RESEARCH Explore examples of the different perceptions of people to hazards:

- Acceptance that the environment is in control and nature cannot be changed. An example is the withdrawal of protection for some coastal areas in the UK.
- Dominance – the idea that humans can provide 'technological fixes' and control the environment by engineering and technology. This was the attitude in California for a time last century when the authorities were so confident that major earthquakes could be prevented by lubricating faults with oil that they built a large hospital next to the San Andreas Fault.
- Adaptation – people perceive that they can adapt their environments to prevent hazards.

Hazards resulting from atmospheric disturbances

Global distribution of areas most at risk from large-scale tropical atmospheric disturbances and small-scale atmospheric disturbances

Hazardous **tropical cyclones** are very large low pressure systems with wind speeds of above 119 km/h and very deep low pressures, which can be as low as 880 mb. They have stronger winds than tropical storms, which have wind speeds between 63 km/hr and 119 km/hr. Tropical cyclones are called **hurricanes** in the Caribbean Sea, Gulf of Mexico and west coast of Mexico, **cyclones** in the Indian Ocean, Bay of Bengal and northern Australia and **typhoons** in the South China Sea and west Pacific Ocean. They will be referred to as cyclones within this chapter, except where a specific geographical context makes the use of typhoon or hurricane more appropriate. With the exception of the hurricanes that affect the west coast of Mexico, tropical cyclones affect the east coasts of continents and are most hazardous to the Caribbean islands and the densely-populated, low-lying coasts of Bangladesh, the Bay of Bengal and south-east USA.

Tornadoes occur on every continent except Antarctica but are most frequent in the Great Plains and eastern parts of the USA in a belt known as Tornado Alley. They can occur at any time but are most frequent in the USA between 16:00 and 21:00 hours in May and June after a long period of heating of the land.

The most disastrous tornado occurred in Bangladesh in 1989 when over 1000 people died. Tornado deaths in Bangladesh are about double those in the rest of the world combined.

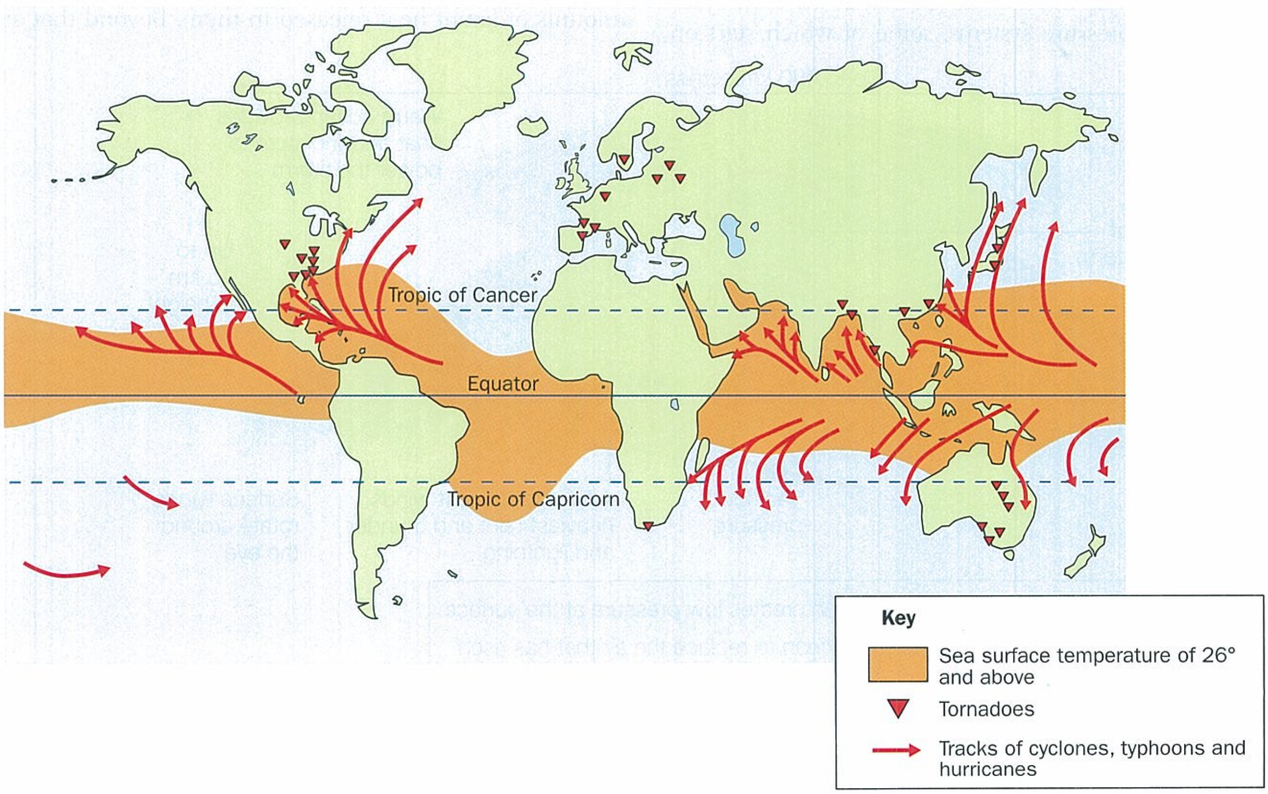


Fig. 9.40 The global distribution of large-scale tropical cyclones and small-scale tornadoes

Processes causing the formation of tropical cyclones

Having ferocious whirlpools of air, torrential rains and associated **storm surges**, flooding and landslides, tropical cyclones are very hazardous. They form over warm oceans between May and November in the northern hemisphere and between November and May in the southern hemisphere. Sea surface temperatures have to be a minimum of 26°C (according to the latest NASA figure) to a depth of at least 50 m. They form in the summer when the noonday sun is high in the sky, with maximum occurrence in late summer and autumn after a long period of intense heating. The warm sea surface is important; it warms the air in contact with it so that large amounts of water vapour evaporate into the air that moves into the storm. This moisture fuels the growth of the storm, which can only happen if the air is unstable (warmer than the air at the same height), so it will continue to rise. The heated moist air expands, becomes lighter and rises. The rise intensifies because of the added latent heat of condensation.

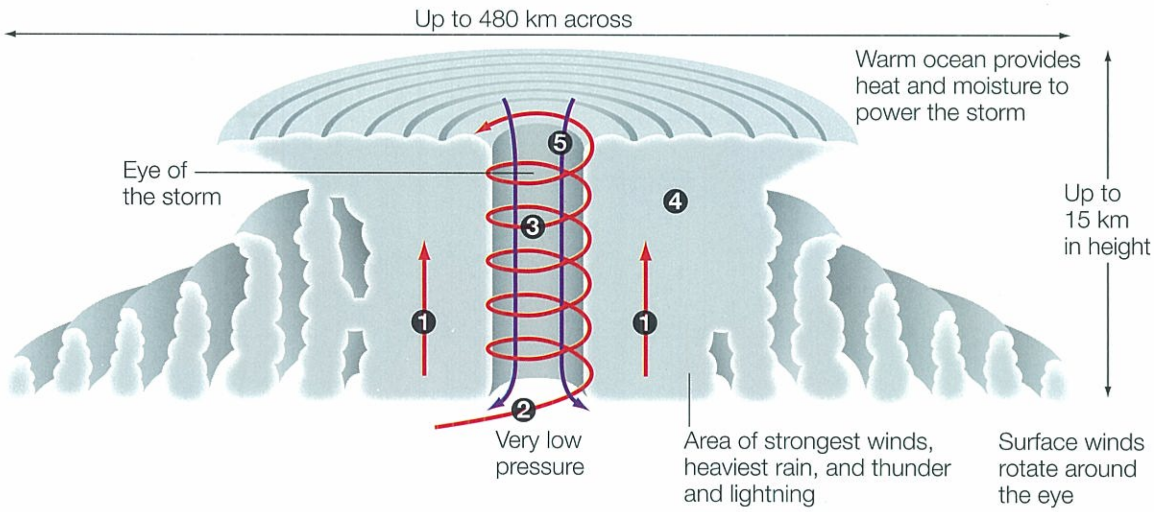
Tropical storms form only between 5° and 20° north and south. They do not form nearer the Equator because Coriolis force is needed to deflect the converging rising air into a spin and the effect of the Earth's rotation is not strong enough near the Equator. In higher latitudes the sea is not warm enough for their formation. There are no strong upper atmosphere winds in these latitudes, so the air can rise to the tropopause.

Cyclones form towards the west sides of the tropical oceans from small low pressure systems, some of which start on the east sides of the oceans and intensify as they move west. Only a few of these easterly waves develop into cyclones with winds of 119 km/h or above. Westwards air movement also results from air flowing out of the sub-tropical high pressure cells, such as the Bermuda high in the north Atlantic.

The effect of the Coriolis force can be seen in the direction of movement of the tropical storms, as they generally deflect to the right in the northern hemisphere and to the left in the southern hemisphere. However, the system is very dynamic and can alter course if very strong winds exceed the Coriolis force and change the direction of rotation. Storms gradually reduce in intensity over cooler seas and do so rapidly over land, where they lose their source of energy, water vapour intake.

These processes intensify while the system remains over warm water because, as the rising air cools to below dew point, condensation releases latent heat. This causes the air to rise even faster, the low pressure to lower even more and the moisture-laden wind to rush into the low pressure centre even faster. The lower the pressure, the more the air is drawn into it and the greater its power.

Very heavy rain falls from the thick cumulonimbus clouds produced by the uplift. At the tropopause the air cools and some sinks, forming the **eye**, a calm, sunny area in the centre of the storm. Other air moves away from the high pressure at the tropopause. A very dense circular band of cumulonimbus cloud known as the **eyewall** of the system surrounds the eye. The eyewall has the most powerful winds and deepest convection, with towering rain clouds that rise above the rest of the cyclone because of the vast amounts of latent heat released in them. Beyond that are



1 Heated, very moist air rising from the ocean creates low pressure at the surface.
2 More warm, moist air moves in over the ocean to replace the air that has risen.
3 The spiralling mass rises rapidly.
4 Thick cumulonimbus clouds are produced from which very heavy rain falls.
5 The air cools at high levels and sinks, forming the eye in the centre of the storm.

Fig. 9.41 Processes in the formation of cyclones circular bands of cumulonimbus clouds, separated by areas clear of cloud where air is subsiding into denser air, causing **adiabatic warming** by compression.

Weather in a cyclone

14. Use Fig. 9.42 to describe the changes in weather and hazardous conditions as a tropical cyclone passes over: as the eye approaches, in the eye and after the eye. Include references to time.

Hazards from large-scale atmospheric disturbances

The degree of hazard from tropical cyclones depends partly on how frequently they occur in the same area, their magnitude and the location of the area affected. The most powerful storms are not necessarily the most hazardous.

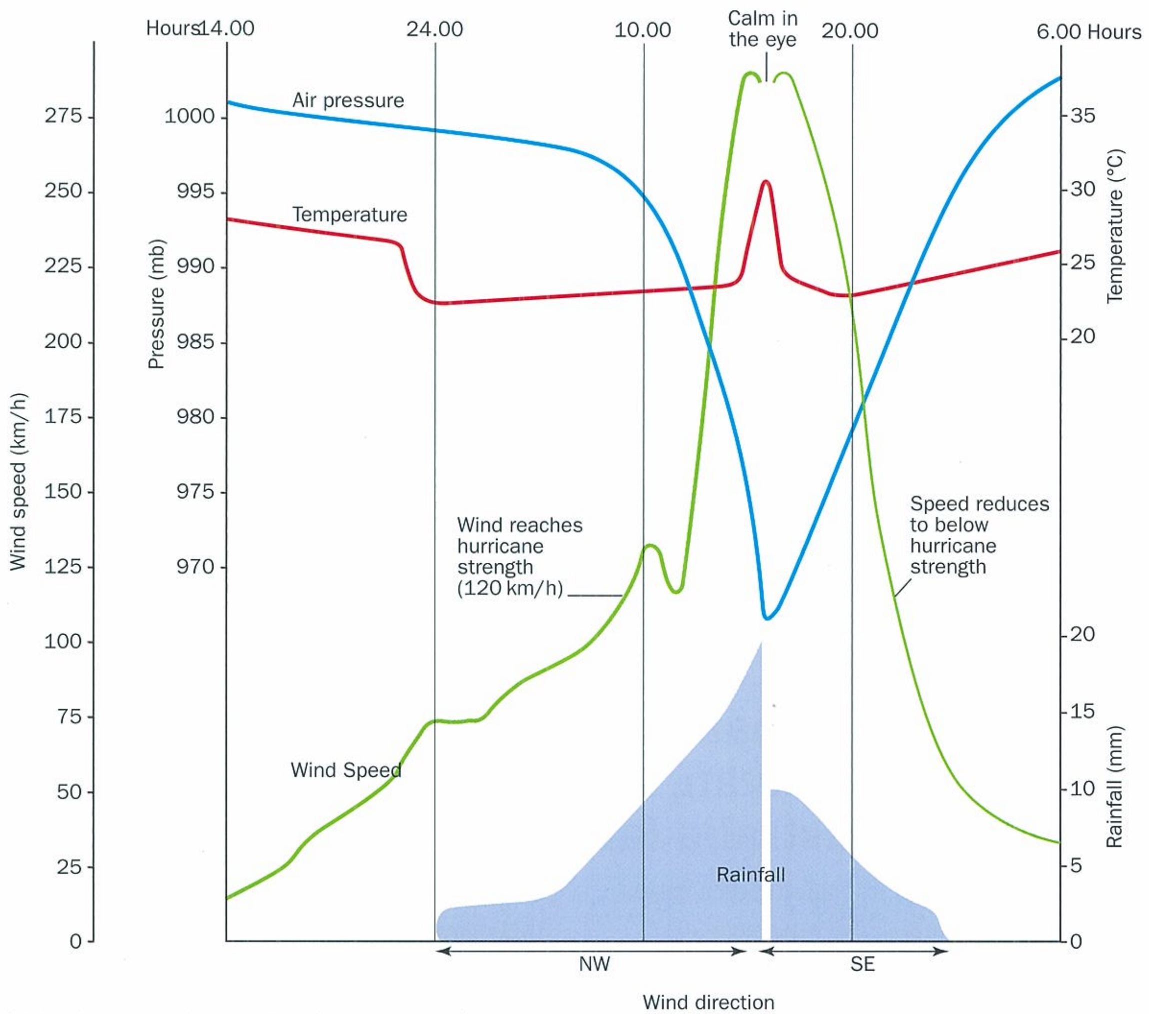


Fig. 9.42 Weather recordings during the passage of a cyclone

Category	Wind speed (km/h)	Damage
1	120–153 (very dangerous)	Well-constructed buildings could have roof damage. Large tree branches may break. Extensive damage caused to power lines.
2	154–177 (extremely dangerous)	Buildings have major roof damage. Shallow-rooted trees are uprooted. Nearly all power is lost.
3 (major)	178–208 (devastating)	Buildings have major roof damage. Many trees are uprooted or broken, blocking many roads. Electricity and water supplies are cut for several days.
4 (major)	209–251 (catastrophic)	Roofs and sides of buildings are extensively damaged. Most trees and power poles are snapped or uprooted. Most roads are blocked, cutting off residential areas. Power is lost for months. Much of the area is uninhabitable for weeks.
5 (major)	252 or higher (catastrophic)	Many buildings are destroyed. Residential areas are cut off by fallen trees and power poles. Most of the area is uninhabitable for weeks or months.

Table 9.9 The Saffir-Simpson classification of the magnitude of tropical cyclones

High winds

The **Saffir-Simpson scale** (revised 2012) indicates the potential damage to structures by sustained wind speeds in tropical storms of cyclone strength.

The **Dvorak technique** has also been developed to estimate cyclone intensity on a scale from 1 (the least) to 8, based on satellite images of patterns in the weather systems, in particular the difference between the temperature within the eye and the coldness of the surrounding thunderstorm clouds. The greater it is, the stronger the tropical cyclone.

Storm surges and coastal flooding

Storm surges, abnormal rises of seawater, are secondary hazards of tropical cyclones. The strong winds drive the surge, which rises in shallow water and pushes inland, causing flooding. The highest part of the surge is where the strongest winds are. The lower the atmospheric pressure, the higher the surge because air rises in low pressure systems, taking weight off the sea surface, allowing it to rise. The surge will be especially high when:

- the storm has strong onshore winds
- it approaches the coast at right angles
- the coastline has bays and inlets to funnel the water
- the sea floor is gently sloping, with a wide continental shelf
- there are few obstructions, such as spits and islands, to slow the flow of water
- the storm coincides with high tide.

The greatest risk from cyclones is at the coast, because they lose power as they pass over land. The slower the cyclone moves, the greater the damage. Also, in the northern hemisphere the greatest risk is for the cities on the right of the eye's path because there the travel speed is added to the speed of the winds that are rotating anticlockwise.

Intense rainfall

Places crossed by the eye of a cyclone experience two bands of intense rainfall from the cumulonimbus clouds around the eye. This causes severe river flooding and mass movements, especially if the system is slow moving. River flooding is illustrated in the case study of Cyclone Yasi.

Mass movement

Super-Typhoon Durian, a category 5 storm, affected the Philippines in November 2006. Nearly all the 1200 deaths occurred when torrential rains saturated volcanic deposits on the slopes of Mayon volcano, causing mudflows that raced down the steep slopes onto the towns beneath. People had no time to escape as entire villages were buried under volcanic debris.

15. (a) Explain why Super-Typhoon Haiyan and Cyclone Yasi (Table 9.10) occurred at different times of the year.

(b) Compare and contrast the facts about Super-Typhoon Haiyan and Cyclone Yasi given in Table 9.10.

Case study: A comparison of intense tropical storms: Super-Typhoon Haiyan, Philippines (an LIC) and Cyclone Yasi, Australia (an HIC)

	Super-Typhoon Haiyan	Cyclone Yasi
Date	7 November 2013	3 February 2011
Width	600 km	1450 km
Category	both 5	
Dvorak intensity	8.1	6.5
Central atmospheric pressure	both 930 mb	
Maximum sustained wind speed	314 km/h	285 km/h
Highest storm surge	both 7 m	
Deaths	more than 6000	1
Homeless	nearly 2 million	a few thousand
Damage to structures	90 per cent of some towns destroyed	4000 buildings severely damaged
Total number of people affected (estimates)	11 million	400 000
Estimated cost	$US 2.9 billion	$US 3.6 billion

Table 9.10 A comparison between Super-Typhoon Haiyan and Cyclone Yasi

Case study: Super-Typhoon Haiyan (local name Yolanda), Philippines, 2013

A super-typhoon is a storm in the north-west Pacific with sustained wind speeds of 242 km/h or more.

Development

Haiyan grew from a tropical storm as it moved westwards, stirring up 15-metre-high waves. It reached its maximum intensity as it made landfall at Guiuan on the east coast of the central Philippines as the 25th typhoon of the season. It was so intense that it was off the Dvorak scale at 8.1.

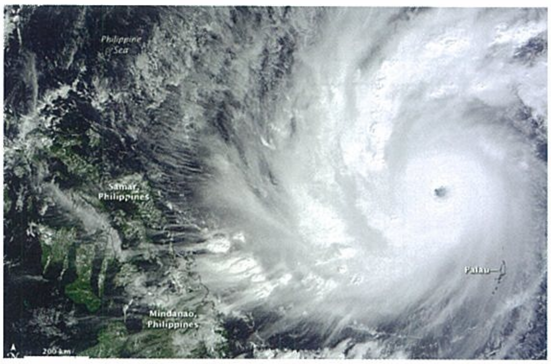


Fig. 9.43 Satellite image of Super-Typhoon Haiyan just before landfall in the Philippines. The eye is clearly visible, together with thick bands of eyewall cloud that produced powerful thunderstorms and very heavy rain. Most places had more than 140 mm in a day. The air is circulating anticlockwise in the northern hemisphere as it is being drawn in to the low pressure centre

Prediction, monitoring and perception of risk

Alerted by satellite images and the track of the typhoon, public storm warnings were issued and shelters opened but there were not enough for everyone and some of them were damaged beyond use by the storm. Many were very basic and not well stocked with essential supplies. Only half a million people were able to use them. The government advised evacuation but did not make it mandatory, so many stayed in their homes because they were afraid of looting. Many lives were saved by the major of Guiuan who constantly urged the residents to evacuate. The army, air force, navy and hospitals were on standby and disaster response teams were sent to areas expected to be affected.

Primary and secondary impacts on lives and property

Fortunately, the system moved so quickly across the country that rainfall totals did not produce the devastating floods and landslides that usually cause the most damage in Philippine typhoons. Although mudflows were less severe than usual, coastal areas were described as wastelands of mud and mudflows and debris slides destroyed many buildings in Guiuan.

Nearly all the damage was caused by the storm surge when Haiyan moved on to make landfall on the islands of Samar and Leyte. It was made more dangerous because Tacloban, a city on land less than 5 m above sea level on the island of Leyte, is on a bay where water was funnelled, causing a greater surge. An inhabitant interviewed on television commented, 'We survived the wind, but could not survive the water', and described it as 'like a tsunami'. The wall of water was over 7 m high and caused almost total devastation, especially in the shanty areas. The first floor of Tacloban City Convention Centre was submerged, drowning many evacuees being housed there. About 90 per cent of the buildings with wooden walls in the poorer parts of Tacloban were destroyed. Even well-built concrete structures had damaged roofs and windows and some were highly damaged. Many people drowned in the streets and many others were injured, as roads became rivers. The floods also swept away bridges and deposited large ships on top of the devastation.

Few buildings in the worst-hit rural areas were left standing. Fallen trees, roofs and tossed-up cars blocked roads. Power lines were destroyed, plunging the area into darkness; four provinces, including Leyte, had no power. Rotting corpses contaminated water supplies and spread disease. Survivors were without shelter, food, water, sanitation and fuel.

As the powerful winds had ripped down telephone lines, the inhabitants were unable to contact the outside world. Satellite images were invaluable for determining which areas were in most urgent need of assistance, as an archipelago over 7000 islands needed checking. Providing aid to them presented massive problems.

Supplies stockpiled for emergency use had been decimated a month before the typhoon when a 7.2 earthquake struck the island of Bohol; where about 5000 people were still living in tents.

After days without relief, desperate people looted for food and water to survive. Tacloban airport had been badly damaged by the storm surge and had lost its electricity supply, so only 20 daylight flights a day could bring in relief supplies and evacuate those in greatest need. Distributing aid was difficult and slow also because of blocked roads. The danger of attack from people desperate to intercept aid supplies caused aid agencies to delay going in until security was improved. Some islands are normally accessible only by ship and plane and planes could not land until runways were cleared of debris. Aid finally reached Tacloban seven days after the cyclone but it was nine days before food was available for distribution. People in the devastated and remote village of Guiuan waited longer. The disaster relief system failed because of a breakdown in power and communications.

Long-term effects

Mangrove forests were replanted along the coast, replacing those destroyed or previously felled because they protect against storm surges and strong winds.

The scale of the disaster was greater because Tacloban's population had trebled in recent years, despite the east coast being known to be the most hazardous for typhoon damage. Afterwards, many inhabitants of Tacloban and Leyte moved to less affected areas. About 20 000 went to Manila and the city of Catbalogan's population doubled because of the influx of refugees. Agriculture, the mainstay of the economy, was badly affected and temporarily slowed the growth of the economy.

Case study: Cyclone Yasi, Australia 2011

Prediction and monitoring

Cyclone Yasi, the fourth cyclone of the 2011 season to hit Australia, began as a tropical low pressure system near Fiji. It grew in intensity as it moved west before turning west-south-west over the warm South Pacific Ocean. It was expected to make landfall somewhere in the state of Queensland along a 300 km stretch of coast that included the cities of Cairns and Townsville, but people as far south as Brisbane were told to be prepared for dangerous flash floods. Heavy summer rain caused by La Niña conditions had fallen for the previous three months, resulting in damaged buildings and 35 deaths in river floods in the Brisbane area. More rain on already-saturated ground was likely to be disastrous. Only three days before Cyclone Yasi's landfall, Cyclone Anthony had uprooted trees and damaged power lines in Queensland.

16. Compare and contrast the cloud patterns in Figs 9.43 and 9.44 and suggest reasons for similarities and differences.

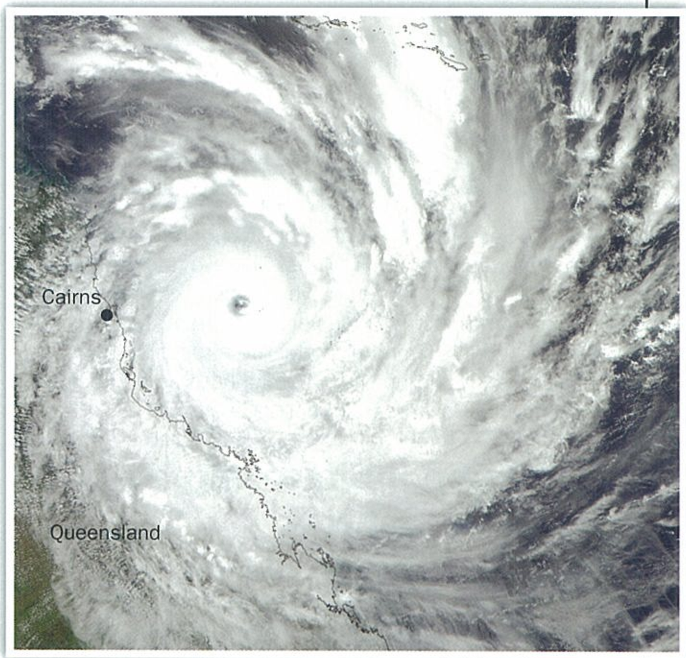


Fig. 9.44 Satellite image showing the enormous size of Cyclone Yasi, which measured 1450 km wide and 19 200 m from ground to cloud top

Perception of risk

- Rigorous building standards had been enforced after a cyclone in Darwin in 1974 killed 74 people.
- The public were informed through the media to prepare for an event worse than anything previously experienced. Storm surge forecasts were given for a high tide situation.
- People in low-lying areas along the coast from Cairns to Townsville were told to evacuate and 29 000 did, including hospital patients moved by the military.
- Schools, universities, airports and ports were closed.

Primary impacts on lives and property

Yasi hit as a category 5 cyclone, destroying the anemometer, radar equipment and communications with the outside world on Willis Island. It moved on to the mainland, affecting 540 km of coast with 400 000 inhabitants, but missed the main cities. It made landfall at midnight at the small settlements of Mission Beach, Cardwell and Tully. Hundreds of homes and businesses, including strongly-built brick buildings, were badly damaged. Strong winds and a 7-metre-high storm surge caused damage up to 300 km inland. Roofs were ripped off and Tully High School was destroyed. At least 226 000 properties were left without power and the water supply system in Townsville failed. Expensive boats and yachts were destroyed. However, because people had followed advice to evacuate, there were few injuries and only one death.

The impact was less severe than it could have been because:

- Yasi turned south just before landfall into a region with low population density, missing Cairns.
- It moved at an unusually rapid speed (35 km/h), which limited rainfall amounts and the length of time structures were battered by the winds.
- As the storm surge did not coincide with high tide, it was 2 m lower than it would have been.

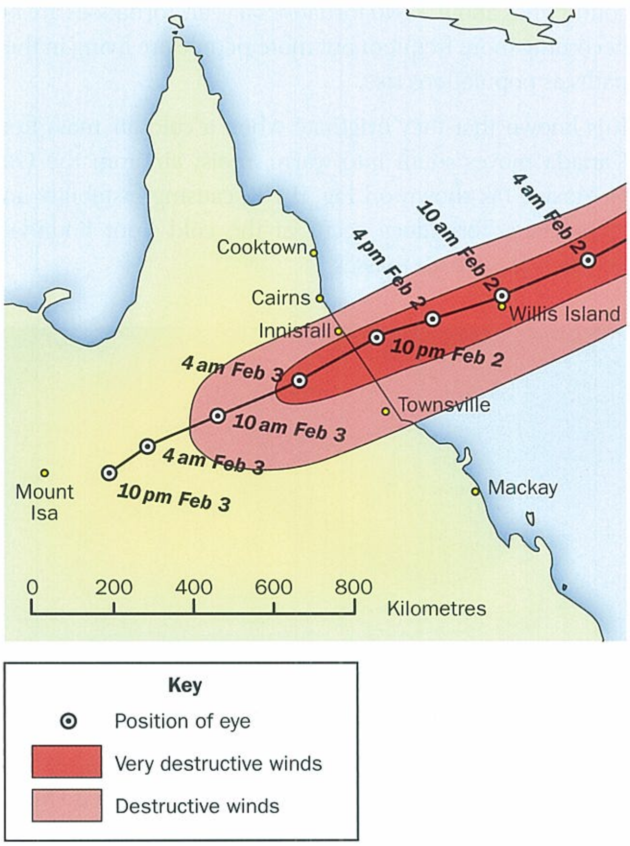


Fig. 9.45 The enormous area affected along the track of Cyclone Yasi

Yasi maintained cyclone strength until more than 700 km from the coast, where it was downgraded to a tropical storm near Mt Isa. It was the costliest Australian cyclone as banana and sugar cane fields were extensively damaged; the state's main exports were lost, including 75 per cent of Australia's banana crop. Estimates put the losses to agriculture, mining and local government at US$ 2 billion, with a further US$ 1 billion cost to the tourist industry.

Record-breaking daily rainfall totals were received over a wide area of Queensland. River floods were extensive and many roads were cut. The highest totals fell from the cloud band south of the eye. Mission Beach recorded the highest daily total of 471 mm and most places had more than 200 mm.

There was little need for urgent relief because of the very good planning by the authorities and the sensible response of residents to warnings and advice. The main problem was to deliver emergency supplies to the many communities isolated by the flooding.

Power supplies were restored quickly and the military helped with the clear-up operation. Nearly 3000 km of road had to be repaired and the railway rebuilt.

Secondary impacts resulting from the primary impacts

- As parks and forests were extensively damaged, the cassowary, an endangered bird species, lost much of its rainforest habitat and food sources.
- Strict building regulations were put in place to make new coastal properties storm surge proof.
- Heavy rain damaged the Great Barrier Reef off the coast, as polluted run-off caused a population explosion of Crown of Thorns starfish, which eat coral polyps.

The people of Queensland were remarkably resilient. Most of the infrastructure was repaired quickly. One year after Cyclone Yasi, farmers were growing bananas and sugar cane again. Bank loans and insurance pay-outs enabled most people to rebuild their homes and re-start their businesses.

In comparison, the resilience of the US city of New Orleans after Hurricane Katrina was considerably less than that of Queensland, partly because many people were too poor to have insurance. A year after the disaster the population of New Orleans was only half what it was before.

Tornadoes

A tornado is a violent, rapidly rotating and fast moving, narrow, funnel-shaped column of cloud that extends from the base of a cumulonimbus cloud to the ground. The very strong rotating wind makes it the most violent type of storm on Earth. Much stronger winds can occur than in cyclones, reaching speeds of 500 km/h. Tornadoes have extremely low pressure and usually last only a few minutes. The pressure falls rapidly as the tornado approaches, is very low in the centre and rises very quickly afterwards, as in a tropical cyclone, but there are differences in scale between these two weather systems. Average central pressure is not known with confidence (because the tornado usually destroys recording instruments) but 850 mb, lower than in a cyclone, is the lowest-recorded central pressure and it was measured dropping extremely rapidly by 100 mb to 850 mb in a few minutes. The majority of tornadoes are less than 600 m in diameter and have a path width of less than 50 m. Although most touch the ground for less than 4 km, the record contact was for just over 350 km.

Most tornadoes become darkened by the debris they pick up. The most dangerous tornadoes occur when the approaching hazard is not noticed because the funnel shaped cloud is hidden by rain or dust.

As well as varying in size, they also vary in shape. **Stovepipe tornadoes** are narrow and cylindrical, whereas very wide ones are **wedge tornadoes** (Fig. 9.50).

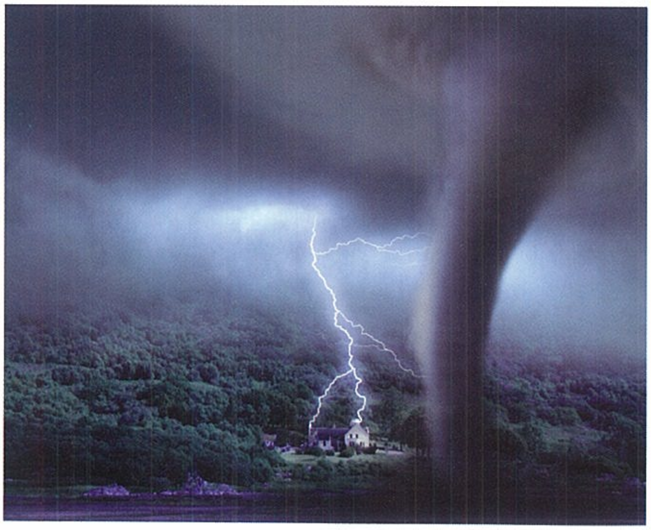


Fig. 9.46 A stovepipe tornado and lightning in Scotland

Although tornadoes are too small to be affected by Coriolis force, most do rotate anticlockwise in the northern hemisphere and clockwise in the southern hemisphere. The rotation is believed to be started by wind shear. Although they generally move in the USA from south-west to north-east, they can take strange, unpredictable paths and can be almost stationary or race across the ground at 80 km/h. Lightning, hail or very heavy rain can accompany them.

Fig. 9.47 A stovepipe tornado in Oklahoma with a dust cloud surrounding its rotating cloud base

Processes leading to the formation of tornadoes

Tornadoes are not fully understood and are being intensively studied in the USA in the hope of being able to give warning of their approach as long as possible beforehand, as the country has about 1200 tornadoes a year. Tornadoes are not becoming more frequent but more people are living in their paths as populations rise.

It is known that they originate when a cold air mass from Canada moves south into warm, moist air from the Gulf of Mexico (as shown on Fig. 9.48), causing instability and turbulence. Tornadoes occur at the cold front boundary between the two air masses.

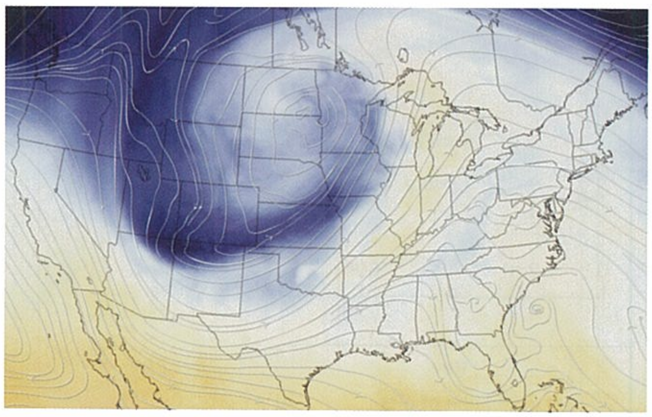


Fig. 9.48 NOAA image of the cold (blue) and warm (orange) air masses at high altitude that caused tornadoes on 20 May 2013, together with lines showing the high altitude wind pattern

It is also known that tornadoes form from rotating **supercell thunderstorms** and always come from a cumulonimbus cloud. However, only 20 per cent of supercell thunderstorms develop tornadoes. They form in the warm, moist air, usually with a temperature in excess of 18 °C. Supercell thunderstorms are extremely violent and have large updrafts extending to the top of the cloud. These

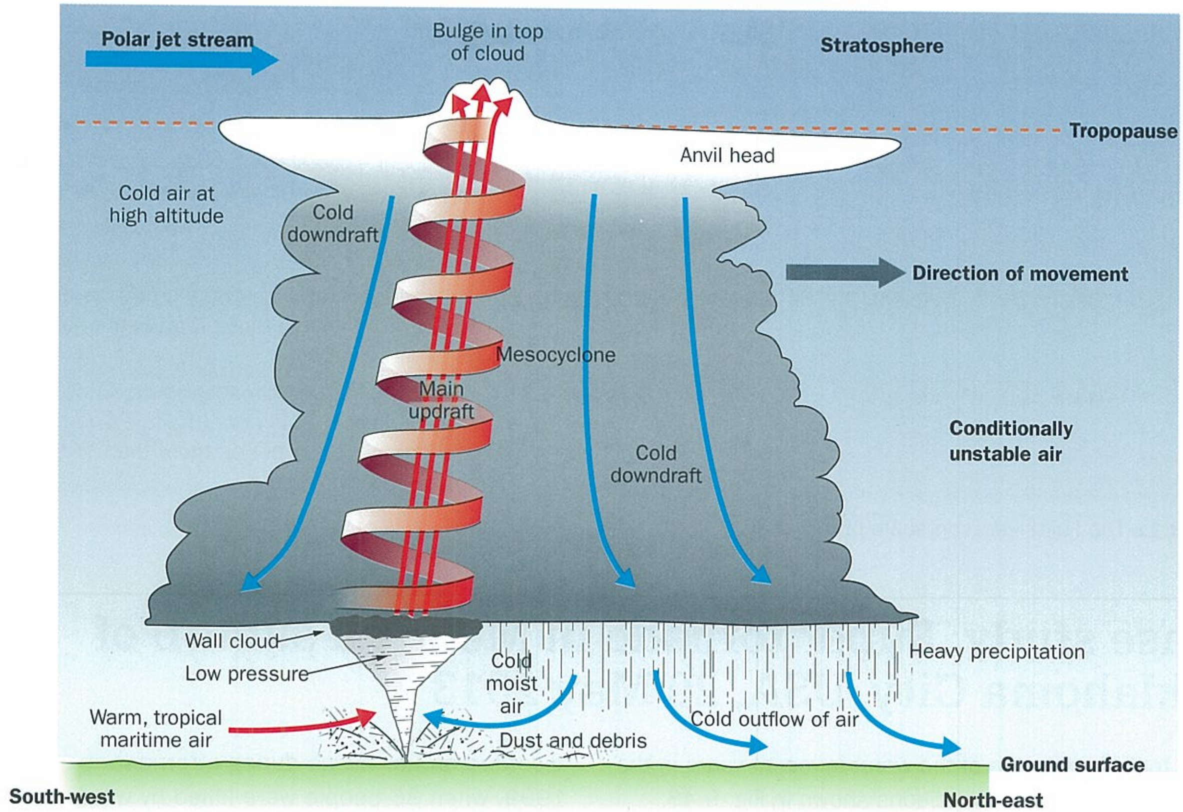


Fig. 9.49 The formation of a tornado from a supercell thunderstorm

rotating up-currents, known as **mesocyclones,** can be up to 16 km in diameter. About half of them become tornadoes by extending downwards, spiralling to reach ground level, narrowing as they do so.

The rotation may be started by a wind shear – winds blowing in different directions or at different speeds, such as when a strong horizontal upper air wind meets a violent updraft. This would cause a horizontal rotation, which is then forced to rise with the strong updraft.

The first stage in the life cycle of a tornado occurs when heavy rainfall in the cumulonimbus cloud drags a column of rapidly descending air down with it, which, in turn, drags the mesocyclone towards the ground.

As the mesocyclone lowers, it pulls in warm, moist air from kilometres around, as well as very humid air from the rainy area at the cloud base. The moisture in this quickly condenses to form a rotating **wall cloud,** an isolated cloud that projects below the rest in the rain-free part of the storm. The increasing outflow of cold air concentrates the base of the mesocyclone into an increasingly smaller area from which to draw its air intake. The updraft grows in intensity, creating a low pressure near the surface. This pulls the mesocyclone down as a funnel cloud. When the downdraft reaches the ground 10 to 20 minutes after the wall cloud forms, it creates a gust that causes severe damage over a considerable distance. Soon after, the funnel cloud itself becomes damaging and dust and debris get drawn into it.

The tornado grows in intensity while it is supplied with warm, moist air, which expands in the low pressure and cools, releasing latent heat when the water vapour condenses. When the funnel cloud has grown to its widest extent and is vertical, the tornado is in its most damaging mature stage, often with very destructive hailstones, up to the size of grapefruit.

Eventually, cold air from the downdraft spreads at the ground surface and cuts off the supply of moist, warm air that was fuelling the tornado. It then rapidly weakens and the funnel becomes wavy and rope-like, before disappearing.

A classification of tornadoes

Tornadoes are measured on the **Fujita-Pearson scale** (Table 9.11), which is really three independent scales measuring wind speed, path length (PL) and path width (PW).

The frequency with which tornadoes occur decreases down the scale.

Tornado hazards

The main hazard is being hit by flying debris or massive hailstones. Other dangers are being lifted up and blown through the air until hitting an object or being crushed, either by falling trees or by collapsing parts of buildings. Broken power lines are a secondary hazard.

Scale	Force (km/h)	Category	PL (km)	PW (m)	Damage
F0	0–116	Weak	less than1.6	less than 16	light – damage to chimneys, sign boards, broken tree branches and shallow-rooted trees
F1	117–180	Weak	1.6–5	16–50	moderate – damage to roofs and mobile homes
F2	181–253	Strong	5.1–15.9	51–160	significant – roofs and mobile homes destroyed, large trees uprooted, light objects blown into the air
F3	254–332	Strong	16–50	161–508	severe – roofs and walls of well-constructed homes damaged, trains overturned, cars thrown in the air
F4	333–418	Violent	51–159	509–1448	devastating – well-constructed houses destroyed and blown some distance if foundations weak, large missiles in the air
F5	419–512	Violent	160–507	1449–4989	incredible – strong houses moved some distance, steel-reinforced concrete structures damaged badly, cars flung through the air more than 100 m, bark stripped from trees

Table 9.11 The Fujita-Pearson scale of tornadoes

Case study: Super tornado in Moore, a suburb of Oklahoma City, USA, 20 May 2013

This tornado was one of the worst in recent years in the USA. It formed in the conditions shown in Fig. 9.48.

Risk perception

The Oklahoma Department of Emergency Management advises inhabitants to:

- keep informed about the weather by listening to local weather forecasts and to have a battery-operated NOAA Weather Radio, which has a warning alarm feature
- sign up for free cell phone (mobile phone) or email alerts
- plan well ahead, knowing what to do to keep safe
- get inside a strong building when a tornado threatens. Go to its lowest floor: preferably a basement. Keep as far away from windows, doors and outside walls as possible
- cover up to protect from flying or falling debris. If possible, wear a hard hat
- avoid being in a mobile home or vehicle.

Many homes have reinforced underground storm shelters but these are too expensive for the poorer people in the community. Schools have weather safety shows and annual drills.

Not everybody takes notice of the warnings because about 75 per cent of them prove to be false and people do not like wasting time. However, it is likely that most people in Moore would have taken the warning seriously because the fastest wind ever recorded on Earth was during a tornado there in 1999, when 36 people were killed by winds that reached 486 km/h. The suburb's population was better prepared as a result of their past experience.

Primary and secondary impacts on lives and property of the super tornado on May 20 2013

The F5 'monster' touched down outside Oklahoma City 16 minutes after the warning was issued. The mayor estimated that the warning saved about 1000 lives. After touching down and tossing horses into the air, it headed east-north-east into Moore, where it did enormous damage.

Fig. 9.50 The wedge tornado that devastated Moore in 2013

Most tornadoes are very localised, but this one was an unusually wide wedge type so, instead of destroying a street, it flattened whole housing estates, reducing two- and three-storey buildings to piles of sticks. It also destroyed two primary schools. The first one was so damaged that it is incredible no one sheltering there died. The tornado had strengthened to 320 km/h when it reached the second school, which had no shelter. It caused the greatest loss of life when the roof tore off and a wall collapsed, destroying the hall, the safest area, where the children were sheltering. Moore hospital, a cinema and bowling alley were also damaged and fires broke out.

Cars were tossed in the air and facades stripped from buildings. Power lines left lying across roads and pavements created obstacles to movement and danger from power outages.

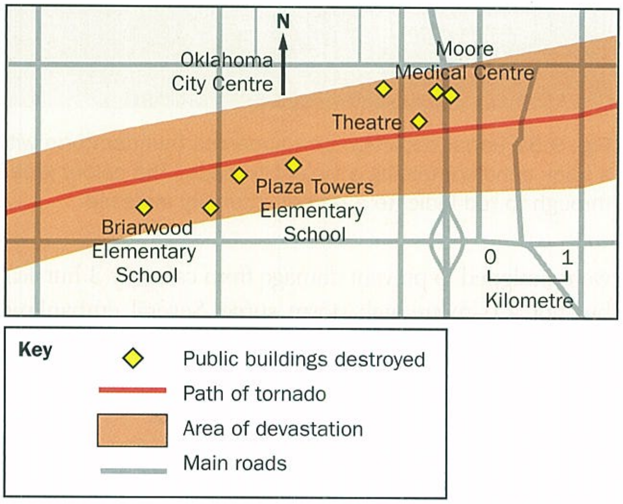


Fig. 9.51 The path of the tornado at Moore, 20 May 2013

The tornado was on the ground for 45 minutes, leaving a path of devastation 27 km long and 2.4 km wide. There were 24 deaths (including seven at the primary school), 237 injuries, 2500 homes demolished or damaged and a total of 10 000 people affected. Gas and water supplies were cut.

A state of emergency was declared and disaster assistance agreed by the US government. Emergency workers from nearby states searched with sniffer dogs for survivors and cleared wreckage that lay over underground shelters. They were hindered by the loss of telephone communications, as lines had been brought down and cell phone networks were jammed as so many people were trying to use them. Power was restored to the hospital quickly. Doctors and nurses were brought in and volunteers with aid organisations served food and helped people search for belongings.

The Moore tornado was not accompanied by a large hailstorm but the day before Moore was devastated, a tornado with hailstones up to 10.8 cm in diameter had struck Shawnee, another suburb of Oklahoma City and completely destroyed a mobile home park.

17. Suggest why tornadoes in Bangladesh kill an average of nearly 180 people a year, more than anywhere else in the world.

Prediction and monitoring of large and small-scale atmospheric disturbances and perception of risk: how the USA prepares for hurricanes and tornadoes

Hurricane prediction and monitoring

Meteorologists in the national Hurricane Centre in Florida track storms on satellite images to provide warning in time for people in the USA and surrounding countries to put strong covers over their windows and evacuate. Satellites have made weather forecasting much more accurate. Meteorologists fly in planes with their instruments across the eyewalls and eye of hurricanes to measure their strength. However, predictions of where the storm will hit are not always successful because tropical storms can suddenly change course and their speeds of movement can vary. Exactly where they will make landfall is not known until very near the time it actually happens. This causes a problem for the state governor and department responsible for giving the order to evacuate.

The Federal Emergency Management Agency makes sure places are prepared for disasters. Practice drills are held regularly. The Hurricane Centre uses various methods to educate people of the dangers they face and what to do if they are caught in a hurricane.

Tornado prediction and monitoring

Prediction of tornadoes is improving all the time. When satellite imagery shows the situation is right for them to form (Fig. 9.48), NOAA sends out a Tornado Watch announcement to the media and arranges for a satellite to send back imagery of the area every five minutes, instead of the normal 30 minutes. Meanwhile, another satellite over western USA acquires imagery at one-minute intervals. Meteorologists also monitor Doppler radar for supercell thunderstorm clouds that have a hook echo at their rears, as these are known to be associated with tornadoes. The large rotating updraft (mesocyclone) from which a tornado may form also helps meteorologists to spot them with more time to warn before it strikes a community. Radar can even detect debris, allowing the location of a tornado to be detected at night or when it is raining. People trained to be tornado spotters then go out to visually confirm the tornado, reporting back to the National Weather Service. The local Weather Service Forecast Office then issues a Tornado Warning and urges people to reach safe shelter.

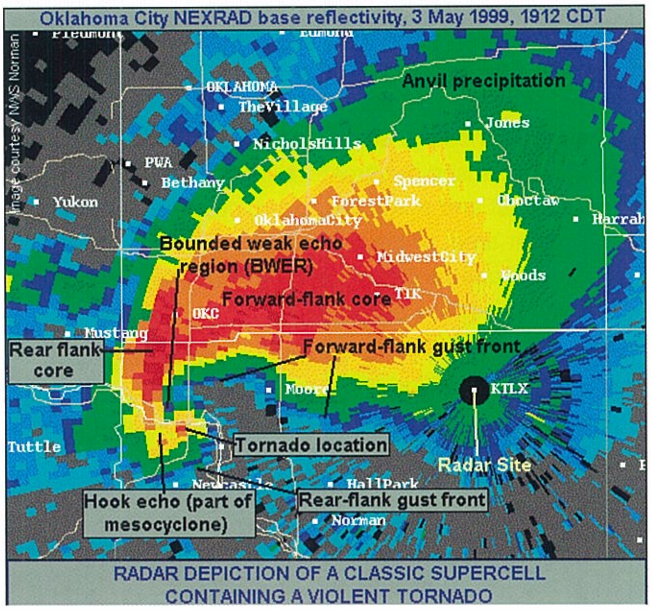


Fig. 9.52 Radar depiction of a supercell thunderstorm with a hook echo containing a violent tornado. The colour green through to red indicate a rainfall intensity increase

Perception of risk

People who have not experienced the hazard are not usually willing to take the necessary action to avoid it. In 1992 when Hurricane Andrew threatened southern Florida, the authorities decided to evacuate people from coastal areas likely to be affected. The decision to do so was difficult because the economy is harmed by stopping normal life, so the authorities who make the decision to evacuate are strongly criticised if a disaster does not occur. The hurricane proved devastating, with 80 000 homes destroyed and 15 deaths amongst citizens who refused to evacuate because they had never known a hurricane affect as far inland as Hurricane Andrew reached.

Inappropriate risk perception was also a factor in the Hurricane Katrina disaster. There were both physical and economic reasons why Hurricane Katrina killed more than 1800 people in the city of New Orleans, in the marshes of the Mississippi delta, USA. Built on soft, easily-eroded sediment, much of the city was below sea level, some more than three metres below, with the seawater kept out by concrete embankments. Economic reasons also contributed to the disaster in New Orleans because it was not thought to be cost-effective to spend a lot on protection against events considered unlikely to happen in a long time period. Therefore, the embankments and floodwalls were designed to prevent damage from category 3 hurricanes but not a 6-metre-high storm surge. Several embankments collapsed and 80 per cent of the city was flooded by as much as three metres. There was little wind damage because buildings had been built to withstand hurricane winds.

Where risk perception leads to protective measures against hurricanes being taken, much depends on the effectiveness of those used against flooding (described in Chapters 1 and 8). People are also deterred from living in vulnerable areas, such as floodplains, by increasing the cost of their insurance.

The integration of hazard prevention measures into the planning of new developments may make it possible to avoid flood damage altogether. Land-use zoning is used to reduce the cost and inconvenience of flooding; floodplains are used for playing fields, pasture and nature reserves, whereas buildings are placed at higher levels.

Case study: The Philippines: a multi-hazard country

The Philippine islands have many typhoons because they are located to the west of a huge area of warm water in the Pacific Ocean. As the case study of super-typhoon Haiyan showed, they experience problems in sustainably managing an environment made hazardous by flooding and typhoons but have some success in reducing the danger from volcanic eruptions.

Problems of sustainable management

As the Philippines is a poor country and a multi-hazard location, it has to balance what to spend on disaster-resistant infrastructure with which basic services to provide. Consequently, many schools and hospitals are not built to withstand hazards and many sustainable management methods are too expensive to employ.