speed as the warm air. Figure 5 shows a cross-sectional view along ABCDE as seen from position X in figure 4.

Note: The accompanying figures and explanations given herein are all for the NH. In the SH, the cold air will be south of the warm air, the 'V' of the bulge will be towards south and the winds blowing spirally inwards will be clockwise.

Since the prevailing winds in these latitudes are the Westerlies, frontal depressions move from west to east in both hemispheres.

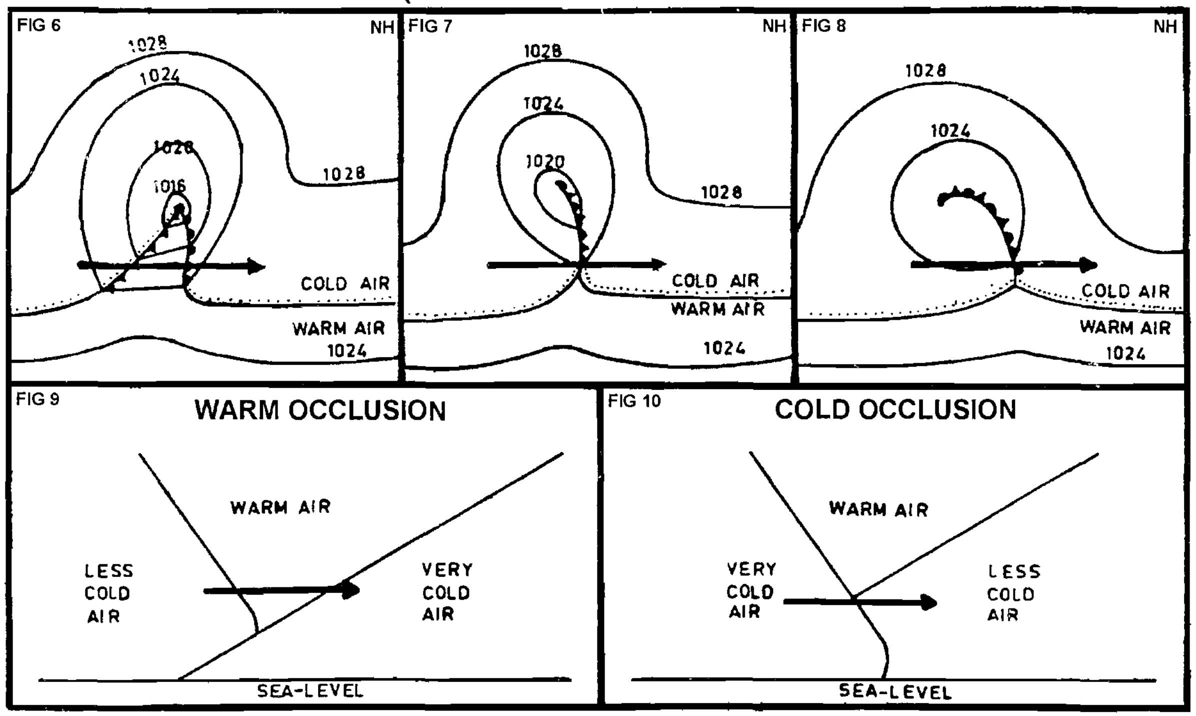
Weather sequence

On the passage of a frontal depression over a stationary observer situated along ABCDE in figures 4 and 5 of this chapter, a warm front, followed by the warm sector and then by a cold front will be experienced. The weather sequence is summarised in the following page, in a tabular form for easy reference. The student is advised to read each horizontal line fully (i.e., pressure at A, then at B, C, D & E respectively) and consult figures 4 & 5 of this chapter. The weather sequence is thus so simple that there is nothing to be learned by heart.

Weather Sequence on the passage of a frontal depression in the NH

	WARM FRONT			**COLD FRONT**	
Reference points in figures 4 & 5	In advance **A**	At passage **B**	Warm sector **C**	At passage **D**	Afterwards **E**
Pressure	Falls steadily	Stops falling and steadies	Constant	Sudden rise	Rises slowly
Wind direction **(NH)**	Steady	Suddenly veers by about 90°	Steady	Suddenly veers by about 90°	Steady
Wind Force	Increasing	Steady	Steady	Squalls	Gradually decreases
Temperature	Slow rise	Quick rise	Steady	Sudden fall	Steadies
Clouds	Ci, Cs, As	Low Ns	St or Sc	Cb of very high vertical extent	Ac & Cu
Weather	Continuous heavy rain or snow	Precipitation stops	Cloudy with occasional drizzle	Heavy rain, thunder, lightening	Heavy rain gives way to occasional showers
Visibility	Very good except in showers	Poor due to mist or fog	Poor due to mist or fog	Poor due to rain squalls	Very good except in showers

FRONTOLYSIS (DECAY OF A FRONTAL DEPRESSION



Line Squall: A cold front is often referred to as line squall because, just before it passes, the long line of low-based (but of very high vertical extent) Cb clouds is visible. Line squalls are sometimes known by local names e.g., Pampero in South America and Southerly Buster in Australia.

Frontolysis

Frontolysis is the decay or weakening and final dissipation of a frontal depression. The first step is the formation of occlusions.

Occlusions: The cold air, in front of and behind the warm sector of a frontal depression, soon manages to undercut the warm air and lift it completely above sea level. The depression is then said to be occluded. The three stages of the decay of a frontal depression (formation of an occlusion) as seen on a weather map are shown in figures 6,7 & 8 of this chapter.

On weather maps, an occlusion is indicated by a purple line or by alternate red and blue dashes.

On facsimile charts, the symbols shown on the next page are used.

Warm and cold occlusions: If after the passage of an occlusion, the air temperature is higher than before, the occlusion is said to be warm and if it is lower than before, the occlusion is said to be cold.

The cross sectional views of a warm occlusion and also of a cold occlusion are shown in figures 9 & 10 of this chapter.

On the passage of an occlusion, the wind veers, more for cold occlusions than for warm occlusions (in the SH, the wind backs).

The weather associated with warm and cold occlusions is similar to, but milder than, that of warm and cold fronts respectively.

Within a few days of the occurrence of the occlusion, the frontal depression fills up and is no longer recognisable on weather maps.

Occlusion. The symbol is inserted on that side of the line towards which the occluded front is moving. In this case, the occluded front is moving east.

Stationary, occluded front.

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CHAPTER 26

OCEAN CURRENTS

An ocean current is the general movement of a body of sea-water on a permanent, semi-permanent or seasonal basis.

A current is different from a tidal flow which is subject to hourly changes and which is caused by the gravitational effects of the Moon, Sun or planets.

A tidal-stream is the resultant of the tidal flow and the current in a particular coastal area. It changes every hour and is described in tidal-stream atlases.

The direction of an ocean current is different at various depths but the navigator is only interested in the movement of the surface of the sea, upto about half his ship's draft. Hence only surface currents are described in this chapter.

There are three main causes of ocean currents:

1. Drift
2. Upwelling
3. Gradient

Each of the above is described below.

1. Drift:

Drift is the direct effect of wind blowing over long stretches of ocean for long periods. The frictional effect of the wind, on the sea surface, causes the sea-surface to move. However, Coriolis force deflects the drift current to the right in the northern hemisphere (left in the southern hemisphere) by about 30° to 45°.

The best examples of drift currents are:

(a) (b)	North Equatorial current South Equatorial current	Caused by the trade winds
(c)	North Atlantic current	Caused by the Westerlies
(d)	North Pacific current	Caused by the Westerlies
(e)	Southern Ocean current Or west wind drift.	Caused by the Westerlies

The maximum strength of a drift current is only upto about 2 knots. If, however, there are other strengthening factors such as gradient, shape of the coast, etc., the drift current can increase two or three-fold and is then called a stream.

2. Upwelling:

Whenever a wind blows away from a long coastline for a considerable length of time, the outflow of water from the coast is replaced by an upward movement (upwelling) of sea-water, from a depth upto about 150 metres or so. Since this upwelling takes place from below, the water that comes to the surface is colder than the surrounding sea-surface.

Upwelling currents are experienced along the eastern shores of oceans, in low latitudes. Here the trade winds blow off shore, resulting in upwelling. Examples - Canary current and Benguela current of the east Atlantic, Californian current and Peru (Humboldt) current of the east Pacific. There is no upwelling off the west coast of Australia as the coastline is not long enough.

3. Gradient:

A gradient current is caused by differences in level (resulting from natural slopes or build-up by winds) or by differences in density (resulting from differences of temperature or salinity). The greater the salinity, the greater the density and vice versa. The lower the temperature, the greater the density and vice versa.

When different water-masses lie adjacent to each other, gradient currents are set up between them because of differences in temperature and salinity.

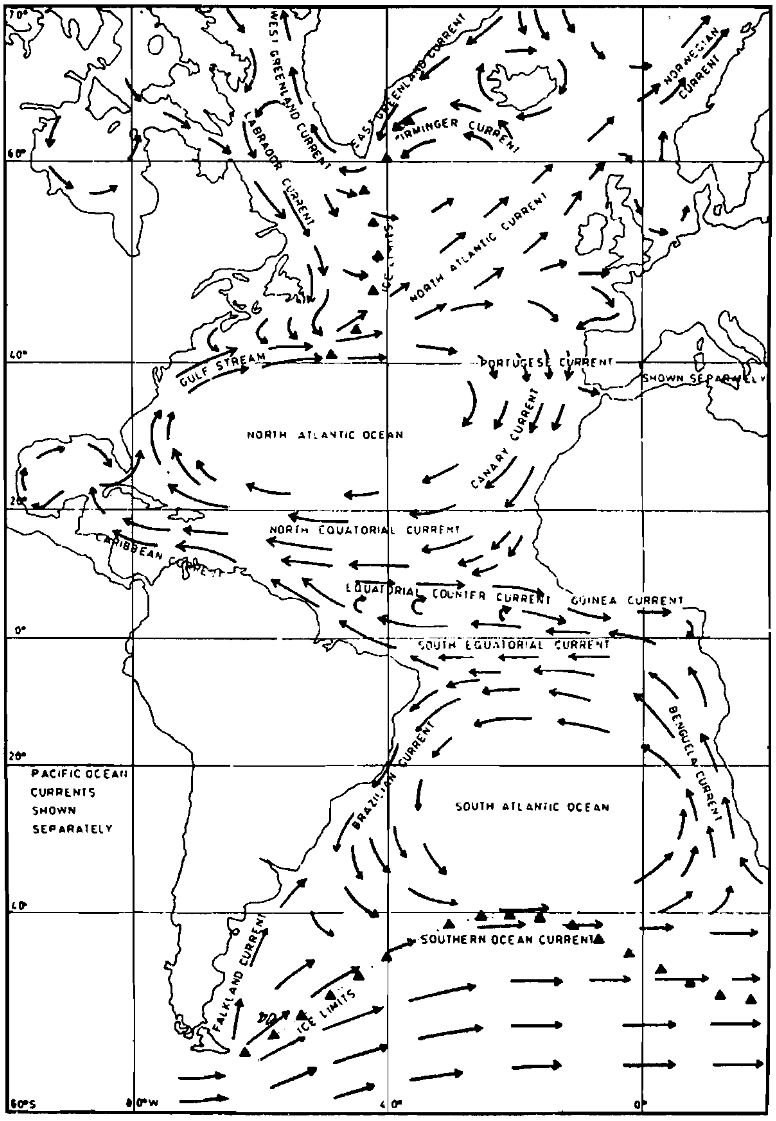
The best examples of gradient currents are:

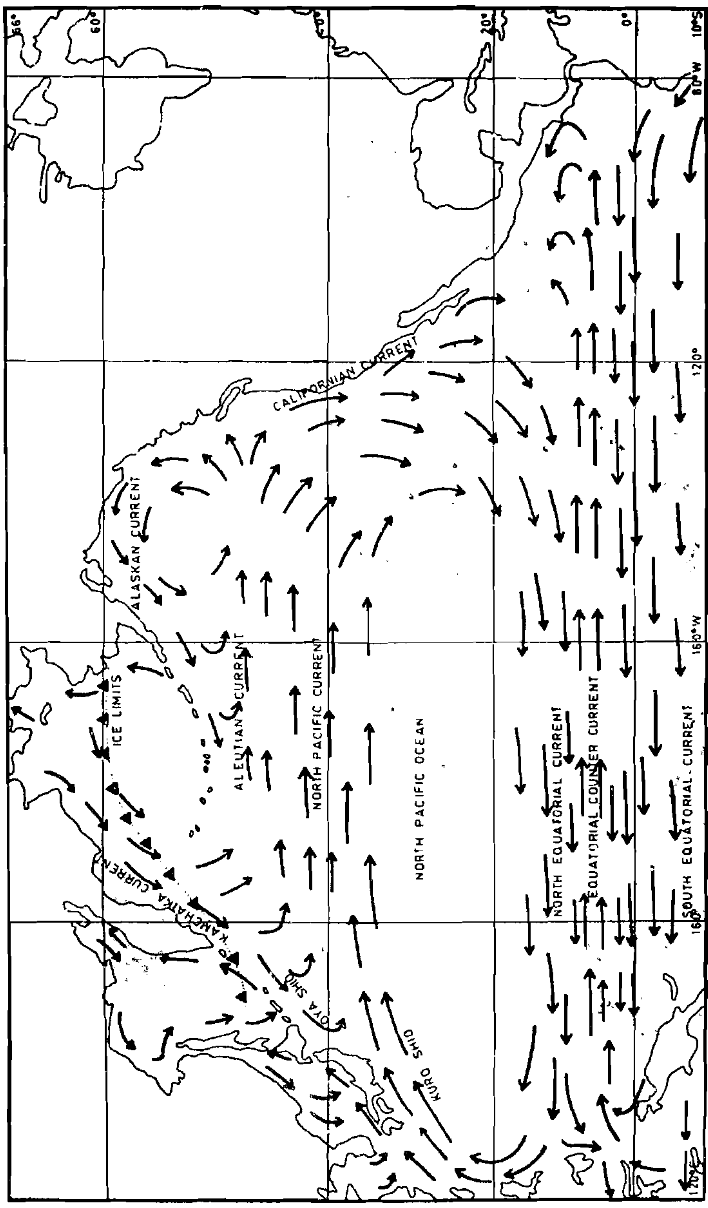
3.1. The surface current that flows from the Atlantic into the Mediterranean is a result of differences in level. The Mediterranean Sea, being land-locked, experiences severe evaporation. Since the input by rivers and rain is very small, its level falls and a gradient current from the Atlantic flows in through the Strait of Gibraltar.

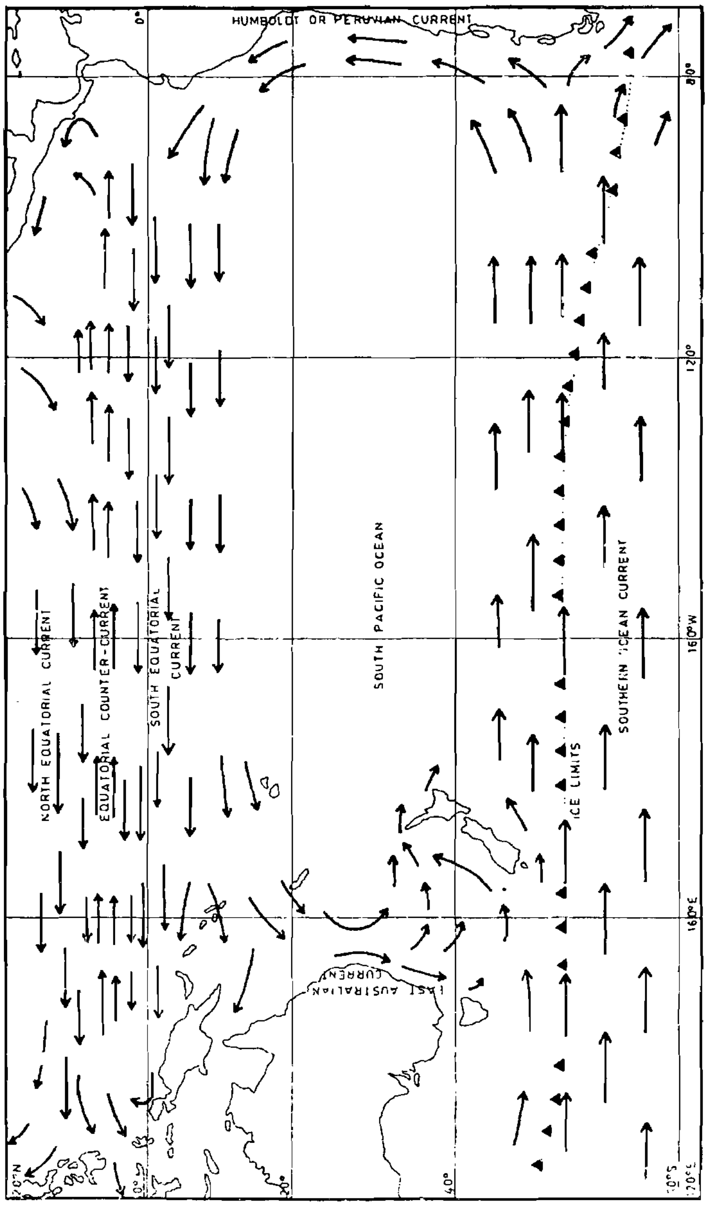
3.2. The northerly current along the east coast of Africa in the Arabian sea, and along the east coast of India in the Bay of Bengal, during the latter part of the NE monsoon, flows against the NE winds because of a thermal gradient. The gradient is formed by the cooling of the waters at the head of the Arabian Sea & Bay of Bengal by the cold NE monsoon during December and January (see Chapter 18).

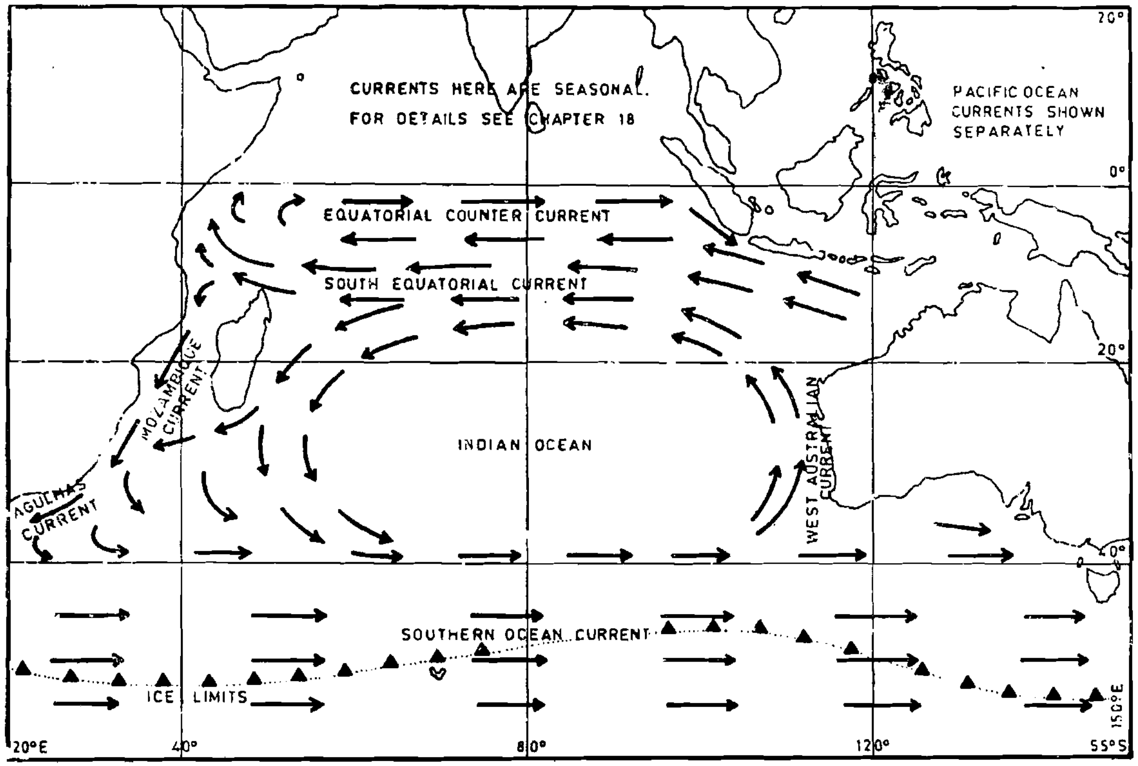
Warm and cold currents

Whenever a current is warmer or colder than the sea through which it flows, it is called a warm or cold current respectively.


WEST GREENLAND CURRENT
EAST GREENLAND CURRENT
NORWEGIAN CURRENT
IRMINGER CURRENT
LABRADOR CURRENT
ICE LIMITS
NORTH ATLANTIC CURRENT
GULF STREAM
PORTUGESE CURRENT
SHOWN SEPARATELY
NORTH ATLANTIC OCEAN
CANARY CURRENT
NORTH EQUATORIAL CURRENT
CARIBBEAN CURRENT
EQUATORIAL COUNTER CURRENT
GUINEA CURRENT
SOUTH EQUATORIAL CURRENT
BENGUELA CURRENT
BRAZILIAN CURRENT
PACIFIC OCEAN CURRENTS SHOWN SEPARATELY
SOUTH ATLANTIC OCEAN
SOUTHERN OCEAN CURRENT
FALKLAND CURRENT
ICE LIMITS
70°
60°
40°
20°
0°
20°
40°
60°S
80°W
40°
0°


CALIFORNIAN CURRENT
ALASKAN CURRENT
ICE LIMITS
ALEUTIAN CURRENT
NORTH PACIFIC CURRENT
NORTH PACIFIC OCEAN
NORTH EQUATORIAL CURRENT
EQUATORIAL COUNTER CURRENT
SOUTH EQUATORIAL CURRENT
KAMCHATKA CURRENT
KURO SHIO


HUMBOLDT OR PERUVIAN CURRENT
SOUTH PACIFIC OCEAN
NORTH EQUATORIAL CURRENT
EQUATORIAL COUNTER-CURRENT
SOUTH EQUATORIAL CURRENT
ICE LIMITS
EAST AUSTRALIAN CURRENT

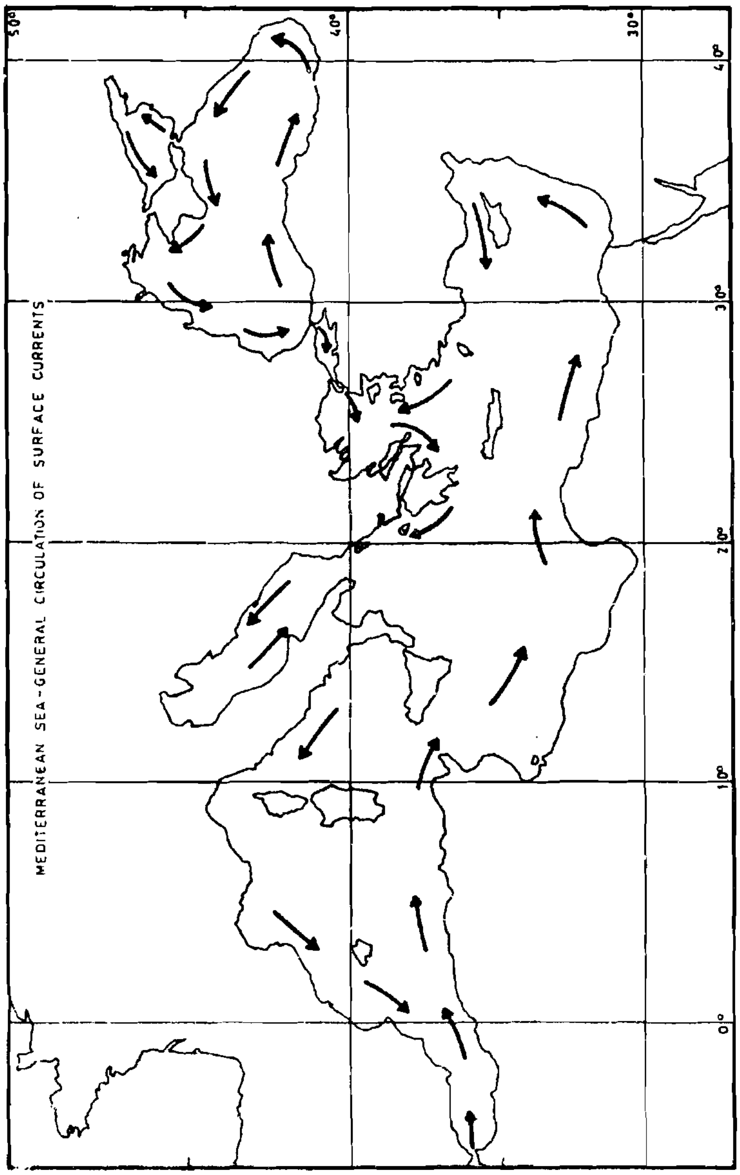

CURRENTS HERE ARE SEASONAL.
FOR DETAILS SEE CHAPTER 18
PACIFIC OCEAN CURRENTS SHOWN SEPARATELY
EQUATORIAL COUNTER CURRENT
SOUTH EQUATORIAL CURRENT
MOZAMBIQUE CURRENT
AGULHAS CURRENT
INDIAN OCEAN
WEST AUSTRALIAN CURRENT
SOUTHERN OCEAN CURRENT
ICE LIMITS
20°
0°
20°
40°
20°E
40°
80°
120°
150°E
55°S

Warm currents: When a current from equatorial regions passes through higher latitudes, it will be a warm current. Warm currents are generally experienced along the western shores of large oceans.
Examples of warm currents: The Gulf Stream, the North Atlantic Drift, the Norwegian current, the Brazilian current, the Kuro Shio, the Alaskan current, the East Australian current, the Mozambique current, the Agulhas current (see adjoining charts).

Cold currents: When a current from higher latitudes passes through lower altitudes, it will be a cold current. If it came from polar regions, it will be very cold, such as the East Greenland current, Baffin Land current (Davis current) and the Kamchatka current. Cold currents are generally experienced along the eastern shores of large oceans.
Examples of cold currents: In addition to the three cold currents named above, the Labrador current, the Portuguese and Canary currents, the Falkland current, the Benguela current, the Oya Shio, the Californian current, the Humboldt current and the West Australian current (see adjoining chart).

General circulation in the Mediterranean Sea.

As explained earlier, under gradient currents, the level of the Mediterranean Sea is lower than that of the Atlantic. This is because the Mediterranean Sea is land-locked, resulting in a very much higher rate of evaporation, and also because the input of water from rains and rivers is very small.


MEDITERRANEAN SEA-GENERAL CIRCULATION OF SURFACE CURRENTS

A gradient current, therefore, flows eastwards along the surface through the Strait of Gibraltar, and on entering the Mediterranean, it is deflected to its right by Coriolis force and flows along the north coast of Africa. Though it reaches a rate of 2 to 3 knots in the SW part of the Sea, the current is generally weak and hugs the coast forming a complete anticlockwise cycle (see adjoining chart).

The water of the Mediterranean Sea is more saline and hence denser (because of the high rate of evaporation) than the water of the Atlantic and also of the Black sea. It therefore flows as a sub-surface gradient current, westwards through the Strait of Gibraltar.

In the Black Sea, the circulation is generally anticlockwise. The denser Mediterranean water flows in through the Dardanells and Bosporus as a sub-surface gradient current while the surface current flows continuously from the Black Sea into the Mediterranean Sea.

Effects of ocean currents on climate

The effects of ocean currents on climate are numerous and a few are listed below as examples:

1. UK and northern coasts of Europe are 10° to 20°C warmer in January than Newfoundland. The Westerlies, blowing over the former, come from over the warm North Atlantic current and carry the oceanic influence far inland, whereas the Westerlies over the latter, come from cold hinterland.
2. Ports in eastern Canada (latitude 55°N) are ice-bound in winter, whereas the ports in Norway

(latitude 70°N) are not ice-bound (see Labrador current and Norwegian current in adjoining chart).

3. Callao (latitude about 12°S), in Peru, is about 6°C cooler than Salvador (similar latitude) in Brazil (see Humboldt current and Brazilian current in adjoining chart).

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CHAPTER 27

THUNDERSTORMS

General description

A thunderstorm is a local squall or storm of short duration, accompanied by lightning and thunder from a Cumulonimbus cloud.

Favourable conditions for formation

Warm, unstable condition of the atmosphere and high relative humidity – as much as 75%. These conditions exist on a hot day over land adjacent to, or surrounded by, large expanse of water.

General information

The energy of thunderstorms is both kinetic and electro-static and is derived from the latent heat of condensation and fusion given off by ascending air. In the tropics, the tropopause is higher than in temperate latitudes. Hence Cb clouds can extent much higher resulting in greater frequency of, and more vigorous, thunderstorms. The passage of cold front is always accompanied by a thunderstorm. The average rate of ascent of air is about 6 m/sec but can, at times, be as much as 30 m/sec. Thunderstorms usually last from about half an hour to two hours.

Formation

The vigorous ascent of air results in a Cb cloud with a cap in the shape of an anvil. The lower part of the Cb cloud consists of drops of water, the middle part of super-cooled droplets of water and the upper part, of ice-crystals. The drops of water grow in size due to progressive condensation from the continuous up-draught of humid air from below. When the diameters of the drops of water in the lower part reach 6 mm or so, they break up into smaller drops. The smaller particles so formed, which are carried upwards to the top of the Cb cloud, have a positive charge whereas those larger drops that remain below after breaking off, have a negative charge.

Lightning: The Cb cloud has large electro-static potential difference between its top (positive) and its bottom (negative). A few small pockets of positive charge may exist in the lower levels of the Cb cloud. The discharge of this static potential difference can take place, in the form of an enormous spark called lightning, within the cloud itself, between two adjacent clouds or between the lower portion of the cloud and tall objects on the earth's surface. Lightning can be seen as far away as 100 miles.

Lightning conductors: When lightning "strikes" tall objects (buildings or trees) on the ground, the enormous heat of the spark destroys the object and sets fire to the remains unless special lightning conductors are provided. A lightning conductor is a metal rod that is made to protrude above buildings or trees. The rod is connected to the ground by a thick cable. In case lightning strikes the building, the electric current and the heat of the spark is led down directly to the earth, thereby saving the building from destruction. Metal towers and masts are themselves good conductors and do not require lightning conductors. Ships at sea are already earthed by contact with the sea but if they have wooden top-masts, they must have lightning conductors, especially on tankers, which give electrical continuity between the truck of the wooden top-mast and the ships hull.

Thunder: Lightning, being an enormous spark of electricity through space, heats up the air through which it passes. The sudden heating of air causes cracking noises or explosive reports called thunder. Rumbling noises, associated with thunder, are (i) overlapping peals of thunder from different parts of a single flash of lightning or (ii) echoes of one peal of thunder from mountains or clouds or (iii) overlapping peals of thunder from several consecutive flashes of lightning. Thunder can usually be heard up to about 10 miles or so. Since sound travels much slower than light (sound 335 m/sec, light 300 m/micro-sec), thunder is heard only *after* lightning is seen.

Weather associated with a thunderstorm

1. Dark, threatening appearance of anvil-shaped Cb cloud.
2. General reduction of daylight.
3. Sudden calm and extremely clear visibility.
4. Flashes of lightning.
5. Thunder (sometimes not audible).
6. Violent squalls.
7. Torrential rain. Hence the term "thunder-showers" but never "thunder-rains". Several intermittent showers may be experienced.
8. Very poor visibility during rain.
9. Hail may sometimes be experienced.
10. Unsteady rise of relative humidity to nearly 100%.

11. Sudden fall of temperature may be experienced (up to 10º C has been known).
12. The entire thunderstorm generally lasts only about half an hour but may go on for about two hours in tropical areas.

Some typical thunderstorms

1. Nor'wester

This is the name given to a severe type of thunderstorm, accompanied by strong squalls, which occurs occasionally in West Bengal and the neighbouring regions and may affect the waters at the head of the Bay of Bengal. They are so called because of the fact that they usually approach from north-westward (sometimes from northward or north-eastward). They are mainly experienced during the hot months (from March to May) but they are sometimes experienced in the latter half of February and in the first half of June. They cease to occur after the south-west monsoon sets in.

The first sign of the approach of one of these storms is a low bank of dark clouds to the north-west, the upper outline of which has the appearance of an arch. The storm leaves the land slowly at first and gathers speed over the sea and arrives with a strong gust or squall. Thunder and lightning usually occur, followed by heavy rain and, occasionally, hail. Wind speeds of 100 knots has been recorded in some of these storms.

Nor'westers nearly always occur in the afternoon or evening after a humid, warm day. They rarely last more than three or four hours and they are generally followed by cool, clear weather. At Calcutta, they usually occur about or just after sunset.

2. Elephanta

Towards the end of the SW Monsoon (late September), frequent thunderstorms are experienced from S or from E, between Mumbai and Kanya Kumari. These thunderstorms are called Elephantas and are regarded by the local people as an indication of the end of the SW Monsoon.

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CHAPTER 28

MORE LOCAL WINDS

1. Tornado and waterspout

A tornado is a violent whirlwind of the cyclonic type - anticlockwise in the NH and clockwise in the SH. Its axis is nearly vertical, extending from the could-base downward and often reaching ground level. Its width is anything between 50 and 500 metres but the wind is often of hurricane force at the centre – up to 200 knots have been recorded in very severe cases. It generally travels at a speed of about 10 to 30 knots. It may last from a few minutes to a few days (most of them last a few hours), covering a track between a few hundred metres and a few hundred miles.

The hurricane force winds, of such a small diameter, cause an intense upward current at the centre, capable of lifting heavy objects into the air, uprooting trees, destroying buildings, etc. Buildings disintegrate in a few seconds with explosive sounds, when a tornado passes over them. The destruction is two fold - one due to the tornado itself and the other due to the falling down of lifted objects and debris.

Tornadoes are associated with isolated Cb clouds. The conditions favourable for the formation of a tornado are similar to those for a thunderstorm - great instability, high humidity and convergence at low levels. The precise reasons for their formation is still not known to man.

Tornadoes occur very frequently and violently over mid-west USA - over the central plains of the Mississippi, east of the Rocky Mountains.

When a tornado forms or passes over sea, large quantities of water are carried up by the vertical current of air at the centre, forming a waterspout, which appears as a thin, funnel-shaped, opaque column, broad at the top and very thin at sea level.

2. Bora

Is a katabatic wind that blows over the north and east coast of the Adriatic sea, from a direction between north and east. Because of the high hinterland, it can attain gale force in a very short time without the usual warning indicated by barometric pressure. It is a danger to ships at anchor and small crafts in its path.

3. Gregale

Is a strong NE wind that blows over Italy, mainly in winter. It is of importance to ships in the Strait of Messina, the port of Malta and other Sicilian ports open to NE.

4. Harmattan

Is a cool, dry, dust-laden wind blowing seawards from a NE direction across the coast of north-west Africa, between the ports of Dakar and Lagos. It generally blows from November to March and brings the dust of the Sahara desert. Because of its cool, dry nature, it provides a relief from the oppressively hot, damp tropical climate of that area and is hence called "the doctor " by local people.

5. Levanter

Is an easterly, light to moderate, moist wind that blows across the Strait of Gibraltar, mainly in March and also between July and October. Its moist nature brings rain, mist or fog, sometimes haze. It is the cause of the "Banner cloud" or "Levanter cloud" which stretches a mile or so to leeward, like a flag, from the top of the Rock. If the force of the Levanter exceeds 7 of the Beaufort scale, the banner cloud lifts and disappears.

6. Mistral

Is a strong N or NW katabatic wind blowing over the Gulf of Lions in the north-western part of the Mediterranean Sea, especially near Marseilles. Its main features are its frequency of occurrence, its dry, cold nature and the rapidity with which it can develop into gale force, without any indication by barometric pressure.

7. Pampero

Is the name given to the passage of a sharp, cold front (line-squall) over the mouth of the Rio de la Plata (River Plate) of the east coast of South America. As usual with the passage of a cold front, Cb clouds, heavy rain squalls, thunder, lightening, sharp fall of temperature, sudden increase of pressure, sudden backing of wind direction, etc., occur. They are most frequent between June and September.

8. Roaring forties

Is another name for the prevailing westerly winds of the southern hemisphere, around 40°S latitude.

9. Scirocco

Is any southerly wind in the Mediterranean Sea. Since such a wind originates from the desert of North Africa, it is a dry warm wind. It may blow across the Mediterranean Sea and reach the north coast as a warm, moist wind where the local people dislike it owing to its energy-sapping humidity and its fog forming nature.

10. Shamal

Is any NW wind in the Persian Gulf and the Gulf of Oman. It is a warm, dusty, dry wind from the deserts of Arabia. It may change direction due to the trend of land features and can blow from W or even SW. No indication is given by barometric pressure, of the approach of a Shamal, though the wind force in winter can reach Beaufort force 8 or 9, sometimes accompanied by rainsqualls, thunder and lightning.

11. Southerly buster

Is the name given to the passage of a sharp cold front over south or south-eastern Australia. It is quite similar to the Pampero of South America. It blows mainly between October and March.

12. Sumatra

Is a thunderstorm that usually occurs at night over the Strait of Malacca, from a direction between SW and NW, most frequently between April and November. A sudden drop of temperature, accompanied by thunder, lightning and torrential rain from Cb clouds are characteristic of a Sumatra.

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CHAPTER 29

OPTICAL PHENOMENA

1. Corona

Corona is the name given to a series of coloured rings, seen though thin lenticular clouds such as Ac, Sc or St, surrounding the Sun or Moon. The space next to the Sun or Moon is bluish white and this is called the 'Aureole'. The outer circumference of the aureole has a brownish red ring around it. In most cases, only the aureole is seen but a complete corona has a set of coloured rings surrounding the aureole - violet on the innerside and red on the outer side, in the order violet, indigo, blue, green, yellow, orange and red (VIBGYOR).

The series of colours may be repeated more than once but the colours are not usually very clear. The angular radius is generally small (less than 10°). The corona is produced by diffraction of light by water droplets. Pure colours mean that the droplets are of uniform size. The smaller the droplets, the larger the radius of the corona and vice-versa.

2. Halo

Halo is the name given to a luminous ring, of 22° radius, seen around the Sun or Moon through Ci or Cs clouds. The space inside the halo is less bright than outside it. The halo usually appears white but if properly developed, it will have the seven colours

VIBGYOR, with red on the inside and violet on the outside.

A halo is produced by refraction of light through ice crystals. Ice crystals of clouds are usually hexagonal in shape and hence have angles of 120° each, resulting in a halo of 22° radius (proof of this can be easily derived).

Sometimes a halo of 46° radius may be seen. This is caused by refraction of light by the faces of two different hexagonal prisms being at right angles to each other.

Note: The differences between a halo and a corona may be summarised as follows:

	HALO	**CORONA**
Brightness	Darker inside	Brighter inside
Radius	22° or 46°	Less than 10°
Colours - VIBGYOR	From outside inwards	From inside outwards
Cause	Refraction through ice-crystals	Diffraction by droplets of water.

3. Rainbow

A rainbow is a bright, multi-coloured band, about 1½° in width, in the shape of an arc, seen by observer with his back to the Sun or Moon. The external radius of this is about 42°. Its seven colours, VIBGYOR, have violet on the inside and red on the outside.

Sometimes a second and larger rainbow is also seen about 3° broad and about 54° external radius. The smaller and brighter one is called the primary bow and the larger and fainter one, the secondary bow. The secondary bow is only about one-tenth the intensity of the primary bow. The colours of the secondary are in reverse order (red inside, violet outside).

Rainbows are the result of total internal reflection and dispersion of light through raindrops. The colours of solar rainbows are clear whereas those of lunar rainbows are faint and not separately discernable to the human eye. Lunar rainbows hence appear white.

Primary bows cannot be seen if the altitude of the Sun/Moon is over 42° whereas secondary bow cannot form if the altitude is more than 54°.

4. St. Elmo's fire

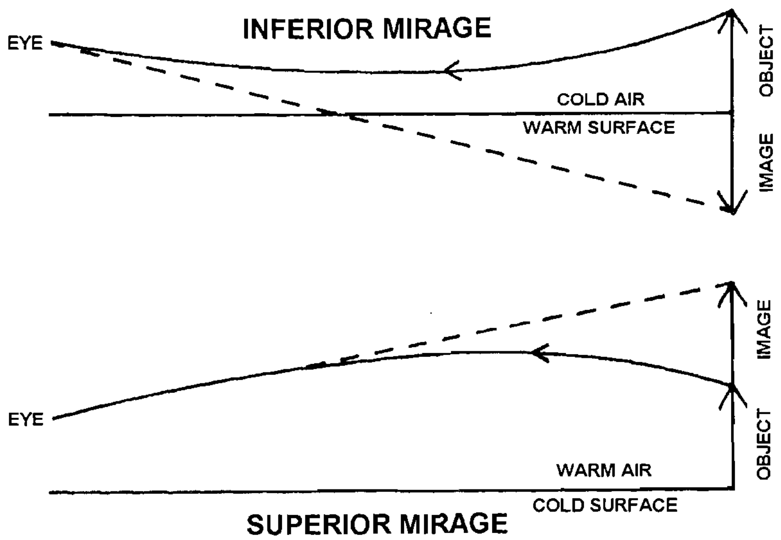
St. Elmo's fire is a fairly continuous, luminous, electrical discharge of weak or moderate intensity in the atmosphere, emanating from elevated objects at the earth's surface (lightning conductors, wind-vanes, masts of ships, etc.) or from aircraft's in flight (wing-tips, propellers, etc).

St. Elmo's fire is usually blue or green in colour, sometimes white or violet and is accompanied by a crackling sound. It occurs when the electrical field in the vicinity of the glowing object becomes very strong, as when a Cb cloud is overhead. St. Elmo's fire is also termed Corposant (ghost-like) because it was considered supernatural, in the old days.

5. Mirage

Mirage is the name given to an optical illusion resulting from a phenomenon called "Total internal reflection". When a ray of light passes from one medium to another of different density, it is refracted. If the angle of incidence was progressively increased, it will be noted that, beyond some large and particular angle of incidence, the ray of light does not enter the second medium but is reflected back into the first medium itself. This is called total internal reflection.

When a ray of light from an object travels through different layers of air having great difference in density, it is refracted progressively by each layer until total internal reflection takes place. If such a ray than enters on observer's eye, he will see an image of the object in the direction from which the ray finally enters his eye. Such an image is called a mirage.



A mirage is produced only when there is a large difference between the temperature of air and the temperature of the surface over which it blows.

There are two main types of mirages:

5.1. **Inferior mirage**: Is so called because the image appears below the position of the object. It occurs over very hot, flat, surfaces such as a road or desert during day-time. It can also occur over sea if a very cold breeze blows over a relatively warm sea-surface.

5.2. **Superior mirage**: Is so called because the image appears above the position of the object. It occurs when warm air blows over a relatively cold surface and is hence very common during day-time over land-locked seas such as Red sea, Mediterranean sea. Persian Gulf, etc.

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CHAPTER 30

THE FACSIMILE RECORDER

The facsimile recorder is an instrument that reproduces, on board a ship, an exact copy of a weather map drawn by a meteorologist ashore, in the office of the local meteorological centre.

The meteorological centre receives weather reports from all stations - land stations, weather ships, ships of the voluntary observing fleet, etc., and a meteorologist draws a weather map. The map is then scanned electronically and transmitted by high frequency radio waves using the FM (frequency modulation) technique, instead of the usual AM (amplitude modulation) technique, to ensure much clearer and relatively static-free reception on board.

The recorder draws a white, moist, electro-sensitive paper over a stainless steel writing surface, at a steady speed. A stylus moves horizontally across the paper at a suitable sweep frequency. The radio signals received cause small, electric currents to pass from the stylus to the writing surface, through the paper. Chemical action discolours the paper wherever the current passes through it and gradually an exact, black and white copy of the weather map appears on the paper. It will be noticed that this is very similar to fax machines, using thermo-sensitive paper, found in many offices ashore.

The recorder reproduces the 48 cm x 30 cm copy of the original map in three or four minutes, from start to finish. The same weather map, sent in the International Analysis Code (IAC) would require a couple of hours to decode and transfer to a map and is subject to errors during transmission, reception, decoding and plotting manually.

In the event of atmospheric disturbances resulting in severe static, the facsimile map is adversely affected but is still intelligible.

The facsimile recorder, once installed, only needs to be switched on and off at the correct times and requires no skill on the part of the operator. Knowledge and skill are required only to interpret the information given on the map and to use it to advantage.

The only items that require periodic replacement are the roll of paper, the tip of the stylus and, less frequently, the writing surface, all of which are fairly inexpensive.

Various types of charts, maps and also regular communications to ships in the area are transmitted in the facsimile wave band, not only for ships, but also for other users.

Facsimile charts fall into two basic categories – analysis and prognosis and each is described below.

1. **Analysis**: is the actual situation existent, at a given time, based on actual reports received.
2. **Prognosis**: is the predicted situation at a specified future time, based on present indications, as deduced by an expert on the subject, using his knowledge and skill.

Facsimile charts for mariners:

1. **Surface weather charts**
   1.1. **Weather analysis charts**: These charts give the weather situation, at the preceding synoptic hour, over the entire area. They show the weather experienced at each land and ship station, all pressure systems, isobars, wind directions, fronts, frontal depressions, etc.

   With the good, basic knowledge of meteorology that a Master is required to possess, he can size up the overall situation and take any urgent steps that may be necessary to ensure the safety of his vessel.

   1.2. **Weather prognosis charts**: These charts are also called prebaratic charts and contain the same type of information as weather analysis charts but predicted for a specified future time. They may be made 12 hours, 18 hours, 1 day, 2 days, 3 days or 5 days before the specified time, so that a shipmaster may route his vessel accordingly.

   A weather prognosis chart is compiled by a professional meteorologist after studying the weather analysis chart, upper air charts, thickness charts, atmospheric change of pressure charts, etc., taking into account various other factors also. The construction of a prognosis chart needs deep knowledge of weather prediction and expertise gained over several years of study of the weather in that ocean.

2. Ice charts

2.1. **Ice analysis charts**: These charts indicate amounts and boundaries of each type of ice, ice-packs, ice-leads and ice-bergs, based on actual observation.

2.2. **Ice prognosis charts**: These charts contain the same type of information as ice analysis charts, but predicted for a specified future time, and are usually made 12 hours and 24 hours in advance.

After studying the situation shown by the ice analysis chart and taking into account various factors such as winds, currents, temperatures of air and sea, etc., the prognosis charts are made by experts.

3. Wave charts

3.1. **Wave analysis charts**: These charts show isopleths (lines joining all places having the same value) of wave-heights, in metres, and their direction, based on actual reports.

3.2. **Wave prognosis charts**: These charts show isopleths of wave-heights, in metres, predicted for a specified future time. They are made by professional meteorologists and based on a study of weather analysis charts, weather prognosis charts, wave analysis charts, etc.

Both wave analysis and wave prognosis charts are very useful to the Master, in routeing his vessel, as explained in the next chapter.

Facsimile coverage

Most of the oceans of the world are not yet covered by facsimile transmissions. However, the situation is improving. The North Atlantic Ocean, the North Pacific Ocean and European Waters are well covered. Many stations in other areas send out only weather analysis maps for their limited areas of coverage.

Though the facsimile recorder is a boon to the shipmaster, a sound knowledge of the International Analysis Code, the appreciation of a weather map and ability to make reasonable predictions based on the same, are essential. The fact that the facsimile recorder went out of order should not make a navigator helpless on an ocean passage. He should pull out a pencil and plot the whole weather map by decoding the bulletin transmitted in the International Analysis Code and make his own predictions. Even if it is tedious, it is still worth the trouble as the shipowner, crew and passengers are all relaying on his competency and efficiency.

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CHAPTER 31

ROUTEING OF SHIPS

1. **IMO reference**: The International Convention for the Safety of Life at Sea 1974 (SOLAS 74), as amended in 2000, includes 'Ships' routeing' in its Regulation 10.

2. **Definition**: Routeing is the art of achieving a safe, economic passage across an ocean, taking into consideration all available meteorological and oceanographical factors.

3. **Advantages**

The following advantages of routeing add up to greater safety and more economy in ship operation:

3.1. Less chances of heavy weather damage.
3.2. Less chances of shift of cargo.
3.3. More comfort for people on board.
3.4. Faster passage resulting in time and fuel savings.

4. **Influencing factors**

The factors to consider while routeing are:

4.1. **Distance**: The shortest distance (the great circle track) is not necessarily the best route to follow because of other factors. Unnecessary deviation from the shortest route is, however, to be avoided.
4.2. **Ocean currents**: Adverse currents mean more passage time. A route covering greater

distance but having a following currents may result in a quicker passage.

4.3. **Wind and waves**: Strong adverse winds result in high head seas that cause the vessel's speed to drop considerably. This drop in speed may be due to:

4.3.1. Wave resistance to ship's progress.

4.3.2. Less propelling power - the axis of the propeller keeps shifting out of the horizontal, due to pitching, and sometimes the propeller even comes out of the water.

4.3.3. Wind resistance caused by hull, super-structure, etc.

4.3.4. Slamming (pounding) which not only resists the vessel's progress but also causes severe structural stresses.

4.3.5. Voluntary reduction of engine RPM, by the Master, to reduce slamming.

4.4. **Ice at sea**: The vessel would, as far as possible, have to keep out of pack-ice and iceberg-infested waters. If she has to pass through such areas, the risk is great and speed would have to be considerably reduced. A detour, where possible, would increase the distance but would also increase safety and allow full speed.

4.5. **Fog**: is the Master's greatest threat at sea because, in fog, he has not only to combat natural dangers but also rely on the judgement and discretion of the Masters of other vessels as well. The worst situation is fog, in confined waters, with high traffic density e.g., the English Channel, Dover Strait, Malacca Strait, etc.

Where the deviation is not too much, it would be preferable to avoid the fog area. However, as fog prediction is not available on facsimile charts, the Master cannot decide too much in advance.

4.6. **Very low temperatures**: Where a great circle track passes through very high latitudes, the vessel is likely to experience very low atmospheric temperatures which should, when practicable, be avoided. Some of the problems associated with extremely cold weather are:

4.6.1. Fresh water, sanitary water and deck service water tend to freeze in the pipes, preventing flow of water through them, sometimes bursting them.

4.6.2. Ice accretion on deck makes it very dangerous for crew to go about.

4.6.3. Severe ice-accretion can be due to supercooled water particles in persistent fog, freezing rain, snow and spray. Steam hoses, sledge-hammers, and shovels have often been tried out, to rid the decks of ice, but in vain.

4.6.4. In very cold, gale force winds, the spray freezes during transit and strikes any objects in its path as solid ice, shattering port-hole glasses, denting plates and injuring human beings.

4.6.5. Persistent snow-fall can reduce visibility, making speed reduction necessary.

4.6.6. Biting cold passes through all protective clothing and saps the will to work. Once a person catches a chill in such-cold weather, recovery will be very slow.

4.6.7. During periods of non-use, moving parts such as radar scanners, doors, ventilators, etc., freeze in position. Containers on deck have sometimes frozen together and delayed their discharge at the arrival port.

4.6.8. In case of accident or disaster, a person in the water rarely survives more than a few minutes.

4.6.9. The morale of the crew reaches a very low level during extreme cold weather due to the combination of all the above points.

5. Climatological routeing

Until recent times, routeing was done solely by the use of Pilot Books and monthly or seasonal charts of the winds and currents of the oceans. Under certain circumstances, it is still the best method possible. The book "Ocean Passages of the World" is still the standard book for reference, while contemplating Climatological routeing.

6. Weather routeing

It has recently been definitely established that in the temperate latitudes of the North Atlantic and North Pacific, day to day changes of weather are so drastic, due to fronts and frontal depressions, that seasonal routeing is inadequate. The ideal route for a particular passage changes from day to day, week to week. For example, the track to be followed by a vessel on the date of departure may be quite different from that of a similar vessel, on a similar passage, a few days earlier - hence the name "weather routeing" as different from "climatological routeing".

However, in tropical regions, especially the northern Indian Ocean and China Sea, climatological routeing is quite successful, as seasonal variation is fairly regular and systematic.

7. How weather routeing became possible

Modern weather routeing techniques have become possible only because of international co-operation, through the World Meteorological Organisation, resulting in standardisation of methods and systems, world-wide gathering of meteorological data and extremely quick methods of world-wide dissemination (distribution) of the data so gathered.

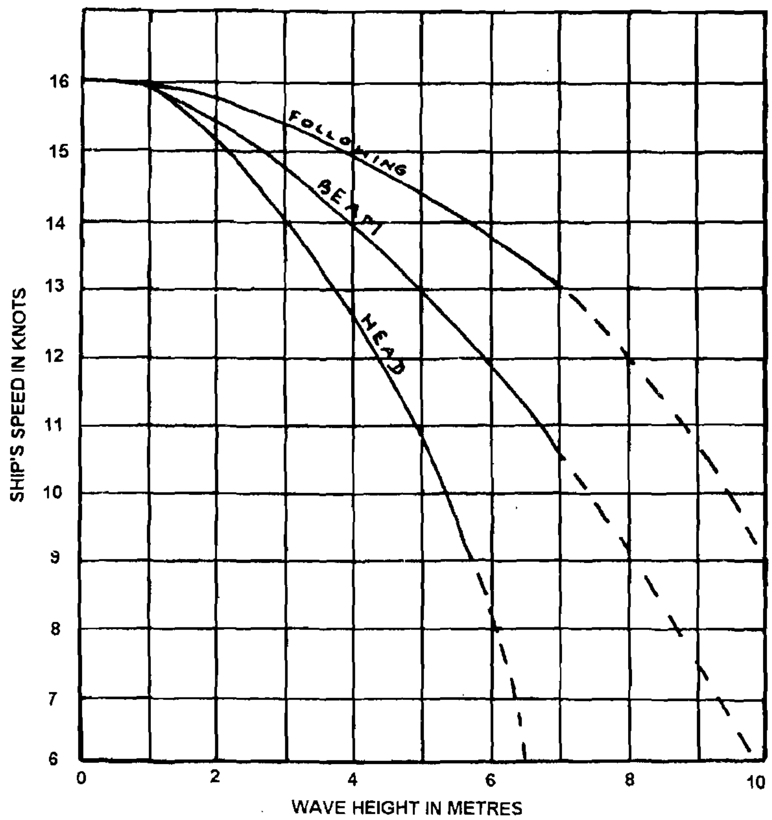
For example, the pilot of a commercial airliner, leaving Bombay for London, would like to know the exact weather situation actually existent enroute so as to route his aircraft to best advantage, involving courses to follow, altitudes to maintain, etc. Such meteorological briefing is now possible only because the weather situation has been observed by meteorological observers so far away, transmitted to their regional headquarters, evaluated and re-transmitted to other regional headquarters all over the world - all this in a couple of hours. However, it must be mentioned here that, from the meteorologist's point of view, weather routeing of a ship is more difficult than that of an aircraft. The former requires long-term forecasts, days in advance, and this poses several problems. The latter requires short-term forecasts based on recent observations, made possible because of the very fast modern methods of communications that have been established.

8. Weather routeing not yet possible world-wide

Owing to a severe lack of regular and frequent weather reports from observers in the southern hemisphere, weather routeing is not yet possible there. Hence climatological routeing is still the only method recommended in the South Atlantic, South Pacific and Indian Oceans. However, the situation is improving steadily.

9. Ship's performance curves

It has been established that, other than ocean currents, waves are the biggest factors that cause a reduction of a vessel's speed. The waves can be sea, swell or a combination of both. It is therefore important that the vessel's performance in various wave conditions be known before attempting to weather route a particular vessel. For this purpose, performance curves should be constructed by inspecting the records of previous voyages and, if they are not readily available, the curves of a somewhat similar vessel may be used in the meantime. Separate performance curves should be drawn for light and load conditions. The curves should be 'faired' and extended wherever necessary. The performance curves of a typical cargo ship are given here, as an example.



Each curve is usually drawn, assuming full engine revolutions, even for very high waves from ahead. Since the Master would be avoiding regions of high head-on waves, there is no danger in this assumption.

In the performance curves, 'head' means from any direction between right ahead and 60° on either bow; 'following' means from any direction between right astern and 60° on either quarter and 'beam' means from any direction within 30° of athwartships.

10. Weather routeing by shipmaster

The shortest possible track is first drawn on a gnomonic chart or polar stereographic chart of that ocean. This track is then transferred to a transparent, plastic sheet placed over the 24-hour prognostic facsimile wave chart. The possession of a facsimile recorder on board is a necessity for weather routeing. Radial lines, 10° apart, are then drawn from the starting position, on either side of the shortest track (see worked example).

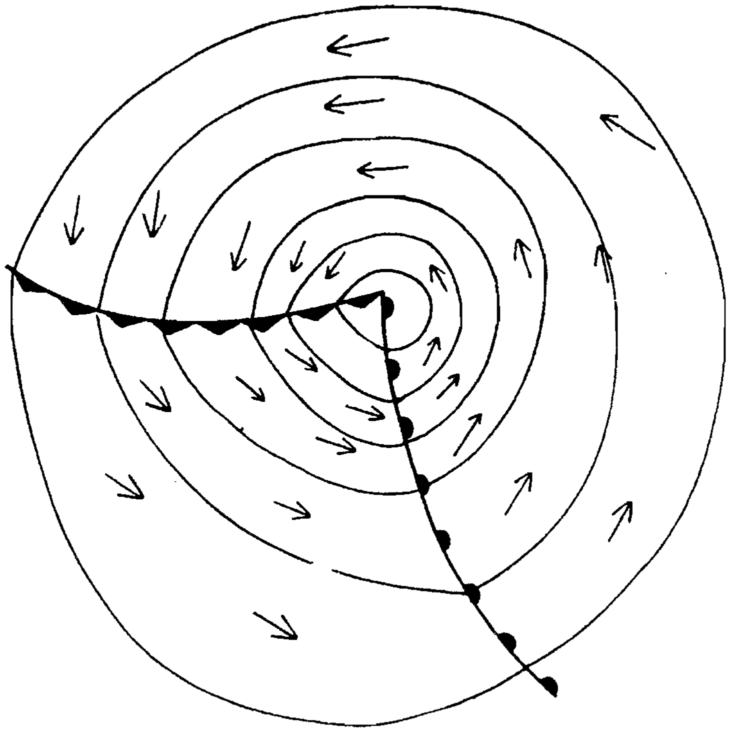
Each such radial is a likely course to steer. On each of these likely courses, the relative bearing (head, following or beam) and wave height is read off from the 24 hour prognostic wave chart. The performance curves are consulted and the ship's likely position at the end of 24 hours run on each likely course is plotted. To each such likely position, the set and drift of current for the 24-hour period (taken from monthly current charts) is applied and series of estimate positions are obtained. A smooth line, curved as necessary, drawn through all these estimated positions, is called locus 1 (see worked example).

The transparent plastic sheet is then placed over the 48-hour prognostic wave chart and 10° radial lines are drawn again at each estimated position on locus 1. Those radial lines that now go goo far off, from the shortest possible track, are left out and locus 2 is drawn in. If more prognostic wave charts are available more locii are drawn.

A line drawn through the convex parts of each locus (viewed from the destination) is the optimum route to follow, subject to daily amendments based on fresh information received.

24-hour surface prognosis chart

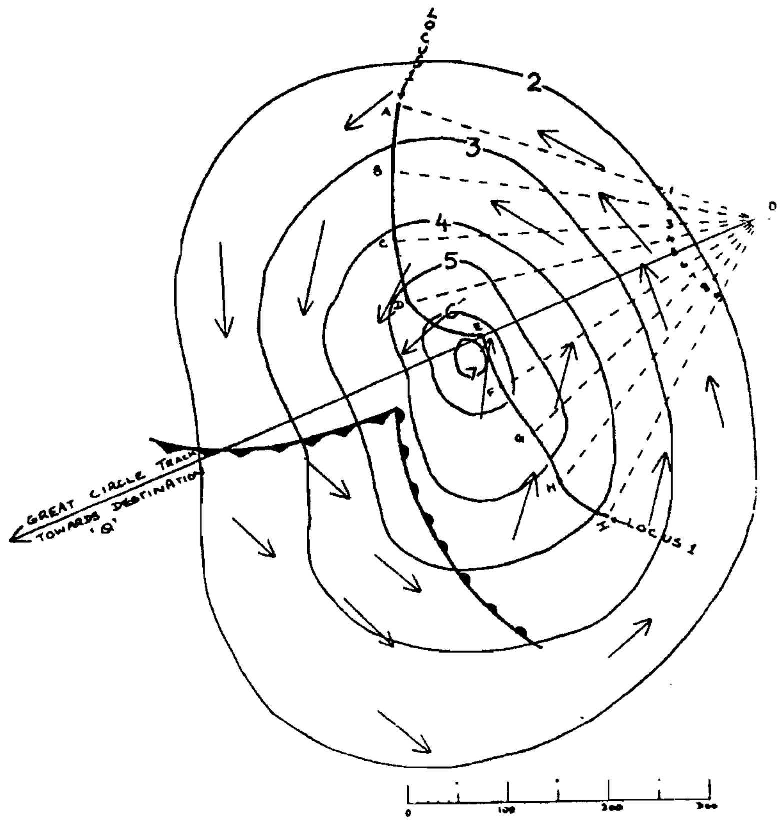
(For worked example)



11. Worked example

The following calculations were made to arrive at points A, B, C, D, E, F, G, H & I, which form locus 1, and are shown here for illustrative purposes. For the sake of clarity, a "no current" situation has been assumed.

24-hour wave prognosis chart with superimposed routes showing locus 1.



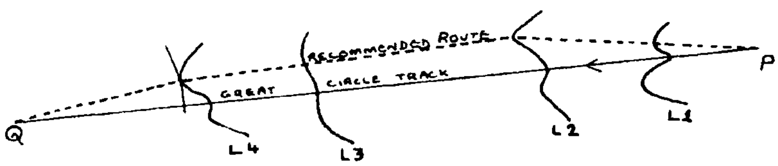
Wave-height isopleths in metres.

Course No.	**Distance** (miles)	**Wave height** & aspect	**Speed** made good (knots)	**Steaming** time (hours)
1.	110 267 **377**	nil ←2½F 	16.0 ← 15.6 	6.9 ← 17.1 **24.0**
2.	90 120 210 163 **373**	Nil 2½F ←3½F 	16.0 15.6 ←15.2 	5.6 7.7 13.3 ← 10.7 **24.0**
3.	75 100 100 275 94 **369**	nil 2½F 3½F ←4F 	16.0 15.6 15.2 ←14.9 	4.7 6.4 6.6 17.7 ← 6.3 **24.0**
4.	70 90 65 45 270 90 **360**	nil 2½F 3½F 4½F ←5½F 	16.0 15.6 15.2 14.7 ←14.1 	4.4 5.8 4.3 3.1 17.6 ← 6.4 **24.0**
5.	70 85 55 55 20 285 14 **299**	nil 2½B 3½B 4½H 5½H ← 7H 	16.0 15.1 14.4 11.6 9.5 ← 4.2 	4.4 5.6 3.9 4.7 2.1 20.7 ← 3.3 **24.0**
6.	70 85 55 50 30 290 21 **311**	nil 2½B 3½B 4½H 5½H ←6H 	16.0 15.1 14.4 11.6 9.5 ← 8.0 	4.4 5.7 3.8 4.3 3.2 21.4 ← 2.6 **24.0**

7.	70	Nil	16.0	4.4
	90	2½B	15.1	6.0
	60	3½H	13.2	4.5
	55	4½H	11.6	4.7
	275			19.6
	42	← 5½H	← 9.5	← 4.4
	317			**24.0**
8.	75	nil	16.0	4.7
	100	2½H	14.6	6.8
	70	3½H	13.2	5.3
	245	← 4½H	← 11.6	16.8
	84			← 7.2
	329			**24.0**
9.	80	nil	16.0	5.0
	120	2½H	14.6	8.2
	200			13.2
	143	← 3½H	← 13.2	← 10.8
	343			**24.0**

*F = Following, H = Head, B = Beam.

It is important to note that the route should be selected only after as many locii as possible have been drawn in. It can sometimes happen that the route that appears most favourable from the starting point to locus 1, may not be the best one denoted by locii 2, 3, 4, 5 etc. as illustrated in the figure below.



12. Shore-based routeing

There are shore-based organisations that do weather routeing of ships across the North Atlantic and North Pacific. They employ meteorological experts and experienced Master Mariners and give routeing instructions radio on a request from a ship. Though the routeing procedure is the same as that described earlier, the meteorologist, aided by a computer, has a better idea of the reliability of the prognosis. After studying various facsimile charts (analysis and prognosis) such as charts showing isobars of 100, 200, 300, 500, 700 & 850 mb values, thickness charts, change of pressure charts, temperature lapse rate charts, infra-red photographs of clouds from satellites and sea-temperature charts, the meteorologist has a good idea of what possible deviation of the weather may occur from the prognosis. The experienced Master Mariners are consulted and routeing instructions are given to the ship by terrestrial or space radio communications, amended as necessary, daily.

Routeing of "selected ships" of the Voluntary Observing Fleet is easier and more economic as the regular weather reports sent by the ship, containing its position, course and speed, transmitted free of cost by the ship, are available to the shore-based routeing organisations.

13. Limitations of weather routeing

Inaccuracies in the performance curves of the ship may result from the following:

13.1. The effect of waves from right ahead to 60° on either bow is considered to be the same. In reality, this is not so. Waves from right ahead affect the ship's speed more than from either bow.

13.2. The amount of trim makes a difference in ship's performance. This is not taken into account in the performance curves of the ship. It is not practical to expect ships to be able to maintain similar trim from voyage to voyage.

13.3. Methods of estimating wave heights at sea depend on the observational capacity of individual officers under various patterns of ship behaviour (rolling, pitching, etc.) and hence performance curves made, using them, are not as accurate as we would like them to be.

13.4. Data of speed made good under various conditions of waves are not always accurately available when making the performance curves.

14. Other inaccuracies may result from

14.1. Wave periods also affect speed of ship, as different from wave heights. These cannot as yet be predicted and are hence not taken into account.

14.2. The prognosis wave charts are mainly for sea waves. Some allowance for swell is included but precise swell prediction is still not available.

14.3. During the period covered by the prognosis wave chart, the wave patterns are considered constant. This is not strictly correct. The analysis condition would gradually change to the prognostic condition (assuming that the prognosis is right).

14.4. Owing to the vagaries of weather, the prognosis is not always right in spite of man's deep study of the subject. However, it is very rarely entirely wrong.

14.5. On eastbound voyages on the North Atlantic & North Pacific, the general movement of wind is towards east and the current also sets easterly. Hence the speed of a ship is increased automatically when it follows the great circle track. Hence weather routeing is generally more effective on westbound voyages than on eastbound voyages, in these areas.

15. Weather routeing advisable

In spite of the lmitations of weather routeing listed above, it is till strongly recommended as weather routed ships are averaging quicker crossings with less weather damage to ship and cargo, than others.

Weather routeing is more for economic than for safety reasons. The wind force, in the worst part of a temperate latitude depression, rarely exceeds 9 or 10 of the Beaufort scale (less than 55 knots). In rare cases, if it does exceed force 10, that area is very small and can easily be avoided by watching weather reports and taking suitable early action. An average ship, well maintained and properly loaded, should be able to weather a temperature latitude depression well, without undue fear of disaster. Speed however, will be reduced by wave action directly or indirectly by voluntary reduction of engine RPM by the Master, to relieve excessive structural stresses.

16. Master's decision

At all times, the Master retains full command of the ship and may disregard the advice of shore-based routeing organisations if he feels justified in doing so for safety reasons. Some of the reasons for such action could be to get away from unexpected fog, to get away from very low temperatures, to avoid heavy rolling due to swell, etc. Here again, the routeing organisation could be informed and they would take this action into account for future amendments in the vessel's route.

17. Choice of weather routeing by ship or shore

This is entirely up to the ship operator (shipowner, charterer) and/or shipmaster. Fast trans-Atlantic liners in the fruit trade, container trade or passenger trade, involving high competition and requiring absolute punctuality, would prefer to be weather routed by shore-based experts. This would partly shift the responsibility from the Master to the ship operator for keeping to the schedules.

Other ships, making regular crossings, would like economical passages but usually have no penalties to pay for a delay of a few hours. Owners of such vessels may prefer to leave routeing to shipmasters.

It would be a good idea for shipmasters to convince their owners to use shore-based weather routeing, as it is fairly inexpensive. While such a vessel is being routed from ashore, during the trial period, the Master may keep watching the facsimile prognosis charts and check for himself the reasons why each alteration of course is recommended by the routeing organisation.

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