Higher 2 (9173)	Tropical Environments	TMJC
Lecture 4	*Tropical Cyclones*	2025

LECTURE OBJECTIVES

- Explain the spatial and temporal patterns of tropical cyclones occurrence
- Explain the surface and atmospheric conditions that lead to the formation of tropical cyclones

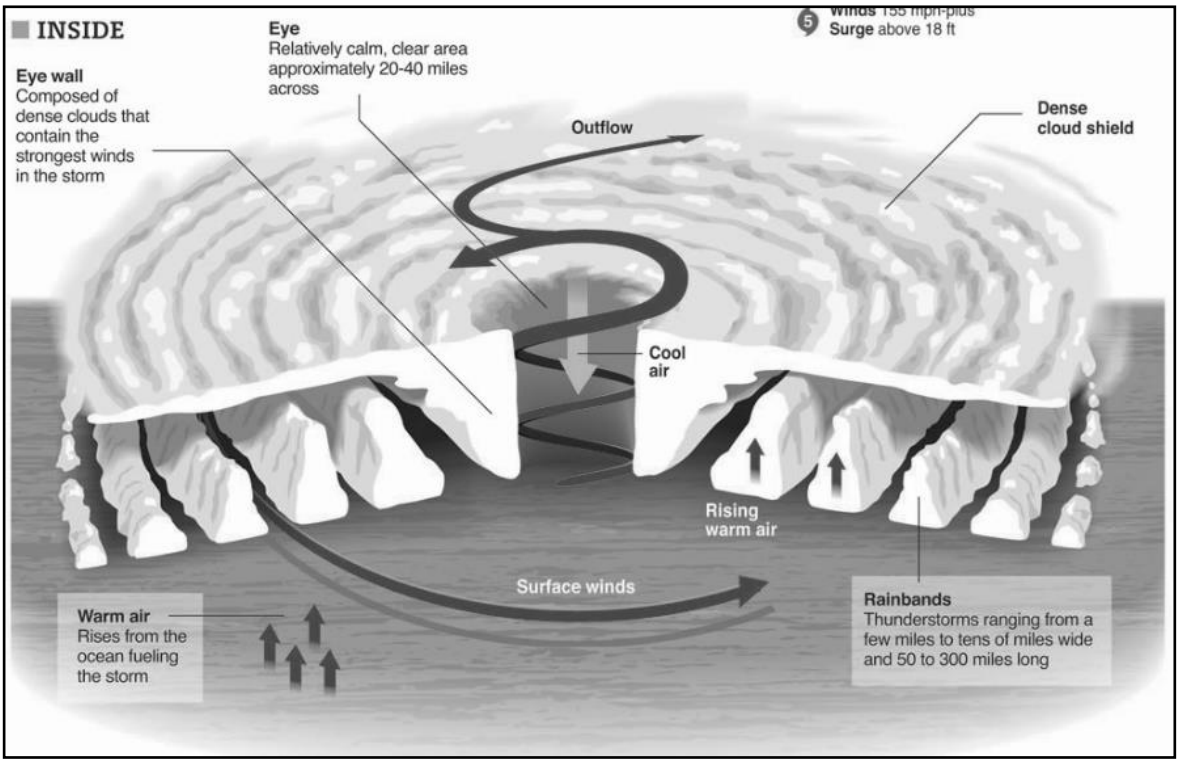
(A) WHAT ARE TROPICAL CYCLONES

Tropical cyclones are intense storms that originate over warm tropical seas, characterised by a low-pressure center surrounded by swirling spiral bands of thunderstorms that produce torrential rain and sustained winds of at least **119 km/hour**. They are another mechanism by which surplus energy is transferred away from the tropics

Fig. 1 - Aerial view of Hurricane Sandy at the east coast of the USA on October 27, 2012

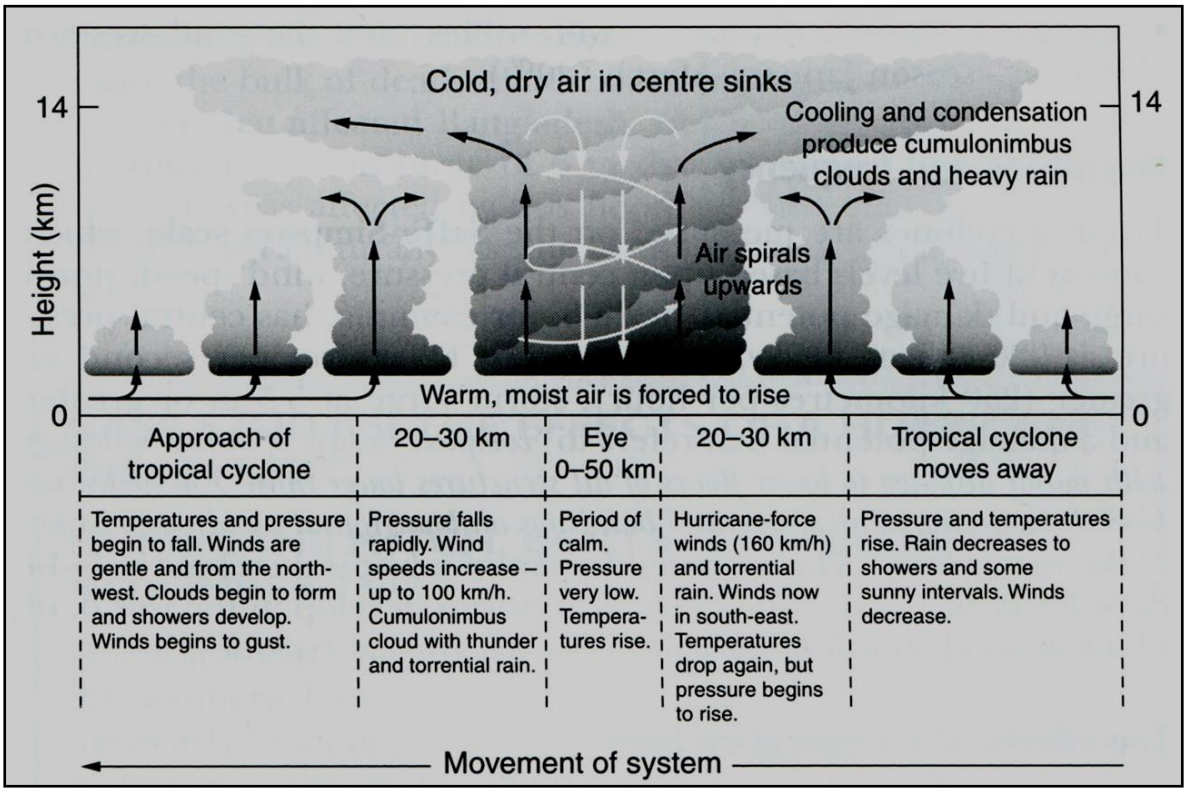
Tropical cyclones are known as hurricanes and typhoons in different parts of the world. They are known as hurricanes over the North Atlantic Ocean, cyclones over the Indian Ocean and typhoons over the Pacific Ocean.

(B) The Structure of a Tropical Cyclone

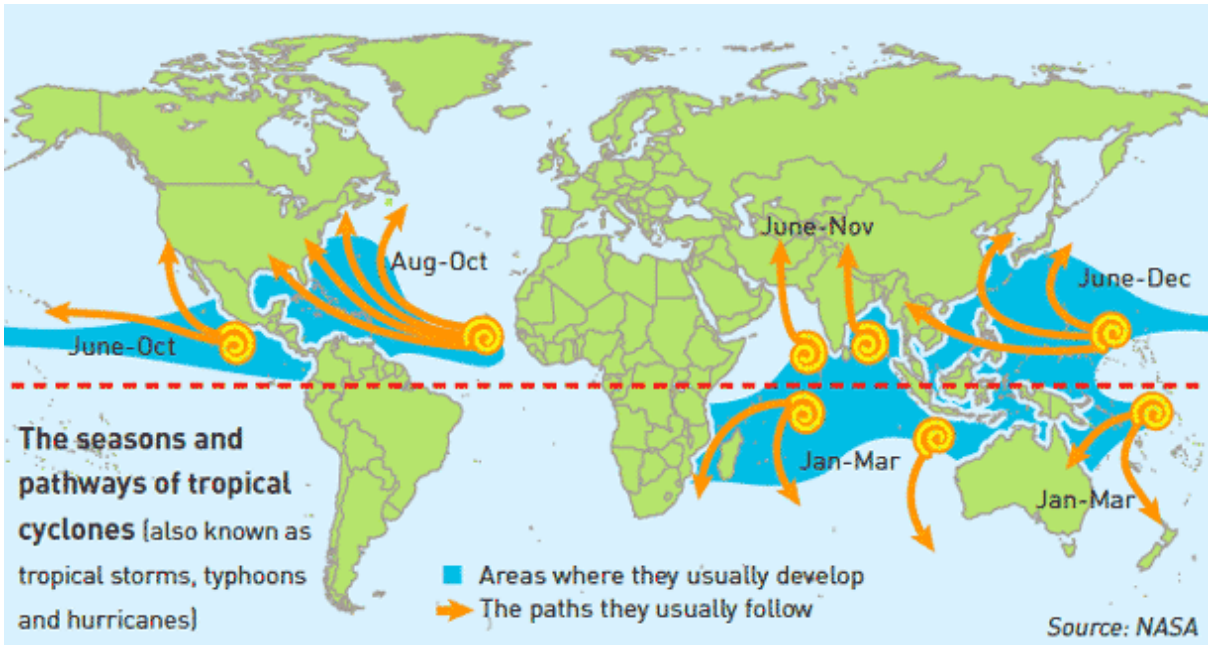


Structure	Tropical cyclones have distinctive sections: the eye, eyewall and rainbands (Figs. 3-6) The centre of a tropical cyclone is called the **eye**. The eye is 30-50km in diameter, has very low pressure, light winds, no clouds and no rain because of subsiding air in the eye. Due to the calm, sunny and clear conditions at the eye of the storm, it gives a deceiving impression that the storm has passed. The **eye wall** is a band around the eye, where there is spiralling rising air, very strong winds around 160km/hr, storm clouds and torrential rain. The greatest wind speeds and rainfall intensity within the tropical cyclone are found in the eye wall. **Rainbands** are found away from the eye wall. Spiralling rising air is also found here. However, wind speed and rainfall intensity is lower than in the eye wall, and temperatures are higher. Note: 1. Air is only subsiding at the eye, while rising at different parts of the tropical cyclone. 2. Temperature is highest and pressure is lowest at the eye. 3. Heaviest precipitation and greatest wind speed is at the eye walls. 4. Due to the tropical cyclone spinning anti-clockwise in the Northern Hemisphere, upon contact with the tropical cyclone, wind direction is from the north-west, followed by calm conditions at the eye, followed by wind direction from the south-east on the other side of the tropical cyclone (i.e. wind directions are reversed on opposite sides of the tropical cyclone).
Size	The diameter of the whole tropical cyclone may be as much as 800km across in diameter, and in terms of height it normally reaches all the way to the tropopause.
Associated	As the storm is passing over land, the weather phenomenon experienced is strong wind blowing from a prevailing direction bringing with it rain and storm surges. The high

Weather conditions	intensity rainfall may exceed 500mm in 24 hours (Note: For reference, Singapore's average total annual rainfall is 2340mm). This is followed by a period of calmness when the eye passes before the return of destructive prevailing winds and intense rain again. However, this time the prevailing wind will be from the opposite direction.



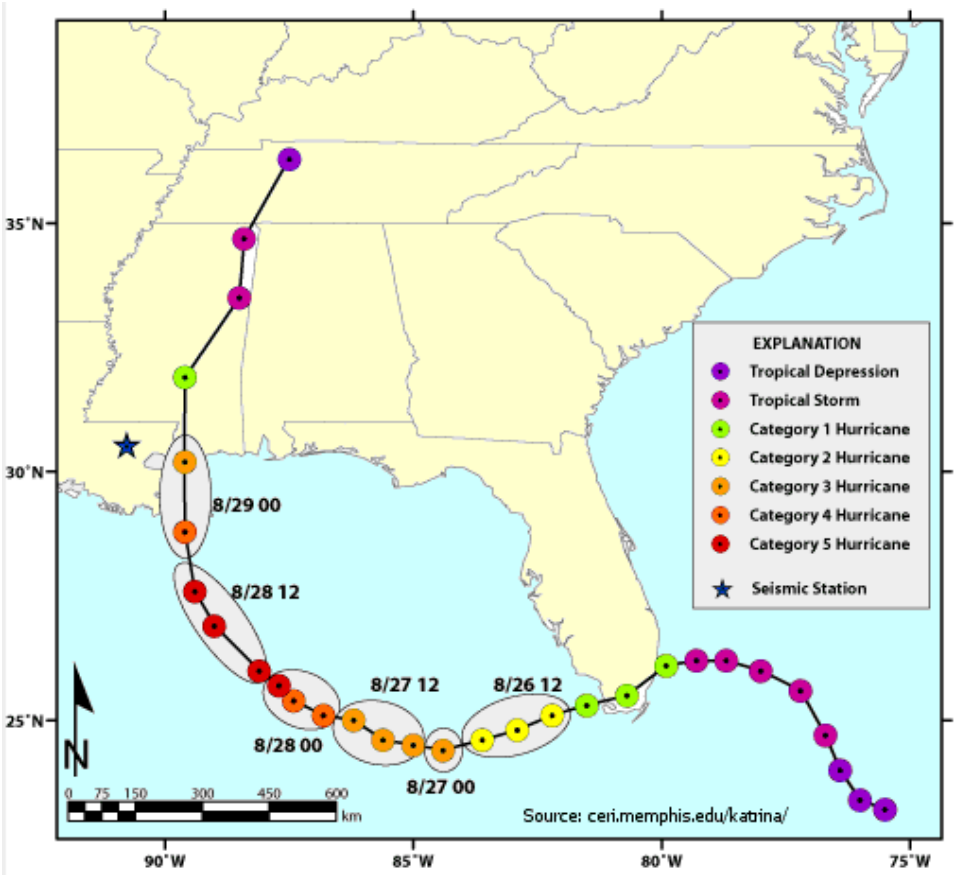
(C) Spatial and Temporal occurrence of Tropical Cyclones



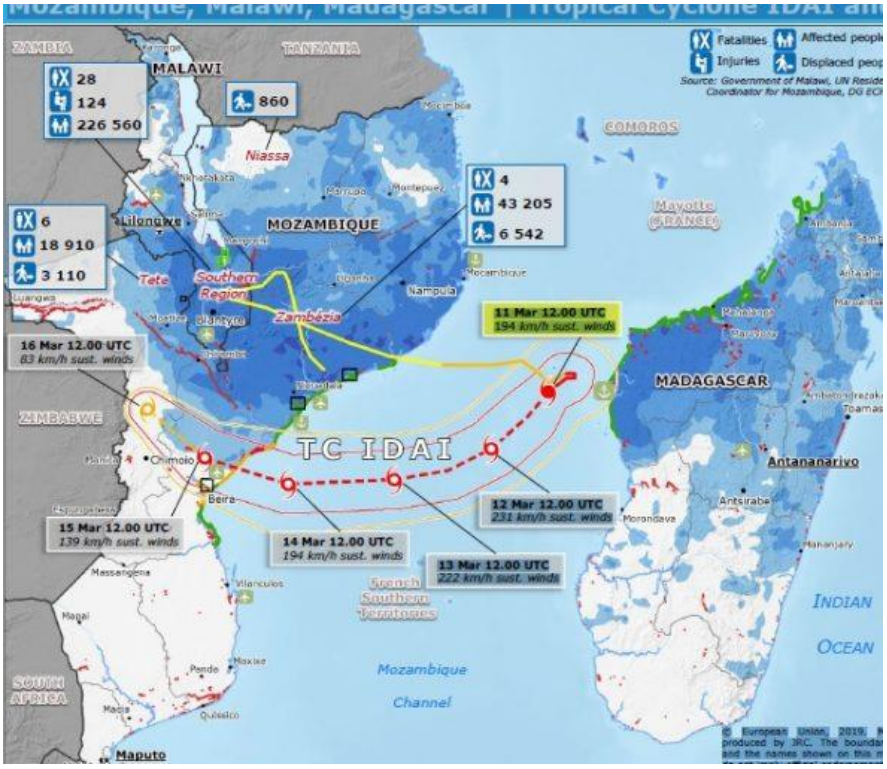
Location	Tropical cyclones normally form 5-20^0 North & South of the equator. They do not form at the equator because sufficient Coriolis force is required to cause the winds to spin. Also do not form at higher latitudes because there is insufficient heating of the ocean to cause intense instability and high levels of evaporation. They generally form over the Western parts of oceans where surface temperatures are warmest (Recall: Walker circulation). Most of these systems actually form between 10-30^o away of the equator, and 87% form no farther away than 20^o latitude N/S. Because the Coriolis effect initiates and maintains tropical cyclone rotation, tropical cyclones rarely form or move within about 5^o of the equator, where the Coriolis effect is weakest. It seldom form beyond 20^o because of the STHPB.
Course	Tropical cyclones generally move westwards and polewards, often on erratic and unpredictable courses. This is due to the easterly trade winds at the low latitudes which blow from east to west. They also tend to move away from the equator due to the Coriolis force.
Duration	The average lifespan of a tropical cyclone is 7 to 14 days. The tropical cyclone rapidly dies off once the source of heat is removed such as when it moves over colder water, or a land surface leading to insufficient supply of moisture.
Timing	Tropical cyclones occur during the summer and early fall, as these months are the hottest months of the year allowing the sea surface temperature to be warm enough Thus, tropical cyclones develop from June to October in the northern hemisphere, and from December to May in the southern hemisphere.
Direction of rotation	Tropical cyclones in the northern hemisphere will spin anti-clockwise in the northern hemisphere and clockwise in the southern hemisphere, due to the Coriolis force.

Examples of Spatial and Temporal distribution of tropical cyclones

Hurricane Katrina (August 2005) Northern Hemisphere → Approaching New Orleans



Cyclone Idai (March 2019) Southern Hemisphere → Approaching Mozambique



(D) How do tropical cyclones form?

Tropical cyclones start as small-scale tropical depressions, an area of low pressure due to warm air rising. Thunderstorms result, which persist for at least 24 hours, and may develop into tropical storms with greater wind speeds of up to 118km/hour. Only about 10% of tropical depressions become tropical cyclones, with wind speeds of at least 119km/hour.

In order for tropical cyclones to form, there are several essential conditions that must be present first: (Note: When explaining formation of tropical cyclones, you must state the essential conditions required first.)

Surface and Atmospheric Conditions required for the Formation of Tropical Cyclones

1) **Ocean water that is heated to at least 28^{0}C to a depth of 60m** (note: some books state 26^{0}C/27^{0}C and 50km/70km depth, both are acceptable but be consistent in your answers). The high temperature is essential because waters of such temperature will cause the overlying air to become unstable and rise to form clouds. Furthermore, the high water temperatures will cause a high rate of evaporation of the ocean water and make the air more humid. The large depth of high temperature of ocean water is required as the storm winds will stir up the ocean water and bring deeper cooler waters to the surface. Thus, the deeper water needs to be sufficiently heated in order to continue the formation of the tropical cyclone. As a result, tropical cyclones usually form over tropical waters where there is sufficient heating of the ocean waters to a great depth. In fact, two-thirds of all tropical cyclones form between 10^0 and 20^0 North / South of the equator.

2) **There must be sufficient Coriolis force acting on the winds**. This condition is essential because sufficient Coriolis force enables the winds to be deflected and spiral around a low-pressure centre. Thus, tropical cyclones rarely form at less than 5 degrees North / South, due to the insufficient Coriolis force at such low latitudes below 5 degrees (Recall: The greater the latitude, the greater the Coriolis force).

3) **Air up to about 5500m needs to have a humidity of at least 75% when it is pulled into the storm.** This condition is essential because there must be a large supply of moisture to provide the latent heat of condensation to drive the storm formation and provide heavy rainfall.

4) **Pre-existing winds (those not created by the storm) should be coming from nearly the same direction and speed at all altitudes.** This means that there must not be strong winds that are disrupting the organised pattern of convection and disperses heat and moisture, which are necessary for the growth of the storm. This condition is essential because if the rising air is vertically sheared and disrupted, the supply of moisture and latent heat of condensation will be lost, weakening the tropical cyclone.

5) **The upper troposphere above the developing storm should be an area of relatively high pressure.** This helps to pump away air rising in the storm and strengthens the convection cycle created, resulting in greater wind convergence at sea level and increasing wind speed.

Formation of tropical cyclones (Fig. 7)

1. Initially, the warm sea surface heats up the air above, causing very large parcels of moist air to rise up into the atmosphere. Because of the intense heating over the ocean, the air contains large amounts of water vapour. As the air rises, water vapour condenses into clouds which releases latent heat of condensation into the surrounding air.

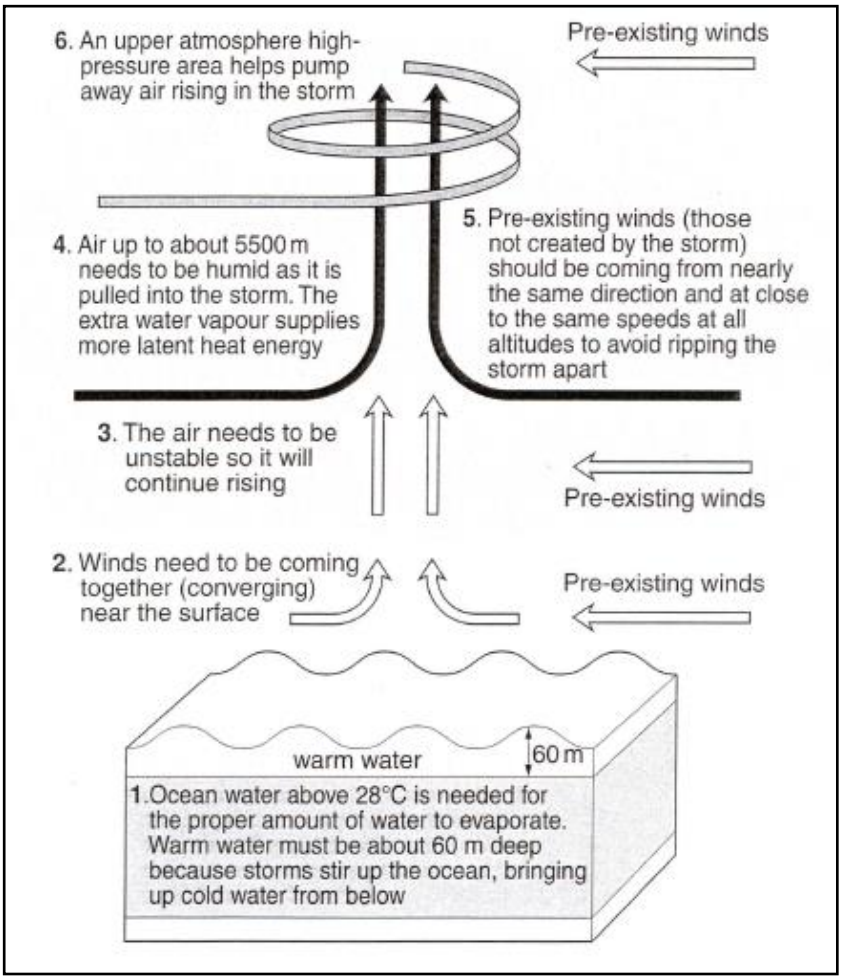


Fig. 7 - Formation of Tropical Cyclone

2. The vast amount of latent heat that is released will cause air to become even warmer than the surrounding atmosphere causing it to rise and fuelling greater instability. This creates a larger pressure gradient between the upper troposphere and the surface, causing more uplift of warm moist surface air above the ocean. The whole process becomes self-sustaining, as the more air that is sucked up and condenses, the more energy is released to heat the storm. This repeated cycle causes the storm to intensify and wind speeds to keep increasing.

3. The rising air leaves an area of low pressure at sea level and easterly trade winds (i.e. blowing from east to west) will then converge towards these low pressure cells. The convergence, together with the unstable air causes upward movement of air (i.e. convergent and convectional uplift).

4. Coriolis force causes the winds to deflect and rotate as they converge and rise. The direction of rotation depends on the hemisphere in which the cyclone is located. The upward motion of air

is marked by air rotating in an anticlockwise in the northern hemisphere and clockwise in the southern hemisphere.

5. Once wind speeds reach 119km/h the storm is considered a tropical cyclone. This cycle continuously repeats itself until the tropical cyclone passes over cool water, land or there is high wind shear to weaken it.

6. Due to the high pressure present at the upper troposphere, most of the rising air flows outward near the top of the storm. A small proportion of the air sinks towards the centre of the storm and warms adiabatically, creating an area of light winds and clear skies (Recall: Clouds cannot form if the air is not cooled to dew point). Once the tropical cyclone reaches maturity, a central eye develops.

EFFECTS OF TROPICAL CYCLONES

Tropical cyclones are a major threat to human life, property and economic activities. There are four main causes of damage due to a tropical cyclone: 1) high velocity winds, 2) heavy rainfall and 3) storm surges.

1. **High velocity winds** often exceed 150km/hour and have been known to exceed over 300km/hour. Such winds can bring about the collapse of buildings, cause structural damage to roads and bridges, bring down transmission lines and devastate agricultural areas. High winds can hurl large pieces of debris around, which often cause a number of deaths. In the Caribbean, strong winds can devastate tree crops such as bananas, on which several countries depend on for a large proportion of their income. For example, in 1979, Hurricane Allen destroyed over 90% of the banana plantations on St Lucia and St Vincent.

2. **Heavy rainfall**, which can exceed 800mm in a single day, causes severe flooding and landslides. This is very common in Hong Kong. This causes considerable damage to property and loss of life.

3. A **storm surge** is a raised dome of water typically 60-80km across and up to 8m above normal high tide. It is by far the most devastating effect of a tropical cyclone as it can wipe out whole coastal communities. **Storm surges creates coastal flooding**. It is caused by a combination of the very low pressure having a 'suction effect' on the sea, and the extremely strong winds. In 1970, a storm surge of 7m swept over 26,000km^2 of low-lying Bangladesh killing over 225,000 people and leaving 2.5 million homeless.

   Storm surges can also cause the intrusion of sea water onto to agricultural land as well. The salt contamination causes can render huge parcels of land becoming useless of cropping. LDCs often suffer the greatest loss through flooding and storm surges that cause damage to cash crops.

   The contamination of water supply by seawater can lead to a severe shortage of freshwater. Freshwater supplies may also be cut off because of the damage to structures that support the supply of freshwater. This can lead to an increase and spread of water- borne diseases through the consumption of contaminated water and collapse of the sanitation system.

Note: Storm surges and tsunamis are NOT the same. A storm surge is an onshore surge of ocean water caused primarily by the winds of a storm (most often a tropical cyclone) pushing sea water onto the coast. Tsunamis are waves generated by disturbances on the ocean floor caused most commonly by earthquakes. As the tsunami wave (or series of waves) moves into shallow water, it builds in height and rushes onto the land. Thus, storm surge and tsunamis differ in terms of how they are formed.

HOW DO THE EFFECTS OF TROPICAL CYCLONES DIFFER BETWEEN PLACES?

The impacts of tropical cyclones are generally more severe in poorer countries due to several reasons:

1) There is more low-quality housing in poorer countries, which are destroyed more easily by strong winds and flooding.
2) The infrastructure is often worse in poorer countries. For example, poor quality roads make it harder for emergency services to rescue people, which leads to more deaths.
3) More people in poorer countries depend on farming. If crops and livestock are destroyed lots of people will lose their livelihoods, and some might starve.
4) Poorer countries have lesser financial ability to protect themselves against tropical cyclones as management measures such as building flood defences require high costs. They also have insufficient money or resources to respond to tropical cyclones (e.g. food and helicopters), hence more people are affected.
5) Healthcare is often worse in poorer countries. Many of the hospitals often lack sufficient supplies to deal with the large numbers of casualties after a tropical cyclone, causing many deaths from treatable injuries.

Below are two important case studies of the effects of tropical cyclone on a DC compared to a LDC:

Tropical Cyclone	**Hurricane Sandy** **(Category 2 Tropical Cyclone)**	**Typhoon Haiyan** **(Category 5 Tropical Cyclone)**
Date	29th Oct 2012	8th Nov 2013
Location	Northeast USA (New York and New Jersey)	Philippines (Province of Leyte and Samar, City of Tacloban seriously affected)
Preparation	• Well forecasted: European Centre for Medium-Range Forecasts (ECMWF) forecasted Sandy 1 week prior to landfall → National Oceanic and Atmospheric Administration (NOAA) launch special radiosondes to better track Sandy • Several states prepared 4 days before storm arrived. New York City declared state of emergency on 26th Oct 2012. 50, 000 Air Force and National Guard members on stand-by. About 5000 flights were cancelled and many schools closed	• Philippine Atmospheric, Geophysical & Astronomical Services Administration, indicated the storm could have winds as strong as 260 km/hr • Newly-installed Doppler radar stations gave clear picture of the storm's size, force of winds and the turbulence of water within • The military readied 3 transport aircraft with supplies, 32 helicopters; 20 Philippine Navy ships were put on a state of heightened readiness

	• 375 000 residents were evacuated before their homes in New York before hurricane reached land. 72 evacuation centres set up around NY City	
Social Effects	• > 200 people killed • 305 000 and 346 000 houses damage/destroyed in New York and New Jersey respectively by flooding and fire • 8.1 million homes lost electricity, outages affected people from 17 states.	• > 5300 people killed • > 18 000 people injured • >1600 people missing • > 1 million houses destroyed • > 4 million people made homeless • 117 criminals escaped
Economic Effects	• 2nd costliest hurricane since 1900: Total around US$65 billion of damage. • Stock exchange closed for 2 consecutive days → • Estimate US$8.3 billion business losses in New Jersey, 19 000 small businesses sustained damage > US$250 000 • >630 storm-related oil spills, increasing the price of fuel.	• Total > US$560 million of damage. • > 5.1 millions people lost their livelihoods. • >1 million farmers affected – many coconut plantations (which accounts for nearly half of Philippines' agriculture exports) destroyed → takes 4-5 years to recover productivity
Environmental Effects	• Flooding destroyed some coastal habitats such as coastal wetlands and salt marshes • Storm surge washed toxic chemicals into New York Harbour. 336 000 gallons of diesel fuel spilled into Arthur Kill waterway (in New York) after a storage tank ruptured during the storm surge → affect salt marsh habitat	• Typhoon Haiyan knocked down Power Barge 103 of Philippines' National Power Corporation in Estancia, Iloilo • Coastal habitats such as mangrove forests were damaged.
Short-term Response	• 70+ disaster recovery centres opened in 4 states to provide information on assistance to survivors • About 23,000 people were given temporary shelter immediately after the storm • US Department of Transport released US$17 million to begin repairs of roads, bridges and bridges 2 days after storm hit. • American Red cross mobilised 1700 disaster workers from all over country who served > 25000 meals to refugees	• Philippines's government declared state of national calamity on 11 Nov 2013, 3 days after Typhoon Haiyan made landfall • Airlift and transfer of some survivors to Cebu and Metro Manila • International aid: UK Department for International Development (DFID) activated funding to get £8 million to be distributed by humanitarian charities (e.g. Oxfam, World Vision, Habitat for Humanity etc.), 6 UK aid planes sent over to Philippines.

Long-term Response	• Updating of flood maps for the first time since 1983 • Launch of "rebuild-by-design" competition to make Sandy affected areas more resilient • Flood protection measures for all buildings above 7 stories high in New York by 2030	• International Labour Organisation (ILO) rallies partners to donate to livelihood recovery in Philippines → at least US$270 million donation collected to aid in debris clearance through cash-for-work schemes, reconstruction and rehabilitation of infrastructure to regain livelihood.
Evaluation	High impact due to: 1. 3200km diameter, hitting shore head-on and coincidence with high tide when storm makes landfall → strong winds and higher than expected storm surge to hit inland areas 2. Position of New York and New Jersey on the right of hurricane eye (strongest winds) and their shallow habour → aggravate damage 3. Occurring in an economically developed area (more infrastructure lost)	High impact due to: 1. Vulnerable topography and geographical location – mostly below sea level, nestled between Pacific Ocean in the East and Gulf of Leyte in the South + sheltered by mountains in the North and West → geographically trapped by nature disallowing them to properly escape when typhoon and storm hit 2. Improper conveyor of severity of typhoon – people did not understand terms used by authorities 3. Reluctance of people to heed warnings also due to previous false alarms, ignorance of severity of storm, protection of property 4. Inefficient aid distribution procedures and corruption in government affecting aid distribution