

## Physical Environment Test Data Set

### 1. MARITIME TOPOGRAPHY

#### 1.1 General Remarks

*Charts 4070, 4071, 4072, 4073*

Stable crustal structures are a predominant feature of the bed of the Indian Ocean.

In the S part of the ocean described in this volume there is very little continental shelf; the 200 m depth contour only extends any appreciable distance from the W and NW coasts of Madagascar. Relatively steep escarpments form most of the continental slope, descending into depths from 400 to 800 m.

The bed of the remaining, greater part of the area is divided by a system of mountainous ridges, described below, into three segments; lesser ridges, plateaux, rises, and chains of seamounts sub-divide these segments into basins. Near land masses, where there are thick deposits of sediments, the bottoms of these basins are smooth, forming abyssal plains; in the central part of the ocean, where sediments are thin and dispersed, they are rough and uneven, forming conical abyssal hills and seamounts.

#### 1.2 Seabed and Features

Land-derived sediments predominate on the continental shelf; the chalky remains of marine organisms are found on the continental slopes and basin bottoms to depths as great as 4300 m, with red clays in deeper parts.

##### 1.2.1 Deeps

Within the area covered by this volume the Indian Ocean attains depths over 5000 m in a number of places. On the W side are:

Mozambique Basin and Madagascar Basin, SW and SE, respectively of Madagascar.

Mascarene Basin between Madagascar and La Réunion (21°05'S 55°30'E).

Amirante Trench (chart 4702) between Providence Island (9°12'S 51°02'E) and Alphonse (167 miles NE).

Somali Basin, W of Seychelles Group (4°30'S 55°30'E).

In the central part is:

Crozet Basin, W of Île Saint-Paul (38°43'S 77°33'E).

On the E side are:

Mid-Indian Ocean Basin, SSE of Great Chagos Bank (6°15'S 72°00'E).

Vema Trench, which is over 6000 m deep, and lies SW of Great Chagos Bank.

Chagos Trench, E of Great Chagos Bank.

##### 1.2.2 Ridges and plateaux

Madagascar Ridge extends S from Madagascar; Farquhar Ridge (chart 4702), on which lies Farquhar Group (10°10'S 51°10'E) and Providence Group (50 miles N), extends NE from Madagascar.

Mascarene Plateau extends between Mauritius (20°17'S 57°35'E) and Seychelles Group (about 850 miles N).

The central part of the area described is dominated by a number of ridges which extend SW, SE and N from approximate position 25°S 70°E; these are, respectively, Southwest Indian Ridge, Southeast Indian Ridge, on which lie Île Saint-Paul and Île Amsterdam, and Central Indian Ridge. Rodriguez Ridge, on which the island of Rodriguez Island is situated, extends W from Central Indian Ridge in about lat 19°30'S.

Ninety East Ridge extends N along the E side of the area described from approximate position 35°S 87°E.

##### 1.2.3 Shoals and banks

Walters Shoals (33°12'S 43°55'E) lie on Madagascar Plateau; the sea breaks on these shoals.

Soudan Bank lies on Saint Gérân Ridge, Cargados Carajos Shoals, Nazareth Bank and Saya de Malha Bank lie on Mascarene Plateau, in that order from S to N.

#### 1.3 Submarine Springs

There are no known areas of submarine springs.

## 1.4 Volcanic activity

Volcanoes with high peaks are widespread on ocean basin floors; the seamounts are volcanic.

On land, Le Kartala, a volcano on Grande Comore (11°40'S 43°20'E), erupted in 1918, and appears to be active.

Piton de la Fournaise, a volcano in the SE part of La Réunion (21°05'S 55°30'E), erupted in 1902 and shows signs of continued activity. There are some hot mineral springs on the island.

On Île Saint-Paul and Île Amsterdam, both of which are of recent volcanic origin, there are some small warm brackish water basins.

## 1.5 Seismic activity

Slight earthquakes are frequent on La Réunion.

Earthquake shocks are felt at times on Diego Garcia (7°16'S 72°22'E).

## 2. MAGNETIC VARIATIONS AND LOCAL ANOMALIES

### 2.1 Magnetic variations

Not applicable.

### 2.2 Magnetic anomalies

A list of places where local magnetic anomalies have been observed is given in the index under the heading Magnetic anomalies, local. For further information see *The Mariner's Handbook*.

## 3. CURRENTS, TIDAL STREAMS AND FLOW

### 3.1 Currents

#### 3.1.1 General information

In most of the sea area covered by this volume, the currents are associated with the high pressure system described (8.4), and circulate counter-clockwise.

The N part of the circulation is formed by the W-going South Equatorial Current, and the S part by the E-going Southern Ocean Current. Currents setting SW off the coasts of Madagascar and Africa form the W part of the circulation, while to the E of the area the circulation is completed by the N-going West Australian Current.

In the extreme N part of the area the currents are seasonal, their direction being determined by the monsoon systems of the North Indian Ocean, described in *Ocean Passages for the World*.

**Currents diagrams.** In the currents diagrams (*not included*) arrows indicate predominant direction, average rate and constancy, which are defined as follows:

**Predominant direction** is the mean direction within a continuous 90° sector containing the highest proportion of observations from all sectors.

**Average rate** is the rate, to the nearest ¼ kn, of the highest 50% in predominant sectors as indicated by the figures on the diagrams. It is emphasised that rates above or below those shown may be experienced.

**Constancy**, as indicated by the thickness of the arrows, is a measure of its persistence; e.g. low constancy implies marked variability in rate and, particularly, direction.

#### 3.1.2 Named currents

**Equatorial Counter-current.** The Equatorial Counter-current, in the area covered by this volume, is a seasonal E-going current which occupies almost all the N-most part from about December to April. The N limit of the current lies between 1° and 3°S, the S limit between 6° and 8°S and the W limit between 50° and 55°E. In the early and late stages of the current its constancy is moderate or even high with rates of 1½ to 2 kn; a rate of 4 kn has been observed (January 1974). From January to March constancy is moderate to low with rates of 1 to 1½ kn.

**South Equatorial Current.** The N limit of this W-going current coincides with the S limit of the Equatorial Counter-current or SW monsoon current, according to season; its S limit is the N limit of the Southern Ocean Current, described below. This limit lies between approximate positions 35°S 40°E and 25°S 90°E in February, and from 35°S 40°E to 22°S 90°E in August. Constancy is mainly moderate N of about 15° to 20°S, but low farther S; average rates are about 1 kn in the N part and ¾ kn in the S part of the current.

On approaching Madagascar the current divides into two branches between about 14° and 18°S. One branch is diverted N and then W round the N end of the island, the other branch S and then W round the S end. Both

branches are variable in constancy and average rates are about 1¼ kn. The rate of the N branch is greater and increases towards N during the South-east Trade Wind season (8.7.2); the rate of the S branch increases towards S.

Less than about 500 miles from the coast of Madagascar and SE of the S point of the island currents setting between E and N are often experienced.

On passing the S point the S branch of the current divides again. One part turns erratically N to the W of Madagascar; the other part continues WSW to join the current systems off the SE coast of Africa or, at times, retroflects S and E to join the Southern Ocean Current. Over the 25 year period from 1961 to 1985 the maximum rate experienced in this area was 4 kn, the current setting in any direction.

**Southern Ocean Current.** The Southern Ocean Current sets mainly E or NE, its N limit coinciding with the S limit of the South Equatorial Current. To N of about 40°S constancy is mainly low with almost as many W or SW sets as E or NE sets; farther S constancy is mainly moderate. The average rate of the N part is about ¾ kn and of the S part 1¼ kn.

**Currents in Mozambique Channel.** On rounding the N end of Madagascar the N branch of the South Equatorial Current fans out to form a fairly constant current with a rate of 1 to 2 kn which sets SW along the edge of an extensive bank off the NW coast of the island; the currents on the bank are described later, with the description of the NW coast.

Farther to seaward, Mozambique Channel can be divided into two zones as far as the currents are concerned. Although the boundary between these zones corresponds closely with the W limit of the area covered by this volume it may, at times, be found farther E, within the area, particularly from June to August. To W of the boundary lies the SW-going Mozambique Current which is of moderate, occasionally high, constancy with an average rate of 1½ kn, although there are instances of rates as much as 4 kn having been experienced. To E of the boundary the current is very variable, but sets predominantly NNE. The boundary can be very sharply defined and considerable differences in rate and direction of current may be experienced over short distances. Around the islands in the channel the currents are strong and irregular.

Little is known of the currents less than about 100 miles from the coast of Madagascar; such information as is available is given later in the text with the descriptions of coastal and offshore waters.

### 3.1.3 Seasonal currents

**Monsoon Current.** The NE monsoon current sets W from about December to April, its S limit being the N limit of the Equatorial Counter-current. It is of mainly moderate, occasionally high, constancy with an average rate of about 1½ kn, although rates as much as 4 kn have sometimes been experienced.

About April, a transition of the currents occurs. The influence of the E-going Equatorial Counter-current is felt farther N and the W-going NE monsoon current is replaced by the SW monsoon current, which sets E or SE. The S limit of this current becomes established about July along a line joining positions on the equator in longitude 50°E and between 6° and 8°S in longitude 90°E. The SW monsoon current is of moderate or high constancy in its early and late stages with an average rate of about 1¾ kn, while from June to September its constancy is moderate or low, with a rate of about 1¼ kn; the maximum rate experienced is about 4 kn. During December the pattern of NE monsoon current and Equatorial Counter-current is re-established.

## 3.2 Tidal streams

### 3.2.1 Madagascar

The coasts of Madagascar being, in general, steep-to there is little impediment to the free movement of water so the tidal streams are weak; however, where there are narrow channels through reefs offshore and in the entrances to deep bays the streams are strong.

### 3.2.2 Other islands

Strong tidal streams are also to be found in the passages through the reefs surrounding the other islands of the Indian Ocean described in this volume; details are given at the appropriate place in the text.

## 4. SEA LEVEL AND TIDES

### 4.1 Sea level

At Jussland, variations in sea level caused by rollers affect the height of tide.

## 4.2 Tides

In that part of the Indian Ocean covered by this volume the tide is generally of a regular semi-diurnal nature; this is especially the case at Comores, the W coast of Madagascar, Chagos Archipelago and Île Saint-Paul.

In Seychelles Group and at La Réunion and Mauritius there is some diurnal inequality of heights of the two HWs.

The largest tides occur on the W coast of Madagascar between Toliara and Nosy Be; at Mahajanga the mean spring range is 3.8 m. There is little rise and fall on the E coast of the island; at Taolanaro tidal movements are difficult to observe.

At La Réunion, the mean range is only about 0.3 m.

## 5. SEA AND SWELL

### 5.1 Sea conditions

In the South-east Trade Wind belt (8.7.2) moderate seas are usual at all seasons with waves 1 to 2 m high. Occasionally when the wind freshens, especially from June to September, seas can become rough but waves rarely exceed 3 to 4 m. Calm seas are unusual except in sheltered areas.

Farther S in the sub-tropical high pressure belt (8.4.1), slight or calm seas are common during the lengthy spells of light variable winds; but troughs of low pressure and associated fresh winds (8.7.2) bring interludes of moderate to rough conditions.

To the S of 30°S frequent strong winds and gales raise very heavy seas often exceeding 3 to 4 m; waves well over 12 m high can be expected in this area especially in winter.

### 5.2 Swell conditions

Apart from tropical storms and cyclones the principal generators of swell are the South-east Trade Winds, the generally W winds of the Roaring Forties (8.7.5) and, to a lesser degree in equatorial waters, the NE monsoon of the N hemisphere and its extension into the S hemisphere, the NW monsoon (8.7.3). Although swell waves and sea waves generated locally are usually present simultaneously, swells are generally much longer in length and period. Swell can cause uncomfortable conditions in an otherwise calm and smooth sea.

From the equator to 20° to 25°S swell is predominantly ESE throughout the year; generated by the South-east Trade Winds. Wave height averages 1 to 2 m but can reach 3 to 4 m. Heights tend to be lowest farther N; swells are highest in winter, and lowest in summer.

The NE monsoon of the N hemisphere raises moderate swells which reach equatorial regions during the S hemisphere summer (about December to March). The NW monsoon which blows S of the equator during the same season raises low, occasionally moderate NW swells as far S as 10° to 15°S. Associated N to NE swells affect the N part of Mozambique Channel.

To the S of 30°S swell from SW to S are an almost permanent feature raised by the strong winds of the Roaring Forties. Swells are often heavy and commonly exceed 6 m in height; wave lengths are usually between 100 to 200 m but long swells are not infrequent. In winter (from about June to August) SW swells extend as far N as 20° to 25°S and affect the S Madagascar coasts. Associated S swells, usually light or moderate, reach the S parts of Mozambique Channel.

#### 5.2.1 Tropical disturbances

Mountainous and confused seas are raised by the violent winds associated with the storms described at 8.5.2. Near the centre of a storm, groups of large waves moving in different directions have very irregular wave heights and can occasionally combine together to produce an exceptionally high wave in excess of 30 m.

Swell travels radially outwards from the storm circulation with the highest swells moving ahead of the storm roughly in the same direction as the storm track. This swell may be an early indication of an approaching or distant storm and also give some indication of the approximate bearing of the storm centre.

When a storm approaches land, abnormally high tides may be caused; with the addition of heavy swells and later, very high seas, severe flooding can occur in low-lying areas. Occasionally an exceptionally high wave or wall of water may race in from the sea with catastrophic consequences.

### 5.3 Abnormal waves

Rollers described in *The Mariner's Handbook* affect La Réunion, Mauritius and Rodriguez Island.

## **6. SEA WATER CHARACTERISTICS**

### **6.1 Salinity**

For an explanation of salinity as applied to seawater, see *The Mariner's Handbook*.

The sea surface salinity remains stable throughout the year and varies between 34·0 and 35·5 across the region covered by this volume. A zone of less saline water, from 34·0 to 35·0, extends across the region, between latitudes 5° and 20°S. The W edge of this zone varies; in February it lies in longitude 40°E, off the E coast of Africa, and in August in 50°E, off the E coast of Madagascar.

To the N of this zone, in the equatorial region, from the equator to 5°S, salinity decreases to the E, from 35·5 to 34·0.

To S of the zone, at latitude 20°S, salinity remains constant across the region but increases with latitude from 35·0 to 35·5 between 20° and 30°S; it then decreases again to 35·0 at 40°S, the Isohalines running E–W across the region.

### **6.2 Density**

For an explanation of density as applied to seawater, see *The Mariner's Handbook*.

The sea surface density varies across the region covered by this volume. In the S of the region the values remain constant at 1·0265 g/cm<sup>3</sup> throughout the year. However, the values vary seasonally in the NE of the region.

A zone of low density 1·0215 g/cm<sup>3</sup> covers a large part of the NE of the region in summer (February), but recedes to the NE in winter (August). Also in winter a small zone of low density, less than 1·0220 g/cm<sup>3</sup>, occurs off the NW coast of Madagascar.

The isopycnals are E–W in the S of the region but curve around the low–density zone in the NE to run NW in the NW of the region.

### **6.3 Sea surface temperature**

Diagrams (*Not included*) show the mean monthly sea surface temperature distribution for February and August, the months when maximum and minimum sea temperatures are usually reached.

The distribution pattern changes little through the year and in equatorial waters sea surface temperature varies only 1° to 2°C seasonally. To S of about 20°S sea temperature falls fairly steadily from February to August by about 4° to 5°C. Thereafter values increase again fairly steadily, towards the February maximum.

Near the equator sea temperature is usually within 1° to 2°C of the monthly mean value. Farther S variability increases and in the S of the region deviations from the mean of 3° to 4°C have been noted.

## **7. ICE CONDITIONS**

### **7.1 Drift ice**

Generally unknown in the area but see Chapter 4.

### **7.2 Icebergs**

Formed in the Antarctic, these may enter the S part of the region covered by this volume, driven NE by prevailing W winds and the predominantly E or NE–going Southern Ocean Current. They may be met as far N as 35°S at almost any time of the year but mainly from July to November. Growlers, described in *The Mariner's Handbook*, may be encountered well N of the limit of icebergs.

## **8. CLIMATE AND WEATHER**

### **8.1 General information**

The following information on climate and weather should be read in conjunction with the relevant chapters of *The Mariner's Handbook* and *Ocean Passages for the World*. *The Mariner's Handbook* explains, in more detail, many aspects of meteorology and climatology of importance to the mariner.

Routine weather reports and forecasts for the area covered in this volume are broadcast regularly, in different languages, from shore stations. Gale and storm warnings are also transmitted as necessary. Details of broadcast schedules and areas to which they apply are given in *Admiralty List of Radio Signals Volume 3 (2)*.

## 8.2 General conditions

### 8.2.1 Climate

Variation in general conditions of climate and weather with latitude is a marked feature of the extensive region covered by this book.

In summer, from December to March, the N part of the region, as far as about 15°S at its greatest extent, is affected by hot and humid conditions associated with the ITCZ and the NW monsoon which move seasonally (8.6.2 and 8.7.3).

To S of the ITCZ the South-east Trade Winds blow throughout the year in an extensive belt the width of which varies with movement of the ITCZ. Conditions in this belt are generally warm and pleasant with well-broken cloud and sunshine predominating, but scattered showers may occur especially in the N. The wind brings rain to the windward sides of the larger mountainous islands (8.10.3 and 8.10.4); by contrast, leeward coasts and slopes enjoy clearer skies, fine weather and higher temperatures.

To S of the SE trade wind belt the region is dominated by a sub-tropical high pressure belt in which weather conditions are generally good (8.4.1).

In the S part of the region, S of the sub-tropical high pressure belt, there is a zone of strong W winds, cloud and rain (8.7.5).

### 8.2.2 Visibility

Visibility is generally good throughout the region although it can deteriorate rapidly in heavy rain when visibility may fall below fog limits. Fog itself is rare at sea.

### 8.2.3 Cyclones

Cyclones affect parts of the region. See 8.5.2 for further information.

## 8.3 Pressure

### 8.3.1 Average distribution

Average distribution of pressure at MSL for February and August is given in diagrams (*not included*). These are representative of the pressure patterns during summer (December to February) and winter (June to August).

At all seasons the dominant feature is the sub-tropical high pressure belt around 30°S (8.4.1).

The equatorial trough of low pressure and associated ITCZ (8.6.2) lies S of the equator from about November to April. It marks the confluence of the South-east Trade Wind and the N or NW airstream which crosses the equator as an extension of the NE monsoon of the N part of the Indian Ocean.

To the S of the sub-tropical high pressure belt pressure decreases as latitude increases towards a zone of major low pressure systems in the Southern Ocean (8.5.1).

### 8.3.2 Variability

It is emphasised that the pressure distributions described are the averages of changing day to day values. Short term variations may be appreciable especially in the extreme S where pressure systems move across the area frequently.

To the N of about 20°S pressures seldom differ very much from average values; when significant falls in pressure are observed they may indicate the proximity of a tropical storm or cyclone (8.3.4).

### 8.3.3 Diurnal variation

Diurnal variation of pressure is well marked in the N part of the region and to a lesser extent farther S. Daily pressure maxima occur at about 1000 and 2200 local time with minima about 0400 and 1600. The amplitude of the oscillation is about 3 hPa near the equator, decreasing to 2 hPa in latitude 40°S.

When disturbances occur, significant falls or rises in mean pressure can be masked by the diurnal variation; it is thus important to take account of the latter when comparing successive barometer readings. The table below gives the hourly amplitude of the oscillation which will enable computation of a mean pressure value; changes in the mean pressure value will indicate the average pressure tendency.

*Correction (in hPa) to be applied to the barometer reading to allow for diurnal variation*

Local time	Latitude belt	
	0°–10°S	10°–20°S
0001	–0.7	–0.4
0100	–0.2	0.0

Note: FOR REASONS OF ECONOMY, DELEGATES ARE KINDLY REQUESTED TO BRING THEIR OWN COPIES OF THE DOCUMENTS TO THE MEETING

0200	+0.2	+0.4
0300	+0.6	+0.7
0400	+0.7	+0.7
0500	+0.5	+0.4
0600	+0.1	0.0
0700	-0.5	-0.5
0800	-1.0	-1.0
0900	-1.3	-1.2
1000	-1.3	-1.2
1100	-1.1	-0.9
1200	-0.5	-0.3
1300	+0.2	+0.3
1400	+0.9	+0.9
1500	+1.4	+1.3
1600	+1.6	+1.4
1700	+1.5	+1.2
1800	+1.1	+0.8
1900	+0.5	+0.2
2000	-0.1	-0.3
2100	-0.7	-0.7
2200	-0.9	-0.9
2300	-0.9	-0.7

The above corrections should not be applied to pressure values entered in the weather log or transmitted in weather reports.

#### **8.3.4 Abnormal falls**

In the zone between the equator and 25°S, the existence, or impending development of a tropical depression, may be indicated if the barometric pressure after correction for diurnal variation shows a fall of more than 3 hPa in 24 hours or a value 5 hPa or more below the appropriate monthly average. Such depressions are liable to intensify rapidly into violent tropical storms or cyclones. Although weather satellites enable development and movement of storms to be monitored closely it is emphasised that it remains important to check mean pressure regularly as it may provide the earliest indication of an approaching or developing storm.

### **8.4 Anticyclones**

#### **8.4.1 Sub-tropical high pressure belt**

The sub-tropical high pressure belt dominates the zone between 20° and 40°S; the axis of the zone is farthest N at 30°S in winter and moves about 5° farther S in summer. Within this belt there are no quasi-permanent anticyclonic centres such as are found in other sub-tropical oceans. The high pressure system here consists of a series of mobile anticyclones which move E in a rather irregular succession at roughly weekly intervals. Speed of movement varies but is usually about 5° to 8° of longitude in 24 hours; occasionally the system becomes stationary for a week or more.

The strongest anticyclones, with central pressures of 1040 hPa or more, develop in winter and usually reach their peak intensity E of 55°E; strong winds may be experienced on the N and S sides of these systems.

Weather in the high pressure belt is generally fine but the troughs between successive anticyclones may bring occasional incursions of cooler air from the S with frontal bands of cloud and rain.

### **8.5 Depressions**

#### **8.5.1 General information**

Major frontal depressions of the Southern Ocean move E in frequent succession but their paths are generally S of 45°S. Associated frontal troughs of low pressure extending N from these depressions sweep E or NE across the S parts of the region and are particularly active in winter (July to September).

These occasionally develop S of La Réunion, Mauritius and Rodriguez Island in summer when the high pressure belt weakens. These depressions may develop in association with trailing low pressure troughs extending NW from depressions farther S. Periods of disturbed weather may affect the islands with humid conditions and heavy showers developing by afternoon but clearing at night. A warning sign of the onset of this type of weather is said to be a deep blue appearance of mountain ridges and distant features. As pressure rises behind the disturbance and the South-east Trade Wind returns, its strength may increase to force 6 to 7 with rain, drizzle and very low cloud on exposed coasts. This weather is especially unpleasant if it occurs in April or May.

### 8.5.2 Cyclones, tropical storms, tropical depressions

The depressions most likely to be encountered in tropical regions are variously known as tropical depressions, tropical revolving storms or tropical cyclones. They usually originate as minor disturbances between 4° and 15°S in the vicinity of the ITCZ and a few of them may intensify to become extremely violent and dangerous storms with hurricane force winds, very heavy rain, mountainous seas and abnormally high tides. A general description with signs of approach and ways of avoiding them is given in *The Mariner's Handbook*.

### 8.5.3 Classification

It is customary to distinguish between the stages of intensity of a tropical depression according to the strength of the wind in the circulation as follows:

Tropical depression - winds up to force 7.

Tropical storm - winds force 8 to 11.

Cyclone - winds force 12 (also known as hurricane or typhoon in other parts of the world).

In the region covered by this book the terms used in warning messages to describe storms at different stages of intensity vary from one country to another. Thus, a tropical storm (winds force 8 to 11) may be described as a "moderate", "strong" or "severe" depression in warnings issued from Mauritius or La Réunion. But all authorities use "cyclone" or "intense cyclone" for a storm with hurricane force 12 winds.

"Super-cyclone" is a term sometimes used to describe a storm with winds exceeding 130 kn which can occasionally develop.

### 8.5.4 Occurrence

Storms may affect any part of the region from about 4° to 30°S; they may reach higher latitudes but they then become progressively extra-tropical in character, though still large and dangerous depressions. No month may be regarded as entirely free from possible storm development, but the period when occurrence is most likely extends from November to April with maximum frequency from December to March. The following table gives the average monthly frequency of tropical storms and cyclones in the SW part of the Indian Ocean. The table is a useful guide; however, storm frequency varies greatly from year to year and the number of storms in any one month may differ significantly from these average figures.

### 8.5.5 Average occurrence of tropical storms and cyclones in the SW Indian Ocean

Month	Tropical storms	Cyclones
January	3-4 per yr	1-2 per yr
February	3-4 per yr	1 per yr
March	2-3 per yr	1 per yr
April	1 per yr	1 every 2-3 yrs
May	1 every 5 yrs	Rare
June, July, August, September	Rare	Rare
October	1 every 2-3 yrs	Rare
November	1 every 3 yrs	Rare
December	1-2 per yr	1 every 2 yrs
ANNUALLY	11 per yr	4 per yr



### 8.5.6 Movement

The movement of storms initially is nearly always in a SW to W direction at speeds of about 10 to 15 kn; most subsequently change direction (re-curve) tracking S or SE and increase their speed as they do so. Recurvature tends to take place near 20°S early in the season and 15°S in later months. Some storms follow extremely erratic tracks and may change direction unexpectedly.

A few storms reach the Mozambique Channel before re-curving and may cross Madagascar. To the N of the channel, in the vicinity of Comores, storms can be very violent though still small in extent. An occasional storm continues W to the African coast; this is most likely early or late in the season.

Cyclones rarely affect Seychelles Group or Chagos Archipelago but Mauritius, La Réunion and Rodriguez Island are very vulnerable and are likely to be struck by storms as they re-curve. The occurrence of cyclones over the various islands is, however, variable. An individual location may not be affected for several years and then two or more storms may strike within a year or even a month.

Diagram (*not included*) shows some typical cyclone tracks.

## 8.6 Fronts

### 8.6.1 Cold fronts

Cold fronts bringing cool air are a common feature of the region. Frontal troughs are usually associated with, and trailing NW from, the major depressions moving E to the S of 50°S. They advance E or NE and may reach as far N as 15°–20°S in winter but in summer rarely progress farther than 25°S.

Frontal belts may be very well marked with large cumulus cloud, squalls and rain especially over the more mountainous islands, but fronts became progressively weaker and of diminishing significance as they move towards the tropics.

### 8.6.2 The Intertropical Convergence Zone

This zone, also known as the Doldrums, is active from November to April. This zone marks the boundary between the SE wind and the NE monsoon winds (8.7.3) of the N part of the Indian Ocean which back to N or NW as they cross the equator.

The ITCZ moves S of the equator in October. It extends farthest S in late January to about 10° to 12°S in mid ocean, thus covering Comores, the N end of Madagascar, Seychelles Group and Chagos Archipelago. The zone moves N to the vicinity of the equator once more in April or May.

Although not strictly a front the ITCZ does have some frontal characteristics. Its features are light variable winds with extensive cloud and areas or belts of massive cumulo-nimbus, heavy thundery showers and squalls. Activity varies greatly from one locality to another and from day to day, being diffuse and insignificant in some parts and very well marked in others. Movement is erratic and inconsistent, often with a tendency for cloud and associated weather to disperse in one locality and re-develop some distance away.

Disturbances frequently originate in the vicinity of the ITCZ. They generally move slowly W and dissipate after a short period of initial development, but a few intensify to become tropical storms or cyclones.

## 8.7 Winds

### 8.7.1 General information

Wind roses showing the frequency of winds of various directions and speeds for February, May, August and November are given in diagrams (*not included*).

There are four well-defined wind “regimes” in this region which are described below. They broadly correspond to bands of latitude but there is some migration of the régimes N and S corresponding to the seasonal movement of the equatorial trough and the sub-tropical high pressure belt.

### 8.7.2 South-east Trade Winds

These diverge from the N flank of the sub-tropical high pressure belt. The wind blows predominantly from SE or ESE with remarkable persistence and steadiness, in a zone which, in summer, usually lies between about 30° and 10°S when it converges on the ITCZ; in winter the zone extends farther N to the equator. It thus covers La Réunion, Mauritius and Rodriguez Island throughout the year and, from April to November, Seychelles Group and Chagos Archipelago, where the wind is sometimes called the SE monsoon.

Average wind speed is about 15 kn over the open sea for much of the year; the wind is steadiest and strongest from May to September at about 15 to 20 kn when fresher winds of 20 to 25 kn are common and on occasions reach gale force especially in the E of the region. The Trade Wind is weakest in mid-summer at about 10–15 kn, its speed decreasing on approaching the ITCZ.

The wind is occasionally disrupted by E moving troughs of low pressure; the frontal depressions (8.5.1) which occasionally develop to the S of Mauritius and La Réunion in summer can give rise to a period of strong winds up to force 7 as the SE wind becomes re-established. At Rodriguez Island the wind may back to NE for a few days during disturbed weather in summer.

### **8.7.3 The North-west monsoon**

Sometimes called the "Cross Monsoon", this is formed as the equatorial trough of low pressure migrates S of the equator from late October to May. The NE monsoon of the N hemisphere is then drawn across the equator backing to N or NW as it does so. From December to March a rather weak and fitful NW flow extends from the equator to about 10°–15°S where it fades on approaching the ITCZ. Comores, the N part of Madagascar, Seychelles Group and Chagos Archipelago are all affected by the monsoon when hot, humid weather prevails and frequent heavy thundery rains are usual.

### **8.7.4 Light or moderate variable winds**

These are generally found within the sub-tropical high pressure belt and extend over about 10° of latitude; in August they are found between 25°S and 35°S migrating slowly to between 30° and 40°S in February. Again the relatively peaceful conditions are occasionally disturbed by E moving troughs which give spells of stronger, shifting winds.

### **8.7.5 The Westerlies**

These blow on the S flank of the sub-tropical high pressure belt S of about 35°S in winter, and 40°S in summer. This is the wind régime widely known as the Roaring Forties; throughout the year winds blow persistently from a general W direction but shift frequently and sometimes suddenly between SW and NW as troughs move E through the region. Strong winds are common and gales are frequent; July to October is a particularly stormy period in the S reaches of this region.

### **8.7.6 Coastal areas**

Within about 20 miles of the land, winds blowing over the open sea may be considerably modified by topographical influences and land and sea breeze effects. *The Mariner's Handbook* gives details.

The climate information at the end of this chapter gives statistical information for the incidence of winds at a number of coastal and island stations.

Small low-lying islands have little influence on general wind flow and any slight local variations extend only a short distance from the shore, but larger and mountainous islands create significant modifications which extend well out to sea.

A notable example is Madagascar, the mountainous interior of which causes major distortion of the surface wind flow. This is particularly so in winter when the S-trade winds, approaching the E coast, divide into two branches at about 18°S; N of this division winds blow from SE increasing in strength as they approach Cap d' Ambre. The S branch blows from NE in the coastal waters of SE Madagascar and veers to SE or SW when W of Cap Sainte Marie. The W coast of Madagascar is in the lee of the island mountain range and here the winds are light and more variable in direction. In summer when the South-east Trade Wind belt moves S, the SE flow affecting the NE coast of Madagascar becomes more ESE and is much weakened; at times it is replaced by the N to NW winds of the cross monsoon, and these winds also extend well down the W coast of Madagascar.

A similar effect though on a smaller scale is evident at La Réunion where the SE trade wind again divides into two branches which blow along the NE coast and along the S and SW coasts of the island. The NW coast from Pointe des Aigrettes to Cap Bernard lies in the lee of the mountainous interior and often has light variable breezes.

### **8.7.7 Land and sea breeze**

These effects are important throughout the year in tropical and sub-tropical latitudes N of 35°S. In coastal areas the sea breeze blows onshore from mid-morning, freshening until mid-afternoon, when it may reach 15 to 20 kn, and dies soon after sunset. Land breezes arise in the late evening and are usually considerably weaker than the sea breeze; where the land slopes steeply down to the coast, however, the land breeze may be re-inforced by downslope effects and in this case squalls can be a hazard in coastal waters. The land breeze fades soon after dawn.

Land and sea breezes are often obscured by moderate or fresh prevailing winds such as the South-east Trade Winds, and a common effect is the introduction of modifying components which re-inforce or oppose the general wind pattern or cause a change in wind direction. Thus in La Réunion and Mauritius the South-east Trade Winds often freshen by day and fall light at night. Other localities experience a regular daily cycle of change in wind direction.

The land and sea breeze cycle is most noticeable in generally calm or light wind conditions such as are found on the leeward coasts of the larger islands. On the W coast of Madagascar the sea breeze regularly reaches 10 to 15 kn; fresh land breezes are a common feature of the early morning, especially where the coast is hilly and steep, whilst sudden unexpected squalls can be an occasional hazard.

## **8.8 Gales**

### **8.8.1 General information**

Diagrams (*not included*) show the incidence of strong winds of force 7 or greater in February, May, August and November.

Winds of gale force, storm force and hurricane force occur in the circulation of tropical storms and cyclones which occasionally strike most tropical and sub-tropical parts of this region S of about 4°S.

### **8.8.2 Winds north of 30°S**

These seldom blow with gale force, except when associated with tropical storms. The SE trade winds may sometimes freshen to force 7 over the open ocean, especially from June to September and generally E of 55°E, but wind strength rarely reaches force 8.

### **8.8.3 Winds south of 30°S**

These frequently blow with gale force, except in mid-summer, and can reach force 11 or 12. This is a stormy part of the region and gale frequency increases markedly with higher latitude; incidence of gales of force 8 or more may exceed 30% between 30° and 40°S from June to September. In mid-summer the belt of strongest winds moves farther S but the S part of the region is still windy S of 40°S and the incidence of gales approaches 20% in the extreme S.

### **8.8.4 Squalls**

Squalls which can be very violent may be associated with severe thunderstorms; they are most frequent in coastal areas of the larger islands and are especially common around N Madagascar from December to March.

Squalls may develop in the SE trade wind airstream and in the NW monsoon, especially in the vicinity of the ITCZ.

### **8.8.5 Waterspouts**

These are occasionally seen and are most likely in March and April and least likely in September and December. They are an indication of violent convection in the atmosphere and are thus to be expected in the vicinity of the ITCZ; squally conditions are often encountered near waterspouts and they should not be approached.

## **8.9 Cloud**

### **8.9.1 North of 30°S**

Over the open sea very well broken cumulus cloud is usual in the SE trade wind airstream. Amounts average 3 to 5 oktas and cloud base is remarkably uniform, typically at about 550 to 600 m. Isolated large cumulus or cumulo-nimbus cloud may develop especially on approaching the ITCZ where giant cumulo-nimbus and extensive layers of upper cloud are a common feature.

Occasional disturbances in the South-east Trade Wind zone give rise to cloud masses or lines which cause overcast or cloudy conditions for one or even several days, but skies may clear at night.

Over the larger islands, coasts and slopes exposed to prevailing winds have large amounts of cloud and rain whilst leeward coasts often have almost clear skies. The W coast of Madagascar frequently has no more than 2 or 3 oktas when the trade wind is giving very cloudy and wet conditions on the E coast.

During the NW monsoon large amounts of cloud and large cumulus and cumulo-nimbus with associated thundery downpours are a common feature. From December to March cloudy skies with 5 to 6 oktas are usual on the N and NW coasts of Madagascar and these conditions spread down the W coast of the island. Comores, Seychelles Group and Chagos Archipelago are similarly affected.

There is often a marked diurnal variation of cloud over islands; cumulus cloud develops by day and disperses at night. The towering daytime cumulus tops can be useful for identifying the position of a distant low-lying island.

Average cloud cover at coastal stations within the area is given in the climate information tables after 9.1 (*not included*).

### **8.9.2 The sub-tropical belt of high pressure**

This is a zone with generally fine conditions and clear skies. Occasionally troughs of low pressure bring belts of cloud, often with large cumulus, but the frontal cloud becomes more diffuse as the system moves to lower latitude.

Note: FOR REASONS OF ECONOMY, DELEGATES ARE KINDLY REQUESTED TO BRING THEIR OWN COPIES OF THE DOCUMENTS TO THE MEETING

### **8.9.3 South of 30°S**

Here, in the belt of W winds, E moving frontal troughs bring frequent and extensive cloud systems giving overcast or cloudy conditions. In the cooler air behind each system there are large amounts of usually well broken cumulus or cumulo–nimbus cloud. *The Mariner's Handbook* describes the cloud conditions associated with frontal depressions.

## **8.10 Precipitation**

### **8.10.1 General Information**

Islands in the region mostly have abundant rainfall but annual amounts and the times of year when wettest or driest weather can be expected vary appreciably and depend largely on the degree of exposure to prevailing winds and the proximity of high ground. Windward slopes and coasts may receive particularly heavy rainfall but localities on leeward coasts or in the lee of high ground may at the same time enjoy much drier clearer weather.

The average amounts of rainfall and number of rain-days at coastal stations within the area are given in the climate information tables after 9.1 (*not included*).

### **8.10.2 The North-west Monsoon and ITCZ**

These bring a well–marked period of heavy rains from about November to April. Thundery downpours occur in N Madagascar and in the Comores, Seychelles Group and Chagos Archipelago; at other times of year rain falls on these islands as a result of the SE trade wind blowing onshore. There is thus no dry season as such but greatest falls occur in the summer months.

### **8.10.3 Madagascar**

The moist South-east Trade Wind brings a plentiful rainfall to the E coast and especially to the central parts; annual amounts up to 3000 or 4000 mm are recorded with the wettest period from January to July. The NE and SE coasts are less exposed but still receive appreciable rain and the N end of the island has its heaviest rains during spells of the NW monsoon in summer.

The W coast of Madagascar is well sheltered from the SE–east Trade Wind. From May to October there is little rain; but from November to April the NW monsoon brings a wet season which extends as far S as about 15° to 20°S. The amounts received are less and the rainy period somewhat shorter with higher latitude.

The SW coast of Madagascar is sheltered from most rain producing influences; only a little rain falls in these parts, mostly between November and April.

### **8.10.4 La Réunion, Mauritius and Rodriguez Island**

These are covered by the South-east Trade Wind belt throughout the year. Rain can be expected at all seasons with heaviest falls in the cyclone season from November to March, and the driest period from about June to October. Rainfall varies greatly from year to year and from coast to coast.

On the E coast of La Réunion, Saint–Denis has an annual average fall of 1810 mm; on the more sheltered SW coast Saint–Pierre has an annual average of about 1000 mm.

At Mauritius the annual mean rainfall is 1700 mm on the S coast and 900 mm on the W coast but in a dry year recorded falls may be less than 900 mm on the S coast and as low as 400 mm on the W coast.

Rainfall tends to be most common in the afternoon but when the SE trade wind is well established it often occurs at night.

### **8.10.5 Cyclones**

These bring extremely heavy rain and the storms of this region are notorious for the torrential downpours that often accompany them. On La Réunion falls of 1319 mm in 12 hours (1964) and 1840 mm in 24 hours (1952) have been recorded.

### **8.10.6 The sub–tropical belt of high pressure**

This is a zone of low rainfall. However, some rain can be expected from frontal troughs moving through the area most frequently in winter.

To the S of 35°S fronts associated with E–moving depressions bring frequent and often heavy rain. Rain can be expected at all seasons; during the winter months it may occasionally fall as snow or sleet near the S border of the region.

## **8.11 Fog and visibility**

### **8.11.1 Sea fog**

This is rarely encountered over the open sea N of 30°S and visibility is generally good although there is usually some deterioration in areas affected by the NW monsoon. Severe reductions in visibility sometimes below fog limits can occur in heavy rain.

Farther S the incidence of fog increases with latitude, where warm moist air is drawn S over cooler seas by depressions of the Southern Ocean. Although information is very sparse, about 5% of observations report fog at about 40°S.

### **8.11.2 Radiation fog**

Radiation fog or mist can develop in the early morning in low-lying coastal areas and valleys and drift offshore to affect coastal waters; some localities on the W and N coasts of Madagascar are occasionally affected. This type of fog generally disperses shortly after sunrise.

The average number of days with fog at coastal stations within the area is included in the climate information tables after 9.1 (*not included*).

## **8.12 Air temperature**

### **8.12.1 Open sea**

Air temperatures over the open sea are largely controlled by sea surface temperatures (6.3) and there is commonly little difference between the two; the air temperature is usually about 1°C lower than the sea temperature, and possibly rather more in winter.

Highest temperatures through the year generally occur in equatorial parts of the region with daily average maximum values about 28° to 31°C and daily minima of 24° to 26°C; there is little seasonal change. Farther S the seasonal variation increases somewhat with highest values from about January to March and lowest from July to September. In latitude 20°S summer temperatures average about 27°C and at 40°S about 15° to 16°C; winter values are about 4° to 5°C cooler.

### **8.12.2 Coastal areas**

Heating and cooling of the larger islands produces greater seasonal and diurnal variability but onshore prevailing winds have a moderating effect and result in more modest maximum and minimum temperatures than those often experienced well inland.

From November to April the E coast of Madagascar and the coastal areas of islands in the SE trade wind belt, including La Réunion and Mauritius, generally have daily maximum temperatures of 29° to 32°C falling to about 22° to 24°C at night. In the cooler winter months highest daily values average 24° to 26°C and lowest are about 17° to 19°C. Extreme summer maximum temperatures can reach 35° to 36°C and winter minima extremes are about 10° to 15°C.

The W and NW coasts of Madagascar and the islands of Comores are somewhat warmer. In the hot NW monsoon season daily temperatures rise on average to 31° to 33°C and fall at night to 22° to 24°C. In the winter months day temperatures are only slightly lower than summer values at about 28° to 32°C but at night they fall to about 15° to 19°C. Extreme temperatures have summer maximum values of 38° to 40°C and winter minima of 13° to 15°C, but in the extreme SW part of Madagascar winter temperatures can fall to as low as 6° to 7°C.

The climate information tables after 9.1 (*not included*) at the end of this chapter give statistical temperature information for a number of coastal stations within the area.

## **8.13 Humidity**

### **8.13.1 General information**

The airstreams affecting the region cover long distances over the sea and humidity is moderately high at all times of year. Relative humidity is dependent on air temperature and maximum daily values of humidity normally occur around dawn when air temperature is lowest; humidity is usually lowest in the afternoon at the time of maximum temperature. The average relative humidity in the morning and afternoon at coastal stations within the area is given in the climate information tables after 9.1 (*not included*).

### **8.13.2 Open sea N of 30°S**

Highest average humidities are experienced in the equatorial zone in midsummer during the period of the NW monsoon; values exceed 85% as far as about 15°S. Farther S mean humidity decreases with higher latitude and at 30°S is about 70% to 80%.

In mid-winter (July) humidities are slightly lower in the equatorial zone with values of about 80% to 85% but S of 20°S there is little seasonal change. Diurnal variation at sea is small.

### **8.13.3 South of 30°S**

Detailed information is sparse but in general humidity varies little seasonally with highest values in summer and lowest in spring. Diurnal variability is also slight with early morning average values of about 80% to 90%, falling by afternoon by some 3% to 8%. Incidence of high humidity of 95% to 100% increases with latitude.

## **9. CLIMATE INFORMATION**

### **9.1 Climate Station Information**

Climate information for Micklefirth is at the accompanying diagram.