CHAPTER 1 TROPICAL CYCLONES

1.1 Introduction

Individual typhoons, during their passage across a port, have caused the loss of tens of thousands of lives and the sinking and grounding of several dozens of ocean-going ships as well as causing a vast amount of damage to buildings, communications, river banks and agriculture. In 1965, the Economic Commission for Asia and the Far East estimated, on the basis of returns from individual countries, that typhoons annually cause US$500 million worth of damage. In some years, of course, the damage is much greater than this, for example, in September 1959 typhoon Vera struck Japan and caused damage there amounting to US$1,280 million. The average annual typhoon damage is of the order of a half to one and a half per cent of the gross national product of the countries affected. This large annual loss constitutes a serious drain on the economies of the countries concerned and reduces the chances of improving the living conditions of millions of Asians. Timely warnings, followed by appropriate precautions, can do much to reduce the enormous loss of life and damage. Although typhoons are well-known for the serious losses that they cause, they do have some beneficial effects. For example, most of the countries affected by tropical cyclones are dependent upon them for rainfall in the quantities necessary to sustain agriculture and life.

Those who have lived through the full fury of a mature typhoon, either at sea or on the coast, retain vivid memories of the experience. New-comers to regions frequented by typhoons hear many hair-raising accounts of the experiences of residents in one or other of the major typhoons of their lifetime. Over the years some of these accounts will have improved in the telling but nevertheless, there will remain much that is true yet hardly credible to the uninitiated.

The typhoon experiences of the average man in his home do not usually make news or get into print; it is therefore difficult for new-comers to appreciate what could possibly happen to them whilst sheltering from a typhoon in a modern house or flat. The following passages describe conditions usually experienced inside an exposed, well built, concrete or brick building during the passage of modest typhoons such as those that affect Hong Kong and other places on the South China coast. Noise is the dominant feature at such times, the wind screams as it blows past the building in frightening blasts to the accompaniment of frequent loud crashes as flying debris and successive gusts slam into the building. Casements rattle and all bang together as the more

powerful gusts arrive, air leaks whistle and increase in pitch with each increase of wind speed. Outside, large and small tree branches, suspended wires and assorted poles all emit their own characteristic notes and these rise to screaming crescendos with every gust. Large raindrops, travelling with the speed of the wind, sound like marbles as they hit the window panes. As each new gust heralds its arrival with what sounds like ever larger marbles, people instinctively back away from the glass. The whole building vibrates in the turbulence of the wind. Variations in atmospheric pressure, caused mainly by changes in wind velocity, cause "popping" in the ears and sometimes affect breathing. Indoors there is a pungent smell of damp furnishings whilst outside the odour of wet mangled vegetation is dominant. Windows bow into rooms and retreat again as the wind eases, fountains of water, forced around the window frames by the pressure of the wind spray into the house dancing higher and lower with variations in wind pressure. On some windows the water will be seen to "drain" upwards under the frictional drag of the airflow. Heavy air-conditioners sometimes break free from their wall or window mountings and crash into rooms. In addition to the leaks around the window frames, water caught on balconies and doorsteps is blown over the threshhold of French windows and doors, being unable to drain away, against the wind, to the appropriate outlet. To reduce the damage from this flooding it is usual to roll up carpets and keep them off the floor. Sheets and towels are used to soak up the water and are then wrung into buckets. This toil continues during the hours that the storm is passing by and is relieved only by the change of scene as mopping-up operations move from one side of the house to another to accord with changes in the direction of the wind. If a window breaks - because of a faulty catch, the impact of flying debris or other cause - then pieces of glass fly through the air like shrapnell and become embedded in the walls and furniture and a new sequence of destruction is begun. People run to escape from the affected rooms and find either that they cannot open the door against the wind pressure or find the pressure is in their favour in which case the door opens with a rush and is blown off its hinges. Curtains and ornaments now become casualties and it is not uncommon for cupboards and even drawers to be blown or shaken open with the consequent loss of the lighter contents.

(17)

Friends of mine were living in a modern high-rise block of flats on a hill in Hong Kong during the passage of typhoon Wanda in September 1962. When their windows broke they sought shelter in the liftwell in the centre of the building, but, as the wind direction changed, so did the air pressures around the building and these caused the contents of the sewers to flow back from the outside and flood the liftwell. Whilst residents stood for many hours in this unpleasant

(A)

A newly arrived manager of a Hong Kong computer service company arrived at his office on the day after the passage of typhoon Rose 1971 to find everything under about 30 cm of water. He was greatly surprised because the office was on the 13th floor! Rain had been driven through window joints in the manner just described.

environment they would occasionally hear their cars being picked up by the wind and dashed against the building and surrounding walls. One lady had misguidedly opened all her windows to give the wind "a free passage"! She returned to find all her lighter belongings and furnishings gone and most of what remained was ruined. It was many months before these flats could be occupied again.

Telephone systems fail during most severe typhoons because overhead lines are blown down, underground cables are cut by landslides, underwater cables are damaged by ships dragging their anchors and junctions and installations become flooded. However, even if the telephones work it is useless to use them to call for help because, at the height of the storm, no one could travel; the wind would blow both men and cars off the roads many of which would be blocked by landslides, floods, debris and fallen trees. In most countries the electricity supply also fails during the passage of typhoons because the distribution lines are cut by falling trees or flying debris or the generating and distributing equipment become flooded or damaged. The loss of electric light at night time adds to the difficulty of protecting life and property. Cars parked in the open are often damaged by falling trees or advertising signs and by flying objects such as dustbins, sheets of corrugated iron, boxes etc. I have seen a car blasted clean of paint by sand and gravel driven by typhoon winds; the windscreen and side windows were "frosted" by the same treatment.

In low-lying coastal areas, and particularly in river deltas, the greatest danger to persons and property during the passage of a typhoon arises from flooding caused by the encroaching sea. The storm surge, as it is called, can cause the sea level to rise by several metres and if it coincides with a normal high tide then the sea rushes across seawalls and banks aided by huge waves. Many thousands of lives can be lost at such times. Particularly severe surges occurred at Haiphong in 1881 when 300,000 people were drowned , in 1922 at Swatow when 60,000 lives were lost and in Hong Kong in 1937 when 11,000 people, mostly boat dwellers, lost their lives. The sea water in rushing inland can damage fresh water reservoirs and make their contents unfit for human consumption; drinking water may then have to be carried into the stricken areas for both people and surviving animals.

In hilly terrain the greatest threat arises from heavy rainfall near the centre of typhoons for by the time that it arrives the ground is already saturated and most of the rain-water immediately runs off the hills in torrents, causing flooding, rock falls and landslides. Often, the landslides or fallen

trees block drains and culverts causing vast quantities of water to be diverted from their proper course. When this happens great damage can soon result for roads and buildings collapse in a very short time when they are undermined by torrents.

At sea, conditions in mature typhoons are extreme indeed, for it is here that the wind attains its full fury and generates phenomental waves. Masters of ships have given us many vivid accounts - often beautifully written - of the phenomena that they have encountered in typhoons. These accounts have inspired novelists to use the experiences in their writings and of these, perhaps, Joseph Conrad's "Typhoon" is the best known. The loss or near loss of ships in typhoons is not confined to the days of wooden sailing vessels for ocean going ships are still lost or abandoned in typhoons to-day. Elsewhere in this book it is recounted how disaster befell the Third Fleet of the U.S. Navy, the most powerful sea force ever assembled, when it encountered a typhoon to the east of North Luzon. This encounter, on 18th December 1944, caused the loss of 800 men, 150 aircraft and three destroyers. Those cruisers and destroyers that survived the typhoon were severely damaged by fire and waves.

When people who are new to the tropics first experience conditions 150 km or so from the centre of a passing typhoon they notice that, apart from the torrential rain, the conditions are no worse than those they have experienced in temperate latitude cyclones on the coast of the British Isles or elsewhere. They are therefore at a loss to understand why masters of ships, local authorities and old residents take such elaborate precautions. The answer is, of course, that the extreme winds in a typhoon seldom extend more than 100 km from the centre (See Fig.). A small change in the path of a typhoon to take it 50 km or so closer to a locality can make a terrific difference to the severity of the conditions experienced. The force exerted by the wind on bodies in its path increases rapidly with rising wind speed; in fact, it increases with the square of the wind speed so that, for example, doubling the wind speed from 30 to 60 m/s increases the force four times and the damage caused, therefore, is much greater. The storm surge also increases in severity as the centre is approached. This is why the prudent usually take full precautions whenever the centre of a typhoon is expected to pass about 150 km or less away although, of course, they realise that the strongest winds in the typhoon may pass them by. I have gone into the "near-miss" (a term which seems to be

used nowadays to mean a "near hit") in some detail because temperate latitude exiles are sometimes sceptical that any wind could blow stronger than in their native land. It is my experience that the Scottish patriot is the most sceptical in this matter and for his benefit we will state here that the highest recognised gust speed on record for any location in the British Isles is 65 m/s (126 kn). This gust was recorded in the Cairngorms, Scotland on the 6th March 1967. For comparison, a corrected gust of 84 m/s (164 kn) was recorded at Tate's Cairn, Hong Kong in typhoon Wanda on 1st September 1962. Winds of this speed have a destructive force almost 70% greater than those of 65 m/s. In most years gusts of 93 m/s (180 kn) or more occur in at least one intense typhoon over the Western Pacific Ocean.

2 What is a typhoon?

At the surface of the earth a typhoon appears as an area of low atmospheric pressure where winds blow in an anti-clockwise direction (viewed from above) spiralling inwards towards a relatively calm centre, or "eye", around which they attain sustained speeds of at least 64 knots. Heavy rain-bearing clouds lie along spiral bands and form a ring, or wall, of dense cloud around the "eye". Torrential rain is experienced below the "eye wall" In the eye itself the wind suddenly falls light or, occasionally, calm; the torrential rain stops and blue sky or stars can be seen through breaks in the low clouds. The "eye" usually has a diameter between a few kilometres and some tens of kilometres but, exceptionally, it can be more than 200 kilometres. The whole system (Fig. 1.1) has a diameter which can range from about 100 km to over 2000 km and moves along bodily at a speed usually between 0 and 20 knots in the tropics although higher speeds occure quite frequently in higher latitudes. Typhoons occur over the Western Pacific Ocean but similar storms occur in other parts of the world (see Fig. 1.2) where they are known as "hurricanes" or "cyclones".

Typhoons are a form of heat engine in which heat energy is transformed into mechanical energy (winds). All heat engines require a heat source, a working substance and a heat sink. For example, a steam engine may use coal as the heat source, the working substance is water vapour (steam) and the heat sink is the atmosphere which receives and carries away the exhausted steam. In the case of a typhoon, the heat source is the warm ocean. The working substance is air which, as it spirals inwards towards the central region of the typhoon, picks up both sensible heat and water vapour from the ocean surface. The convergence of the winds towards the centre causes the air to rise, expand, cool and so condense its water vapour releasing latent heat. This released heat makes the core a typhoon warmer and less dense than its surroundings. Pressure is nearly uniform on the horizontal top of a typhoon, the less dense core therefore causes the surface pressure near the centre to be lower than that of the environment; this pressure difference maintains the winds. The necessary heat sink takes the form of air currents in the upper atmosphere which carry far away the air exhausted at the top of the typhoon. Some of this exhausted air leaves the typhoon at a pressure about one-tenth of that at which it entered and at a temperature about 100°C lower.

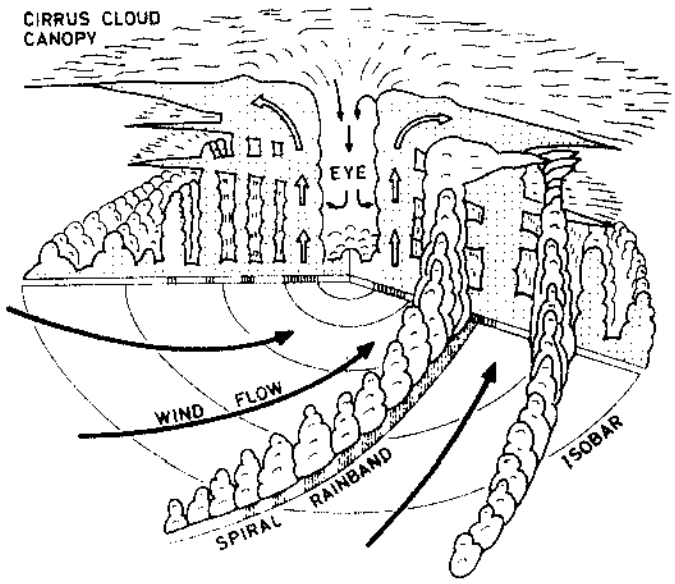

Fig. 1.1

A schematic cut-away section of a typhoon. The arrows depicting ascending air in the "eye-wall" should really be drawn as corkscrew spirals because the air blows around the "eye" as it rises. Typically, the faster rising air will take about one hour to reach the top of the typhoon and will have circulated twice around the "eye" in this time. Typhoons are about 50 times as wide as they are high. This drawing would be 1.6 m wide if the horizontal scale was made equal to that in the vertical.

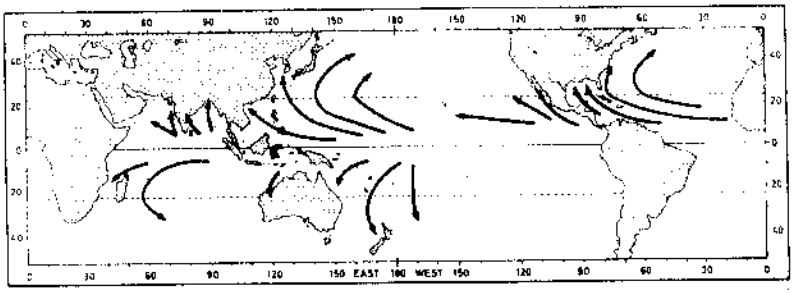

Fig. 1.2

Areas of the world where tropical cyclones are encountered shown by typical tracks. Tropical cyclones are not encountered in the South Atlantic Ocean.

When a typhoon moves over land or colder waters, it immediately looses its source of heat - the warm ocean - and so weakens rapidly. Typhoons are therefore found only over warm waters, they do not form or persist over cold water or land although, of course, intense fast moving typhoons may cross a coast and move inland for some tens of kilometres before losing their "eyes" and 64 knot winds. A typhoon will also weaken if the heat sink is removed so that some of the relatively warm air aloft is not carried away from the storm.

An average typhoon yields about 20,000 million tonnes of rain every 24 hours . The heat relased when this amount of water is condensed is approximately 5×10^{19} Joules* Calculations indicate that the efficiency of a typhoon as an engine for converting heat into mechanical energy - e.g. air motion - is very low and probably about 3%. Nevertheless, 3% of the heat released amounts to about 15×10^{17} Joules per day. This is the energy equivalent of half a million Nagasaki-type atomic bombs, 10^{10} tonnes of T.N.T. or, in everyday terms, 4.2×10^{11} kilowatt-hours. This amount of electrical energy is sufficient to meet the needs of a large city like Hong Kong for well over a century at the present rate of comsumption of 3.3×10^{9} kilowatt-hours per year.

Enough has been written to set the scene. A typhoon is the most destructive phenomenon in nature. Tornadoes may possess stronger winds but they are much smaller in area and have a shorter life. Cyclones of temperate latitudes are usually more extensive and can have more energy than typhoons but the energy is spread over a greater area, so that, although the area of gale force winds can be greater, winds do not achieve the violence of those near the centre of a severe typhoon. Furthermore, the rate of rainfall in temperate latitude cyclones does not approach that encountered in typhoons and, of course, it is the torrential rain which is responsible for much of the devastation caused by typhoons.

* The Joule (J) is a unit of energy. In practical terms 1 kilowatt - hour equals 3.6 million Joules i.e. 3.6 MJ. 10^{19} represents the large number equal to 1 followed by nineteen noughts- just as $10^{2} = 100$, $10^{3} = 1000$ and $10^{6} = 1$ million etc.

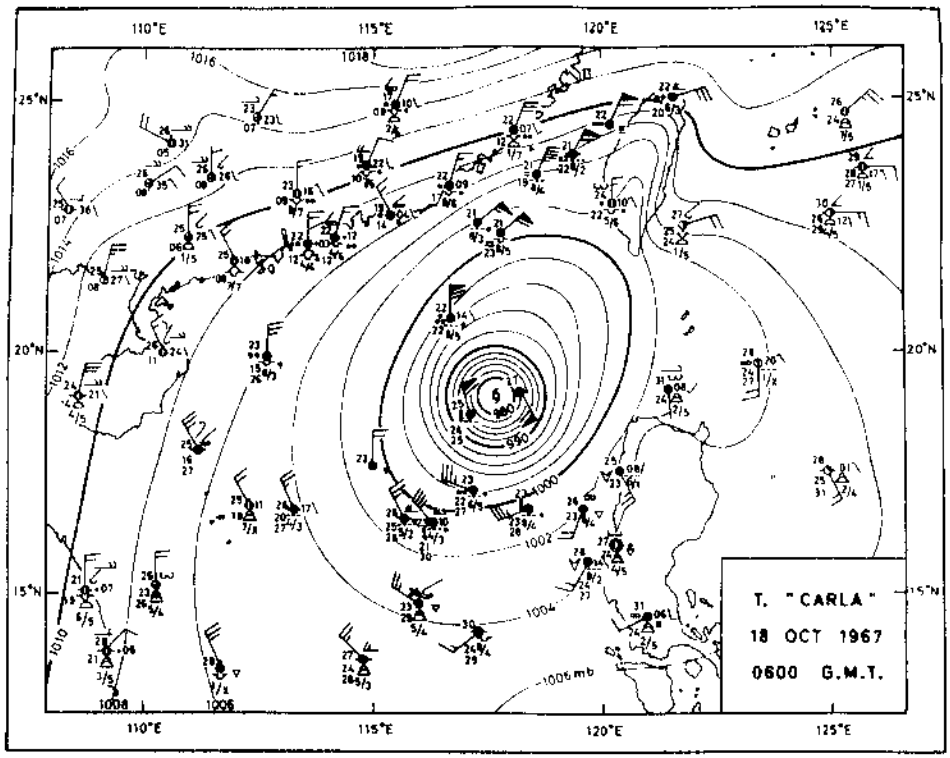

Fig. 1.3. Weather observations from ships and land stations are shown plotted on a weather chart. The centre of typhoon Carla is indicated by the symbol 6 . Isobars have been drawn at intervals of 2 mb from 980 mb with every fifth one accentuated. The arrows indicate wind direction; speed is given by the number of pennants and barbs each of which represent 5 m/s (10 kn) and 25 m/s (50 kn) respectively.

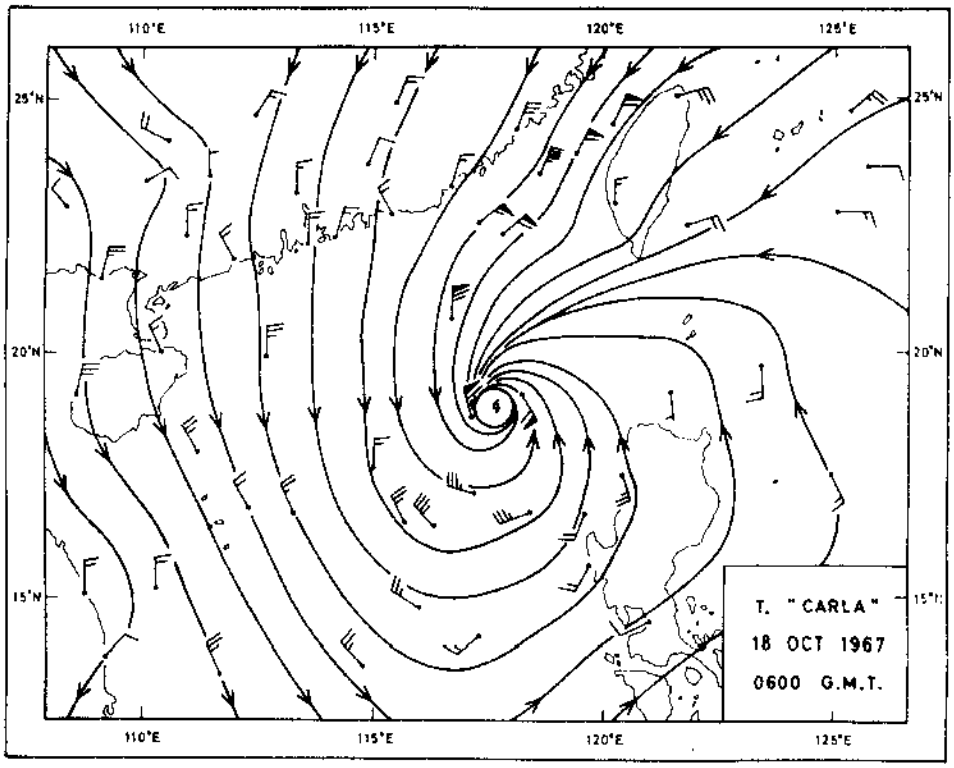

Fig. 1.4. Streamlines have been drawn on this chart to indicate the instantaneous direction of the surface wind at the time of the weather chart shown in Fig. 1.3 above. Note how the streamlines spiral in towards the "eye" of the typhoon.

1.3 Terminology

It is unfortunate that at present there is confusion in the ~~naming of~~ terms used to describe tropical cyclones of different origins and intensities. It is desirable, therefore, to give a little attention to this rather dull but important subject; its importance derives from the obvious need for practical people to understand precisely what is meant by the terms that are used in warnings. Geographical, nautical, aviation and meteorological publication use terms such as tropical revolving storm, tropical storm, tropical depression, tropical disturbance, tropical hurricane, tropical vortex, tropical low, tropical cyclone, hurricane, cyclone, cyclonic disturbance, cyclonic storm, typhoon, storm, willy-willy, depression and disturbance together with other terms formed by combining these names with the adjectives weak, moderate, severe and intense. These terms are frequently used loosely or incorrectly and some have never been defined. However, meteorologists responsible for warning services are very conscious of the need for precision in their writings, as in their warnings, and they tend, therefore, to define their terms with care. For example, Gordon Dunn - Chief of the U.S. Weather Bureau's National Hurricane Centre from 1955 to 1968 - carefully defined the terms he used both in his 1951 article on tropical cyclones (Dunn 1951) and in his book, with Banner Miller, on "Atlantic Hurricanes" (Dunn and Miller 1960) and fortunately this practice is growing. The distinction between the different terms is of vital importance to mariners and others and is sometimes crucial in disputes between merchants, ship owners and insurance companies. With this introduction we move on to the internationally agreed terminology and hope that this book will contribute a little towards spreading the use of the agreed terms and so reduce the confusion that exists to-day.

A cyclone, generally, is an atmospheric system in which the barometric pressure, at a given level, diminishes progressively to a minimum value at the centre. Such a system is represented on a surface weather chart by one or more closed isobars+ approximately circular in shape and having a diameter from 100 km to over 2000 km Fig. 1.3. This pressure distribution is associated with winds which, at the surface of the earth, spiral in towards the centre Fig. 1.4. The convergence of these winds as they move towards the centre of a cyclone causes the air to rise, thereby forming clouds and rain Fig. 1.5. The sense of rotation of the spiral wind flow is the same as that of the earth namely, clockwise in the Southern Hemisphere and anti-clockwise in the Northern Hemisphere when viewed from above. When meteorologists refer to a "cyclonic circulation" or "cyclonic motion" they mean that the rotation is in the same sense as that of the earth; by using these terms it becomes unnecessary to specify which hemisphere is involved. An essential feature of a cyclone is the low pressure, and for this reason cyclones are sometimes called "lows" or "depressions". Tornadoes water-spouts and whirlwinds are vortices having low central pressures and rotating winds but they are too small and too short-lived to be shown on conventional weather maps and they are not included in the tropical cyclone family.

Typhoons, hurricanes and cyclones of the Bay of Bengal, Arabian Sea, Indian Ocean and South Pacific Ocean belong, along with lesser relatives, to a class of atmospheric disturbances known as "tropical cyclones". They usually form over warm seas within the tropics but they may subsequently move out of the tropics into temperature latitudes (Fig. 1.2) The circulating winds of a tropical cyclone can have any speed from a few metres per second to, rarely, 100 m/s (200 knots).

It is clearly important that navigators should be in no doubt about the intensities of the tropical cyclones which they might encounter and for this reason the directors of the world's meteorological services agreed - at a World Meteorological Organization, meeting in Geneva in 1959 - on a nomenclature to describe tropical cyclones of different intensities. They graded them according to the severity of their winds as this meets the practical requirements.

+ Isobars are lines joining places having the same atmospheric pressure. The pressure is usually measured in millibars (mbar or mb) and is adjusted to refer to mean sea level. In the tropics isobars are usually drawn for even values at intervals of 2 mb.

For this purpose they used Captain Beaufort's scale of wind forces (see 5.2.1) and the equivalent hourly mean wind speeds determined by Simpson (1906). Table 1.1. shows this scale together with:-

(i) Simpson's equivalent hourly mean wind speeds;
(ii) The name of winds of specified strength;
(iii) The term for tropical cyclones containing specified winds;
(iv) The name of the warning issued to give notice of the winds.

It will be noted, therefore that tropical cyclones are classified internationally according to Beaufort's scale of wind forces and the relevant wind speeds are Simpson's hourly mean equivalents.

Although many years have passed since the 1959 agreement on the classification and naming of tropical cyclones, the practices in the various centres responsible for warning these disturbances are still far from being uniform. Table 1.1 shows that the only departure in the West Pacific Region is that the word "moderate" is not used to qualify the less intense of the two grades of tropical storms. However, the U.S. Navy and the U.S. Air Force operate a Joint Typhoon Warning Centre at Guam and in their warnings, ~~which are broadcast for seamen an appear in the~~ press from time to time, the term "tropical storm" is used to include both moderate and severe tropical storms. The same practice is followed by the U.S. Weather Bureau for tropical cyclones in the Atlantic and the Eastern Pacific Oceans and they use a different definition of a hurricane (or typhoon). This latter difference arises because the descriptions of the winds in Table 1.1 were first made in terms of Beaufort numbers and were later coverted to Simpson's equivalent hourly mean winds. The speeds in Table 1.1 are therefore hourly means. (32.7-15)" However, the U.S. Weather Bureau uses a "one minute mean wind of 64 knots" or more as the criterion for a hurricane. The wind in a typhoon is never steady but fluctuates rapidly as is shown in Fig. 5. In one hour there will be shorter periods in which the wind speed is higher than the average and in Chapter 5 it is shown that a one-minute mean wind of 64 kn would be expected to occur with an hourly mean speed of approximately 56 knots. 56

There are several reasons why the agreed terminology is not yet in universal use. In some parts of the world it is difficult to reach people with an educational programme to introduce the new nomenclature, and it coul be dangerous if there were misunderstandings; in some countries conservativ tendencies are dominant; in other areas observations are sparse and it is difficult to determine wind speeds. However, meteorological satellites weather radars and reconnaissance aircraft are overcoming this latter d ulty and navigators and others now expect more precision from the meteorologist in his classifying of tropical cyclones.

From Table 1.1 it will be seen that a tropical depression has maximum sustained winds of less than gale force (less than 34 knots (17.2 m/s)). There is no inferior limit to the wind speed in tropical depressions which may contain only light winds. Tropical depressions, therefore, are not dangerous in themselves but they are potentially dangerous because all typhoons develop from tropical depressions; fortunately, not all tropical depressions become typhoons.

The definitions of tropical storm and severe tropical storm are quite explicit and correspond to tropical cyclones with sustained maximum wind speeds of 34 - 47 knots (17.2 – 24.4 m/s) and 48 - 63 knots (24.5 – 32.6 m/s) respectively.

The recommended international practice allows the use of the term "typhoon, hurricane or local synonym" for the most intense tropical cyclones. The use of the term "typhoon" is restricted to the Pacific Ocean north of the equator and west of the date line (180° longitude) whereas the synonym "hurricane" is used in the Pacific east of the date line and in the Atlantic. It should be noted that a wind with a speed of 64 knots (32.7 m/s) or more is also known as a hurricane; care must therefore be taken to avoid confusion between the wind and the tropical cyclone of the same name. Fortunately, one usually talks of "winds of hurricane force" so that we can say that a "typhoon contains winds of hurricane force";this practice tends to reduce confusion.

From the foregoing definitions of a typhoon and a hurricane it follows that if a hurricane in the Pacific Ocean crosses the date line then it will become a typhoon. In the twenty years 1949 to 1968 there were only three hurricanes which achieved this distinction. One of them - hurricane Betsy 6th September 1959 - became a typhoon before finally returning to the Western Hemisphere as a hurricane again.

The Indian Meteorological Department uses the following terminology for tropical cyclones in the Bay of Bengal and Arabian Sea:-

"depression" - tropical depression, winds from 17 to 27 knots (8 - 13.8 m/s).
"deep depression" - tropical depression, winds from 28 to 33 knots (13.9 - 17.1 m/s)
"cyclonic storm" - tropical storm, winds from 34 to 47 knots (17.2 - 24.4 m/s)
"severe cyclonic storm" - severe tropical storm, winds 48 knots (24.5 m/s) & above.

There is no separate nomenclature for tropical cyclones of hurricane (typhoon) intensity but the phrase "severe cyclonic storm with a core of hurricane winds" is sometimes encountered (Ananthakrishnan 1964). Additonally, the term "tropical disturbance" is used as equivalent to the usual term "tropical cyclone" being a general term irrespective of maturity. In the years before 1924 the term "cyclone" was used as a synonym for hurricane (typhoon) and this usage is still encountered from time to time.

In the South Indian Ocean tropical cyclones are graded as:-

"Weak tropical disturbance" - tropical depression, winds up to 33 knots (17.1 m/s).
"Moderate tropical depression" - tropical storm, winds 34 - 47 knots (17.2 - 24.4 m/s).
"Severe tropical depression" - severe tropical storm, winds 48 - 63 knots (24.5 - 32.6 m/s)
"Intense Cyclone" - Synonym for hurricane, winds 64 knots (32.7 m/s) or above.

Tropical cyclones also occur in the South Pacific Ocean off northern Australia and most books state that these are called "willy-willies". In fact, this term has not been used officially, for this purpose, for many years (Wilkie 1963 and Spark 1971) but is reserved for the dust devils that develop inland as a result of surface heating on hot sunny days. However the term is still occasionally used, unofficially, on the North West Coast for tropical cyclones which occur there. Since 1957 the term "tropical cyclone" has been the official term for tropical cyclones with winds greater than gale force (34 knots) although the word "tropical" is frequently dropped as eg. in the official report on "Cyclone Tracy" 1975. For weaker tropical cyclones, the term "tropical depression" is used.

Finally, to complete the introduction to the terminology and to put it into context we consider the life cycle of a tropical cyclone from birth through maturity to death. Areas of disturbed weather form over the warm tropical oceans and meteorologists refer to them as "tropical disturbances". They cause only a small fall of pressure at the surface and the wind flow does not form a complete circulation, it may be curved cyclonically and there may be a complete rotation of winds at a higher level but not at the surface. Some of these disturbances intensify and cause a further fall of pressure at the surface of about two millibars. This will usually be shown on the weather map by one or two closed isobars if they are drawn at 2 mb intervals as is usual in the tropics. Simultaneously the winds pick up speed and blow cyclonically all around this low pressure area, a "tropical depression" is then born.

If conditions are right, the newly formed tropical depression continues to develop i.e. to become more organized with a lower central pressure and stronger surface winds. When, somewhere in the circulation, the sustained wind speed attains gale force ~~(34 — 47 knots)~~ then the tropical depression, by international definition, becomes a "tropical storm". As development continues with falling central pressure and rising wind speeds an "eye" is formed. When the maximum sustained wind speeds reach 48 knots (24.5 m/s) and 64 knots (32.7 m/s), the storm is called a "severe tropical storm" and "typhoon" (in the West Pacific) respectively. This whole process can take several days, on the other hand, tropical depressions have intensified to become typhoons within a few hours. The mature typhoon will persist until it moves over colder sea or land or meets some other adverse environmental condition, when it weakens successively to a severe tropical storm, a tropical storm, an area of low pressure and extinction. In some cases, at the tropical storm stage when north of about 30^{o}N, the warm core and tropical characteristics are lost and the storm changes in nature to become an extra-tropical depression (Fig.) There are variations of this simple life cycle, but nevertheless it is typical. When the central pressure of a tropical cyclone falls it is said to be "deepening" and when it is rises it is said to be "filling".

There is no international agreement on a lower limit, in terms of wind speed or pressure, for a tropical depression. It is therefore permissible to use the term tropical depression for any tropical area where the pressure is a little less than the environment so that it can be delineated by an isobar. However, most weather offices would mark such an area on their charts as "Low" - meaning an area of relatively low pressure - and would not refer to it as a tropical depression until the low pressure area became more concentrated in space with a complete cyclonic circulation of fresh or strong winds (16 to 22 knots). At this stage the depression will usually be defined on the weather map by at least two nearly circular isobars (2 mb interval).

In recent years
Chinese meteorologists have also used this numbering
systems.

There is a further difficulty — warning centres may
not agree on the time at which a (particular) storms formed.
Different numbers may be allocated to the same
storm. This difficulty was overcome in 1981 because the
Typhoon Committee (Cont.) had by then agreed that
the numbering of storms should be coordinated by
Japan. Countries using names were urged to use the
number as well to further ensure that the identity of
tropical cyclones is not mistaken. //

Table 1.1 THE CLASSIFICATION OF TROPICAL CYCLONES
(After W.M.O. Vol. D. Part A Chap. I)

Name of Tropical Cyclone	Name of the Associated Warning	Beaufort Number (Forces)	Range of Sustained Wind Speeds at 10m above the sea surface knots (m/s)	Descriptive Term for the Associated Winds
Tropical Disturbance[1]	Warning[1]	0	1 (0 - 0.2)	Calm
		1	1 - 3 (0.3 - 1.5)	Light air
		2	4 - 6 (1.6 - 3.3)	Light breeze
		3	7 - 10 (3.4 - 5.4)	Gentle breeze
		4	11 - 16 (5.5 - 7.9)	Moderate breeze
		5	17 - 21 (8.0 - 10.7)	Fresh breeze
Tropical Depression[1]		6	22 - 27 (10.8 - 13.8)	Strong breeze
		7	28 - 33 (13.9 - 17.1)	Near gale
(Moderate)[2] Tropical Storm	Gale Warning	8	34 - 40 (17.2 - 20.7)	Gale
		9	41 - 47 (20.8 - 24.4)	Strong gale
Severe Tropical Storm	Storm Warning	10	48 - 55 (24.5 - 28.4)	Storm
		11	56 - 63 (28.5 - 32.6)	Violent storm
Typhoon[3] (hurricane or local synonym)	Typhoon Warning	12	64 and over (32.7 and over)	Hurricane

Notes:- 1) There is no formal agreement on when a tropical disturbance becomes a tropical depression.

2) The word "moderate" is not used by countries in W.M.O. Region II i.e. Middle and Far East countries. It is also not used by the Philippines and the J.T.W.C. Guam (Region V) but there is no formal recognition of this.

3) WMO Region V - which includes Australia, U.S.A. and Philippines - reserve the right to use their own definitions for this category. The U.S.A. uses a "one minute mean wind speed of 64kn" as the interior limit of both typhoons and hurricanes

1.4 Naming of tropical cyclones

Meteorologists are often asked why tropical storms and typhoons are often given girls' names. Some say, that it is because they are capricious and hard to predict! Others consider that their possession of such a feminine attribute as clear roving eyes is the cause but, whatever the true reason, the procedure is generally popular. Weather offices often receive requests for typhoons to be named after somebody's wife, daughter or mother-in-law; however, these callers cannot be accommodated because the names used are taken in sequence from special lists. It is obvious that some method of identifying typhoons is desirable especially at times when there are more than one in the area. To identify each cyclone only by its ever-changing latitude and longitude is cumbersome and, for the general public, unsatisfactory.

The Japan Meteorological Agency allocates a number to each tropical cyclone which reaches tropical storm intensity. The number consists of four figures which identify the year and cyclone number within the year, for example 6909 would be the nineth tropical ~~cyclone~~ in 1969. The U.S. Joint Typhoon Warning Centre at Guam number those tropical cyclones for which they issue warnings, starting from the first in each year. ~~Chinese meteorologists have a similar numbering system~~. However, numbers do not catch the attention of the public as readily as do names nor are they as easily remembered.

Towards the end of the nineteenth century, a remarkable and well known Australian character named Clement Wragge - also known for various reasons as Inclement - became the first person to give names to cyclones. Wragge emigrated to Australia from Scotland after having received a gold medal in 1882 for his meteorological observations obtained by climbing daily to the summit of Ben Nevis (1 343 m). He began these climbs at 4.40 a.m. each day reaching the summit around 9 a.m. and returning to sea level by 3.30 p.m. When in Australia in 1887, Wragge organized the Queensland Weather Bureau in Brisbane and subsequently began to issue a meteorological gazette entitled "Wragge". It was during this period that he caught the attention of the public by naming extra-tropical cyclones after politicians who had earned his disfavour. He gave girls' names to tropical cyclones and this practice was also followed in the South Pacific, just before the Second World War, by a Pan American Airways' meteorologist named E.B. Buxton. Names were dropped from Australian weather charts after Wragge left his government position in 1902.

In 1945 the U.S. Air Force (~~at that time~~ called the Army Air Force) and the U.S. Navy began reconnaissance flights into Western Pacific tropical cyclones. It was at this time that Air Force Weather Officers first began to identify typhoons and tropical storms in their warning by giving them the first names of the wives of their commanding officers (Kidd and Reed 1946). Tropical storm Ann of 19 April 1945 was the first storm to be so named. The idea may have been inspired by Wragge or Buxton's earlier practice or by George Stewart's novel "Storm" which was published in 1941 and was concerned with a ficitious storm named "Maria".

In the late nineteen-forties national meteorological services in the Western Pacific were not normally in close communication with U.S. military meteorologists and so the general use of girl's names was slow to spread. It came first to countries in which there was already a U.S. military presence such as Japan and the Philippines and then spread to other countries as communications improved. For example, Japan began to use names for tropical storms and typhoons in 1947 and Hong Kong first did so in 1952.

For several hundred years past it has been a West Indian habit to name particularly destructive Caribbean hurricanes after the particular saint's day on which they occurred. "Santa Ana" and "San Felipe" were two memorable hurricanes to affect Puerto Rico in the 19th century. In the U.S.A. famous prewar hurricanes carried such names as "Labor Day 1935" and "New England 1938" but, in 1951 the U.S. authorities responsible for Atlantic hurricane warnings decided to identify tropical storms and hurricanes with names taken from the old phonetic alphabet - Able, Baker, Charlie etc. beginning with "Able" each year. However, the introduction of a new international phonetic alphabet - Alfa, Bravo, Coca etc. in 1952 caused some confusion and so, in 1953, girl's names were used instead. The greatest number of tropical storms to have occurred in any one year in the Atlantic is twenty-one. It is therefore possible to use one list of names for each year so that the name of the first storm begins with an "A". Four lists are used and these suffice for four years after which they are repeated except that the names of particularly severe hurricanes which affect the United States are retired for ten years and replaced.

There is a third set of four lists of girl's names for hurricanes and tropical cyclones in the Eastern Pacific and, as in the Western Pacific, these names are used in sequence without considering the year. The names used in the Atlantic, East Pacific and West Pacific are all different. If a hurricane crosses the date line and became a typhoon, or vice versa, it retains its original name.

In the early nineteen seventies the Women's Liberation Movement in the U.S.A. and elsewhere began to campaign against the use of feminine names for tropical cyclones. In Australia in February 1975, following the devastating Darwin Cyclone Tracy and in commenoration of International Women's Year, it was announced that, henceforth, cyclones near Australia will bear both boy's and girl's names so that"..... both sexes should bear the odium of the devastation caused by cyclones". Cyclone Alan 1975 was the first tropical cyclone to be given a masculine name in this series. The warning centres at Brisbane, Darwin and Perth have their own alphabetical lists which contain alternate girl's and boy's names. The names of cyclones which severely affect Australia are permanently retired and so far (1975) four tropical cyclones have earned this distinction - Ada 1970, Althea 1971, Tracy 1974 and Trixie 1975.

In the U.S.A. men gained equality with women - or discrimination against women ceased - when it was announced in May 1978 that hurricanes in the Eastern North Pacific would be named after both men and women and an internationally agreed list of names was prepared. The first name on the new list was Aletta and the first male hurricane was Bud, christened on 18 June 1978. From 1979 male and female names have been used for hurricanes in the Atlantic, Caribbean and the Gulf of Mexico and for typhoons in the Pacific.

The U.S. Joint Typhoon Warning Centre (JTWC) at Guam (p.) christens tropical cyclones in the Western Pacific as soon as they attain tropical storm intensity. When some other warning centre has information that a storm depression has attained tropical storm intensity and no name has been issued then they usually alert the JTWC. This responsibility for naming tropical storms was not allocated to Guam by international agreement but followed naturally from the Centre's interest in all tropical cyclones in the JTWC's

Pacific and from the early information it receives, from satellites and reconnaissance aircraft, on the intensity of each cyclone. Names are taken in sequence from the ~~following~~ alphabetical list in Table 1.4(1). The name of the first storm in any year follows on alphabetically, from that of the last storm in the preceeding year. It will be seen that there are only 21 names in each ~~alphabet~~ list because suitable names beginning with Q, U, X, Y and Z are too few.

Some Asian countries, such as the Philippines, use their own national lists of names and care has to be taken to ensure that warnings using these national names do not get into overseas communication channels and so cause confusion.

Some Asian countries, such as the Philippines, use their own lists of national names. For example, typhoon Patsy which crossed Honshu on 18 November 1970 and which caused more damage there than any other storm in this century, is known in the Philippines as typhoon "Yoling".

Philippines. Care has to be taken that warnings using these national names do not get into overseas communication channels and so cause confusion. The decision taken in 1981 to use a unified numbering system as well as names was designed to minimise confusion caused by the use of different names for the same storm.

In 1981, the Central Pacific Hurricane Centre at Honolulu, Hawaiian adopted a list of names for hurricanes occurring in their area - 140°W to 160°W north of the equator. The list includes the names Akoni, Eme, Hololu, Ione, Kika, Luke, Malulani, Napua, Oliwa, Pua mole, Uleki and Wila. Hurricanes are relatively rare over the Hawaiian islands, the first to threaten the chain after World War II was called "Hiki", meaning Able - Alphabetically the first. In the three decades since Hiki, Hawaii experienced a direct hit from Dot in August 1959 and has a number of near misses.

Table 1.4(1)

CENTRAL & WESTERN PACIFIC NAMES FOR TROPICAL STORMS AND TYPHOONS
(Effective from 1 March 1979)

ANDY	ABBY	ALEX	AGNES
BESS	BEN	BETTY	BILL
CECIL	CARMEN	CARY	CLARA
DOT	DOM	DINAH	DOYLE
ELLIS	ELLEN	ED	ELSIE
FAYE	FORREST	FREDA	FABIAN
GORDON	GEORGIA	GERALD	GAY
HOPE	HERBERT	HOLLY	HAZEN
IRVING	IDA	IKE	IRMA
JUDY	JOE	JUNE	JEFF
KEN	KIM	KELLY	KIT
LOLA	LEX	LYNN	LEE
MAC	MARGE	MAURY	MAMIE
NANCY	NORRIS	NINA	NELSON
OWEN	ORCHID	OGDEN	ODESSA
PAMELA	PERCY	PHYLLIS	PAT
ROGER	RUTH	ROY	RUBY
SARAH	SPERRY	SUSAN	SKIP
TIP	THELMA	THAD	TESS
VERA	VERNON	VANESSA	VAL
WAYNE	WYNNE	WARREN	WINONA

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