Tropical Cyclone

(Weather disturbances represent secondary or synoptic circulations and are simply alternations of low and high pressure systems. They refer especially to those termed 'travelling' lows and highs, which are relatively short-term features embodied in the global or general circulation. They develop from a wide range of atmospheric processes operating in low, middle & high latitudes. Disturbed weather develops in low latitudes, especially in the summer, due to active ITCZ invasions and cyclogenesis, when resultant troughs or cyclones can also alternate with anticyclonic ridges to produce tropical secondary circulation or weather disturbances. Organised synoptic-scale disturbances are supposed to produce more than 90% of the rainfall in the Tropics) these disturbances may take a variety of forms, the commonest types being varieties of the easterly wave within the trade winds and the tropical cyclone.

(The most vigorous of the tropical disturbances are the tropical cyclones, also known as hurricanes in the North Atlantic, around the coasts of North America & the Caribbean, as typhoons in the North-west Pacific, & as cyclones in the Bay of Bengal & as willy-willies in northern Australia. Tropical cyclones are intense, circular low-pressure systems with strong cyclonic circulations & vigorous airflows. They are violent tropical maritime storms. World Meteorological Organisation publications refer to tropical storms as being tropical cyclones with closed isobars & maximum sustained wind (averaged over a period of 10 mins.) between 17 and 32 ms^{-1} (34 & 63 knots), & typhoons & hurricanes as tropical cyclones with max. sustained winds of at least 33 ms^{-1} (64 knots). Tropical cyclones are hence classified into 4 types — 1) Tropical depression — wind speed upto 33 knots (17.1 ms^{-1}),

2) Tropical storm, moderate — wind speed, between 34 & 47 knots (17.2–24.4 ms^{-1})

3) Tropical storm, severe — wind speed, between 48 & 63 knots (24.5–32.6 ms^{-1})

4) Hurricane — wind speed, in excess of 64 knots (32.7 ms^{-1})) Add 1/M

Such definition of t. cyclone & usage of terms are variable. Other groups regards travelling tropical disturbances within Hadley circulation as tropical depressions if wind speed averaged over 1 min. does not exceed 17 m/sec (33 knots); they are tropical storms if the winds average between 17 & 33 m/sec. & they are designated tropical cyclones only if the winds exceed 33 m/sec or 64 knots measured over 1 minute.

A tropical cyclone first appears on the m.s.l. pressure chart as a tropical disturbance. Under favourable condition its central pressure decreases rapidly, frequently to less than 960 mb with the lowest recorded being 870 mb. (They are strictly oceanic phenomena and tend to die over land & only occur in certain seasons, mainly late summer to early autumn. (although they often move into) (The diameter is generally small, only about one-third the size of extra-tropical cyclone.. normally in the range of 200–600 km. Pressure gradients are very steep and the winds in quasi-gradient balance may reach 100 ms^{-1} with torrential rain (averaging 25 mm) & thunderstorm activity. ~~The st~~ Tropical cyclones usually move with a deep-layer-steering environmental wind. ~~The move towards~~ quite slowly. They ~~move~~ may move in any direction & are quite erratic) although in the mean they move westward & poleward before recurving to move poleward & eastward. They are not always mobile & may become stationary over a place for several days & yield heavy rainfall. Unlike the temperate cyclones, they are not characterised by temperature contrasts in their different parts as they do not have ~~fronts~~ warm & cold fronts. There are also no different rainfall cells & each part yields rainfall.

*(Despite the vast expanse of tropical ocean of the Southern Hemisp.)

Regional Distribution & Time of Occurrence –

(80–85% of tropical cyclones originate in or just poleward of the ITCZ, in latitudes 5°–15°, most of the remainder forming within the trades. Tropical cyclones of hurricane intensity occur only in certain regions of the tropics)*. Many more occur (69% occur in the northern hemisphere) than in the Southern hemisphere. There are large variations in the numbers experienced per year over each of the tropical oceans; they are most frequent over the western North Pacific Ocean (off the East Asian coast*), while one-half of the world's total occurs over the Pacific Ocean as a whole. The best known hurricane region is the Caribbean & western N. Atlantic. Despite the large expanse of tropical oceans in the southern hemisphere, some 69% of the tropical cyclones occur in the northern hemisphere. (None occurs in the South Atlantic & the southeast Pacific Ocean, owing to the presence of the cool Benguela & Peruvian sea currents respectively.) Given the appropriate region & the appropriate season, they still do not develop with any regularity from year to year; despite the reliability of the Hadley circulation, & the numbers recorded vary greatly from year to year.

*in the China Sea & the Philippines

(7)

There are 6 general regions of origin & concentration of these strictly oceanic phenomena.

1) (The south & especially the southwestern parts of the North Atlantic Ocean):

a) (Cape Verde Island area) (in August & September),

b) (East & north of the West Indies, including Florida & the South Atlantic coast of the United States) (in June through October),

c) (Northern Caribbean Sea) (late May through November),

d) (Southwestern Caribbean Sea) (principally June & October), In short

c) (Gulf of Mexico) (June through October).

2). North Pacific Ocean, (off the west coast of Mexico) (June through November),

3). Southwestern North Pacific Ocean (especially the China Sea, the Philippine Islands & southern Japan) (chiefly May through December),

4) North Indian Ocean

a). (Bay of Bengal) (April through December)

b) (Arabian Sea) (April through June, September through December)

5). South Indian Ocean - (area extending from Madagascar to 90°E longitude) & (southwestern Australia in Timor Sea) (November through April),

6). ~~South~~ Western South Pacific Ocean, (west of Tuamotu Islands & the Coral Sea in the region of Samoa & Fiji islands (& the east coast of Australia to about 140°W (December through April)).

Tropical cyclones do not develop over land, although they often move far into continents.

Tropical ~~cs~~ cyclone (*and its activity is at its max. in late summer & early autumn, coinciding with the period of highest ocean surface temperatures & max. poleward displacement of the ITCZ) ** trigger ?

Conditions required for development –

(4) Explanation of the formation of tropical cyclones is still an uncertain area of knowledge. (They only form in barotropic atmospheric conditions (where temperature, pressure, lapse rate & humidity are fairly uniform over large areas), unlike the baroclinic atmosphere associated with frontal depressions. Disturbances are common in the tropics) & a trigger mechanism is required to transform these frequent storms into rarer tropical cyclones with winds of over 33 m/sec., a well-developed cyclonic organisation, intensely violent weather & a central warm core. (The and necessary trigger is the result of several necessary conditions ~~being right~~ coinciding at the same time)

Gray (1968) showed that tropical cyclone genesis is related to 6 factors:

1) above-average low-level vorticity;
2) middle-level moisture;
3) conditional instability through a deep layer;
4) a warm sea surface (>26.5°c) & a deep oceanic mixed layer;
5). a weak vertical shear of the horizontal wind;
6). a location at least a few degrees from the equator).

The seven ~~seven~~ essential conditions are summarised below:

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1) (The basic requirement is a suitable source of sensible & latent heat energy. Oceanic thermal energy represents the major energy source of a tropical cyclone, which develops a warm core in association with excessive rates of evaporation & subsequent condensation or latent heat release. High sea surface temperatures (in excess of 26°C & integrated to a depth of 60-70 m) are present in warm tropical oceans). Warm conditions extending to 60-70 m. depth allows deep convection to occur, unaffected by any cooler water being brought to the surface by the churning & mixing of the disturbed water beneath the tropical cyclone. (These and conditions are indespensable) for the required amount of lapse rate steepening & deep, free convection inherent in any tropical cyclone. There appears to be a strong correlation between the seasonal location of the ITCZ (& its thermal energy concentration) & cyclonicity. There is a clearly distinct cyclone season related to ITCZ control, which occurs in late summer or early autumn, when ocean temperatures are at their highest. In South Pacific, the season occurs between December & April, whereas in the Caribbean ~~En~~ between July to October.

2) (A pre-existing ~~storm~~ low-level weather disturbance is required to act as a 'parent' vortex in order to release sufficient latent energy to break down the stabilising trade wind inversion). Surface charts

(9) by Love (1985) identify synoptic features such as enhanced winds into the ITCZ, a surge from a subtropical high, & the intrusion of mid-latitude fronts to low latitudes. In qualitative terms, such features serve to increase the value of relative vorticity (ζ) & V/r term (cyclonic wind speed divided by radial distance from the centre of the eye) & thereby increase the rotational Froude number (F_R), so that scale interaction is more likely. (The necessary convective mixing can be provided by sequences of active cloud clusters & the associate band of convergence), but it is usual for an (easterly wave) to provide the parenthood by convection (which is necessary for the generation of tropical cyclone seedlings). Within the disturbance convergence will be present in the boundary layer above the ocean providing initial organisation. Only about 10% of these can develop into mature hurricanes due to other basic requirements not being evident at the time of seedling initiation.

3). <u>The Coriolis parameter (f)</u>, a function of latitude must exceed a certain critical value. * Researches show that <u>f must exceed 10^{5}/sec. in magnitude</u> ~~which means that tropical cyclones do not form within 5° of the equator.~~ In other words, the influence of earth's rotation must be strong enough to

* Coriolis effect weakens toward lower latitudes & becomes zero at the equator. Any semblance of organised balanced rotational motion to sustain deep cyclonic rotation is not within 5° of the equator.

to induce & sustain a cyclonic circulation. Hence, maximum development occurs around 15° latitude with 65% of the global total developing between 10°–20° according to Gray).

4) (Tropical cyclogenesis requires weak vertical shear of the horizontal wind in the basic air circulation between the upper & lower troposphere (i.e. the layer 850 mb to 200 mb). Westerly wind shear (in the vertical) inhibits genesis). With strong wind shear, the latent heat of condensation released by the developing convection (i.e. the primary energy cell or 'hot tower' in a tropical cyclone) will be dissipated in the upper atmosphere as the heat energy in these layers is now advected in a different direction from that in the lower layers, where this energy is released. Thus, ~~optimal~~ optimum conditions occur where the high level easterlies overlie the surface trade-wind easterlies. Strong wind shear is always present throughout the year in the western South Atlantic & central Pacific, so cyclones cannot develop in these areas. The weakest tropical wind shear is found in the western North Pacific, where cyclogenesis peaks.

5) ~~There~~ (The presence of divergent flow in the upper troposphere, above 12 km. is required in order to sustain an intense free convection, & storm generation). The ~~outflow~~ large pressure fall at the surface will only develop if the outflow from the system aloft exceeds the surface inflow. Such high-level

outflow (at a greater rate than surface inflow) is normally provided by an upper-air anticyclonic cell or ridge. The divergence aloft maintains the ascent & low-level inflow that is necessary to generate potential & kinetic energy continually from latent heat release. Upper level divergence areas can be associated with tropical upper tropospheric troughs (TUTTs) & with entrances to upper level easterly jets. This allows the removal of the airmass which flows through the convective cloudmass.

(11)

6) (This flow must be linked to a deepening trough in the upper westerlies in higher latitudes which transports excess energy away from the storm, acting as an external heat sink.) The internal heat source which generates the warm core & provides potential energy for the system is provided by the hot tower convection within cumulonimbus cores.

7) (Humidity levels in the mid-troposphere need to be high), for entrainment of moist air into updraughts does not inhibit the growth within cumulonimbus clouds as much as the entrainment of dry air. Cumulonimbus convection tends not to occur over oceanic areas where the relative humidity of mid-tropospheric air is less than 50-60%.

(An attractive conceptual model of tropical cyclone genesis proposed by Emanuel (1988) is that tropical cyclones are self-amplifying systems. They intensify to attain their MPI (Maximum Potential Intensity) unless their surroundings disrupt the process, as is usually the case. (Strong vertical shear is the most common inhibitor.) MPI is the function of sea surface temperature & the temperature of the outflow ~~which is assumed to be~~ at the Tropopause.

[(Gray has pointed out that aggregate tropical cyclone genesis appears to fluctuate on several quasi-periodic scales owing to):

1) (ENSO (El Nino Southern Oscillation)) - The response of each basin is individual; for eg, during El Nino, the North Atlantic basin has a large decrease in cyclone frequency whereas the South & Central Pacific basin has an increase.

2) (QBO (Quasi-Biennial Oscillation)) - This is a 26 monthly oscillation in the equatorial stratospheric winds from an easterly phase to a westerly phase. The effect is also basin dependent.

3) (MJO (Madden-Julien Oscillation)) - Alterations of active & inactive genesis periods of 15 to 25 days have been observed with a 4:1 ratio of cyclone numbers between active & inactive periods.]

If conditions favourable to hurricane genesis persist, a cyclonic circulation develops & the central air pressure begins to fall. Water vapour condenses within the storm, releasing latent heat of vapourisation, & the heated air is then forced to rise by neighbouring cooler air. Expansional cooling of the rising air triggers more condensation, release of even more latent heat & a further increase in buoyancy. Rising temperatures, coupled with an anticyclonic outflow of air aloft, cause a sharp drop in air pressure, which induces convergence of air at the surface. The consequent uplift around the developing eye leads to additional condensation & release of latent heat. ⊗⊗

Through these processes, the tropical disturbance intensifies & winds strengthen. When max. wind speeds ~~tops~~ reach 37km/hr, the developing storm is called a tropical depression. When max. wind speeds reach 63 km/hr., the system becomes a tropical storm & when it exceeds 119 km/hr, it officially becomes a hurricane.

STEERING: (Once developed, tropical cyclones tend to move northwestwards & then northeastwards recurving around the periphery of the subtropical anticyclones before entering the circulation of midlatitude westerlies where they either die out or regenerate into extratropical disturbances as colder air is drawn into the circulation & fronts develop).

(In seeking to understand the motion & development of tropical cyclones, a variety of concepts like the beta effect, steering, empiricism, the Fujiwhara effect, numerical models & statistical techniques are used by forecasters).

(The ~~Beta~~ beta effect proves that the tropical cyclone will be displaced toward the region with greatest max. cyclonic

⊕ The equation can be enumerated as:

$$\partial\zeta/\partial t = -V\cdot\nabla\zeta - \beta v - f\nabla\cdot V - \zeta\nabla\cdot V$$

where V is the horizontal wind vector & v is its meridional component.

vorticity tendency) For an initially stationary axisymmetric tropical cyclone experiencing no background flow, it can be shown that the cyclone itself generates a westward & poleward movement. (According to the linear beta effect, to the west of the cyclone, the $-\beta v$ term, in the equation using vorticity-divergence relation, contributes cyclonic vorticity; to the east, it contributes anticyclonic vorticity. ⊕ Thus, westward motion is expected in either hemisphere. On the poleward side there is an asymmetric contribution of cyclonic vorticity & anticyclonic vorticity ⊕ on the equatorward side.)

Steering - (Tropical cyclones tend to move with the speed & direction of the mid-level environmental wind) Holland says that interaction between the tropical cyclone & the environment has a marked impact upon the track of the tropical cyclone.) (In general, the steering flow is easterly near the equator & becomes westerly with latitude). The mean tracks are initially westward prior to an anticyclonic recurving away from the equator.

Empirical rules - (Recognising synoptic patterns, Foley & Hanstrum (1994) observed that in the case of a subtropical ridge poleward of the t. cyclone, the latter will maintain its westward course). A trough in the upper level westerly flow to west of a t. cyclone usually indicates recurvature. T. cyclones tend to move towards the downstream end of convective clouds bands in the outer circle & seem to avoid cumulonimbus-free sectors. A mass of middle-level cloud streaming poleward from a t. cyclone indicates possible recurvature.) 'Nearby' t. cyclones mutually affect each other in complex ways. ~~the interactions of binary t. cyclones & of t. cyclones with other systems~~ It is often observed that t. cyclones within 1000 to 1500 km of each other tend to inhibit each other.

~~Rotation~~ Fujiwhara effect — (T. cyclones within 1500 km. tend to rotate about each other, or more precisely, about a common 'centroid'. This effect is the Fujiwhara effect.) (At first it appears to be chaotic motion of 2 t. cyclones that may be resolved into components of mutual rotation & of advection of the centroid on the broad scale. The centroid is the geometric centre of the line joining the centres, sometimes weighted towards the larger cyclone.)

Dissipation & interactions —

(The tropical cyclone will dissipate when any of the conditions required for its growth is no longer met. Degeneration occurs relatively quickly when the storm trajectory takes the vortex over a cool sea surface away from the equator & especially over land, where friction increases & heat & moisture fluxes are much smaller. Rapid decay also occurs when cold polar air enters the system, or when the vital upper-level outflow becomes detached from the surface vortex), which now fills since the inflow at the lower levels exceeds the divergence aloft, or if ~~effect of friction~~ vertical wind shear from upper westerlies distorts the organisation of the flow. Dissipation may be slow ~~& ef~~ & dissipating ~~ex~~ cyclones will tend to maintain gale force winds within 2 kms. of the surface for several days & these gales force winds can be brought down to surface by vertical mixing due to convection or passage over rough terrain. ~~Cyclones~~.

(Cyclones can redevelop if the decayed system moves back over water. But, about a quarter of t. cyclones moving into mid-latitudes interact with a mid-latitude front & transform into an extra-tropical cyclone. During transformation, the cyclone merges with a pre-existing extra-tropical cyclone which then intensifies due to addition of moisture & diabatic heating). (Complex transformation occurs when a t. cyclone approaches a front & induces a wave low on the front. The t. cyclone then accelerates into the wave low & forms a single extra-tropical cyclone.)

The Structure – By combining the information from reconnaissance aircraft flights, meteorological satellites and weather radar with the conventional surface & upper air information, a reasonably clear picture of the structure of a mature tropical cyclone has emerged.

(**Horizontally**, the tropical cyclone is characterised by strong convergence & cyclonic inflow towards the low-pressure centre at low levels, with divergence & anticyclonic outflow aloft. It is considered to consist of 6 regions, from the outside of the storm to the central eye):

1) (Away from the main cloudmass there is limited cloud & limited depth of convection within the trade-wind regime. Subsidence from the outflow of the t. cyclone appears to lower the trade-wind inversion locally, intensify it & suppress cloud. Here (wind speeds increase towards the storm & become increasingly cyclonic)

2) (The outer convective band consists of an outer fringe of deep convective cloud around the edge of the main cloudmass. It is often fragmented), i.e. may not extend around the main cloudmass continuously & occurs where the subsident outflow from the storm edge aloft converges with the main surface inflow, triggering of localised instability.

3) (The annular zone ~~is~~ has suppressed cloudiness, relatively high temperatures & low humidities associated with subsidence from aloft around the outer limits of the t. cyclone).

4) A region of intense convective cloud provides the main cloudmass of the storm. Here winds increase to hurricane force towards the centre & very heavy rainfall occurs from the spiral rainbands or feeder bands which spiral towards the storm centre. These bands are usually quasi-stationary with respect to the moving storm. ~~The strongest band & the~~

5) Greatest intensity in every aspects is attained in a more-or-less circular inner rain region, the 'throat' of the storm, some 10 to 20 km. wide. The convection occurs in towering cumulonimbus clouds with violent vertical motion whirling around the centre ~~central eye~~ (eye) & is called the eye-wall cloud. Sustained violent winds with speeds to over 50m/sec, approaching $100 ms^{-1}$ in hurricanes ~~have~~ are recorded near the base of the eye-wall cloud together with torrential rainfall rates on the order of $10 cm h^{-1}$. The eye-wall cloud often does not form a complete ring around the eye. In such cases, peak wind speeds observed just outside the eye may vary by as much as a factor of 2 between the eye-wall cloud & the open sector.

thunderstorm activity to tropopause levels on all sides of it. The warm core of the storm is imp. in maintaining the central low pressure (a deep column of warm air exerts a lower pressure on the surface than the surrounding columns of cooler air, because of their differing densities), & in maintaining the ~~central low pressure~~ high-level outflow.

from mixing, subsidence evident above, dry adiabatic ... the physical size of the storm. ... a critical radius (the radius of the eye) the pressure gradient force which causes the air to accelerate inwards towards the storm centre cannot overcome the outward centrifugal force arising from the cyclonic rotation about a small radius. The air cannot penetrate beyond this radius, is forced upwards & eventually thrown outwards at high levels. ... manner in which the warm core & the eye is first developed in an tropical disturbance is not yet fully understood.

The strongest band & the most strongly developed segment of the eye-wall cloud are usually found in the quadrant of the storm centered about 45° to the right of the storm movement direction in the Northern Hemisphere & to left in the Southern Hemisphere. The cumulonimbus towers represent the rainbands & the eye-wall cloud. Strong updraughts within these rain areas are fed by the radial influx of mass & moisture within the subcloud layer. The outflow from updraughts exists from the cyclone by way of an immense cirroform anvil.

6) The 'eye', in the heart of the storm, is central well or funnel of subsidence & adiabatic warming of high-level air drawn down into the heart of the vortex. It is some 5–50 km in diameter. Centred on the axis of rotation, the eye is a distinct, circular & ~~Here there is a rapid decrease of windspeed to low values, there are comparatively clear skies or scattered low-level stratocumulus~~, the sun may be shining & the temperature is warmer than in the body of the storm, particularly at middle & high tropospheric levels. In intense hurricanes sea-level pressures as low as 880 mb. have been observed within the eye.

* ~~cloud free area~~ region of quiescence, characterised by abnormal warmth, ~~limited cloud~~ or comparatively clear skies or limited scattered low-level stratocumulus, rapid decrease of windspeed to low ~~levels~~ values & active subsidence, which contrasts markedly with violent

The eye of the t. cyclone only develops when the storm has reached its most intense state at maturity. ~~It is~~ The air within the eye comes from 2 separate sources. Most com

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from mixing & subsidence from the surrounding cloud walls, the remainder from subsidence from the stratosphere through the break in the tropopause often evident above the eye. Air within the eye is therefore warmed as it sinks at the dry adiabatic lapse rate, producing the anomalous warm core of the t. cyclone. The physical size of the eye is thought to be determined by the rate of inflow of the storm.

At a critical radius (the radius of the eye) the pressure gradient force which causes the air to accelerate inwards towards the storm centre cannot overcome the outward centrifugal force arising from the cyclonic rotation about a small radius. The air cannot penetrate beyond this radius, is forced upwards to be eventually thrown outwards at high levels. The manner in which the warm core of the eye is first developed in an initial disturbance is not yet fully understood.

Vertically, the tropical cyclone can be divided into 3 layers :

1) The lowest layer is the inflow layer from the ocean surface up to 3 km. This layer is the basic engine generating the storm's circulation. Water vapour evaporated into the air in large quantities from the warm ocean surface subsequently condenses in the convective clouds, liberating latent heat. This potential energy is converted into kinetic energy of motion of the storm. In this layer, the motion of the inflow is essentially radial towards the low pressure centre.

2) The middle layer is from 3 to 7 km.; This is the main cyclonic circulation of the storm, within the cloudiness; the airflow is here more tangential than radial.

3) The outflow layer is from 7 km. upwards to the tropopause & max. outflow at 12 km. & above. The air motion here is anticyclonic & air which has passed through the storm is evacuated to higher latitudes via upper westerly flow.

There is much recycling of air within the t. cyclone. The air does not simply flow into the storm, up through the throat & out in the downdraughts before reaching the core

The air spiraling inward within the subcloud layer undergoes a steady increase in equivalent potential temp. (θ_e) due to the fluxes of water vapour & enthalpy from the sea surface. The fluxes are greatly enhanced by the strong winds & the highly disturbed sea states that prevail in the vicinity of the ~~hurricane~~ t. cyclone. The air ascending moist-adiabatically in the updraughts & spiraling outward in the anvil maintains a nearly constant value of θ_e. The ~~high~~ equivalent potential temperatures are high in the interior of the storm. At any given level up to about 200 mb., the air within the eye is about 10° warmer than the air outside the storm at the same level.

Most of the energy of a large tropical cyclone is concentrated in a ring within 100 km. of the centre, the winds attain max. force in this zone. The strongest winds are found in a ring encircling the storm centre at a distance of about 24 km. from the eye. Inside the ring, wind speeds decrease rapidly to relative calm conditions of the eye. Outsi the high velocity ring, wind speeds decrease progressively to the storm periphery. The strongest winds are found near the base of the eye-wall cloud. Wind speed decreases rapidly with height through the middle troposphere. In the upper troposphere, the wind field ~~speed~~ is highly asymmetric with respect to the centre of the cyclone, with the outflow air from the spiral rainbands often rotating in the opposite sense as the air between the bands. When averaged around the storm, the tangential velocity at these levels is close to zero.

Schematics on t. cyclone assume an axisymmetric structure, but this is not strictly true. Much of the asymmetry is due to the superposition of the environmental flow upon the vortex. ~~The central pressure of~~

The central pressure in a t. cyclone is estimated using a scheme devised by Dvorak (1975) which relates the central pressure to features of cloud configurations & size. Holland (1982) has developed a semi-empirical formula for the surface pressure p at a radial distance r from the centre of the eye. The formula is:

$$p = p_c + (p_n - p_c)\exp(-R/r)^b$$

where p_n and p_c are respectively the environmental pressure away from the influence of the

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cyclone & the central pressure, and b is a factor between 1 and 2·5. At this stage, R is simply a suitable scaling constant, but has a physical significance. The tangential wind speed is a function of $\partial p/\partial r$. Thus,

$$v^2 = [b/\rho(R/r)^b(p_n - p_c)\exp(-R/r)^b - r^2f^2/4]^{1/2} - rf/2$$

Using the cyclostrophic approximation, i.e. max. significant wave height or $H = 0{\cdot}2(p_n$- due to t. cyclone in deep sea water at $r = R$, the max. speed V is given by

$$V^2 = b(p_n - p_c)/(\rho e)$$

where ρ is the density & e is the base of natural logarithms. This implies a maximum wind speed at some distance from the centre, R (the radius of max wind) which is usually about 8 km. within the eye wall. To estimate b, Love & Murphy suggest the following:

$$b \approx 0{\cdot}25 + 0{\cdot}30 \ln(p_n - p_c)$$

Where $(p_n - p_c)$ is in hPa. Thus, only the central pressure & environmental pressure are to be known in order to estimate the pressure & wind speed profiles.

[In T. cyclones the core is relatively warm & $\partial T/\partial r$ is strongly negative in the mid-troposphere. The implication is that cyclonic wind speed is decreasing with height because this is a warm-core

? system. The cyclonic wind speed decreases & reverses to form anticyclonic outflow aloft. Thus the system can have low-level inflow located beneath upper level outflow. The linking upward motion at mid-level in the eye wall has been recorded at $20 ms^{-1}$ or more.

The main source of this energy is the diabatic heating from the latent heat of condensation. This occurs as the pressure of the inflowing low-level air reduces, thereby tending to cool the inflowing air adiabatically; however, any cooling is countered by sensible heat drawn from the warm sea surface. Most of the latent heat that drives the primary circulation is derived from evaporation from the sea surface located within a radius of 12° latitude ~~surface~~ (Frank, 1987). Evaporation increases with reduced pressure & high winds. A model mechanism to feed in the energy is the CISK ~~pr~~ process. Linear CISK can be distinguished from wave CISK.) Under the linear CISK theory, the growth of cumulus clouds is predicted because the max. growth rates occur at smaller scales. Linear CISK can maintain & intensify existing tropical cyclones, but cannot initiate them. For tropical cyclones to occur, there must be an effective interactive coupling between the cumulus-scale vertical motion & the large-scale horizontal wind field. The hypothesis of wave CISK is an attempt to match the scales of vertical & horizontal motion so that self-sustaining growth occurs. In the model of wave CISK, a wave, ~~which~~ could be a synoptic-scale wave in the easterlies, for eg., with its associated upward motion is a precondition. With the wave, the zone of vertical motion slopes with height. The low-level vertical motion initiates moist convection & latent heat release. Because of the sloping of the wave with height, the max. heating is out of phase with the max. upward motion & this leads to greater vertical motion at low levels &, thus, to self-amplification. Fraedrich & McBride (1995) proposed a third type of CISK based on the large-scale convective overturning in which the heating & the synoptic-scale vertical motion are related, or matched, to the cumulonimbus mass flux & the synoptic-scale mass flux. Positive feedback occurs for motion of the order of several hundred kilometres & does not occur for sea surface temperatures below 25.5°C.]

Destruction & Damage —

Enormous amounts of destruction & damage can be caused by t. cyclones, particularly in coastal areas. There are 3 main causes of hurricane damage:

1) Winds - These can blow at over 50 m/sec (180 km/hr), with gusting in excess of this. The damage arises from the winds themselves, from the objects which are blown along by the winds & from pressure differentials set up between upwind & downwind sides of buildings causing oscillations & ultimately building collapse.

2) Storm surges - These inundate coastal areas, with wind-driven seawater 'piled up' ahead of the storm (especially in constricted coastal configuration). Sea-level will be locally increased beneath the cyclone because of the drop in surface pressure; if this coincides with a normal hightide & a storm surge of water is superimposed on this abnormally high sea-level (with waves upto 10 metres high arising from winds), the danger of severe coastal flooding is very serious.

3). Flooding - This results from the storm surge & coastal inundation & from the very heavy rainfall associated with tropical cyclone. Such heavy rainfall may cause river flooding & landslides inland.

Frequently t. cyclone damage is experienced most by countries where disaster preparedness are not well developed. During 1947-73, Asia suffered 96% of the known deaths caused by t. cyclones (acc. to UN). In the USA, warning systems are more developed. Hence numbers of human deaths has decreased since 1900. But the amount of property damage has increased with time.