These include retaining devices, drainage pipes, grading of slope and diversion walls (Figure 9.34). Concrete blocks or gabions may be used to strengthen slopes. Slopes subject to creep can be stabilised by draining or pumping water from saturated sediment. Oversteepened slopes can be made gentler by regrading. However, not all communities can afford such measures and so may opt for low-cost sustainable forms of management.

Eliminating or restricting human activities in areas where slides are likely may be the best way to reduce damage and loss of life. Land that is susceptible to mild failures may be suitable for some forms of development (for example, recreation or parkland) but not others (for example, residential or industrial). Early-warning systems can provide forecasts of intense rain. High-risk areas can then be monitored and remedial action taken.


Figure 9.34 Engineering techniques, Brunei

9.3 Hazards resulting from atmospheric disturbances

Large-scale tropical disturbances – tropical storms (cyclones)

Tropical cyclones are known as 'hurricanes' in the Atlantic, Caribbean and north-west Pacific; they are known as 'typhoons' in the north-western Pacific; and they are called 'tropical cyclones' in the Indian Ocean and south Pacific.

Tropical storms bring intense rainfall and very high winds, which may in turn cause storm surges and coastal flooding, and other hazards such as (inland) flooding and mudslides. Tropical storms are also characterised by enormous quantities of water. This is due to their origin over tropical seas. High-intensity rainfall, as well as large totals – up to 500 millimetres in 24 hours – invariably cause flooding. Their path is erratic, so it is not always possible to give more than 12 hours' notice of their position. This is insufficient for proper evacuation measures. In North America and the Caribbean, tropical storms are referred to as hurricanes.

Tropical storms develop as intense low-pressure systems over tropical oceans. Winds spiral rapidly around a calm central area known as the 'eye'. The diameter of the whole tropical storm may be as much as 800 kilometres, although the very strong winds that cause most of the damage are found in a narrower belt up to 300 kilometres wide. In a mature tropical storm, pressure may fall to as low as 880 millibars (mb). This, and the strong contrast in pressure between the eye and outer part of the tropical storm, leads to very strong winds.

Tropical storms move excess heat from low latitudes to higher latitudes. They normally develop in the westward-flowing air just north of the equator (known as an 'easterly wave'). They begin life as a small-scale tropical depression, a localised area of low pressure that causes warm air to rise. This causes thunderstorms that persist for at least 24 hours, and may develop into tropical storms, which have greater wind speeds of up to 117 kilometres per hour. However, only about 10 per cent of tropical disturbances ever become tropical storms, with wind speeds above 118 kilometres per hour.

For tropical storms to form, a number of conditions are needed (Figure 9.35):

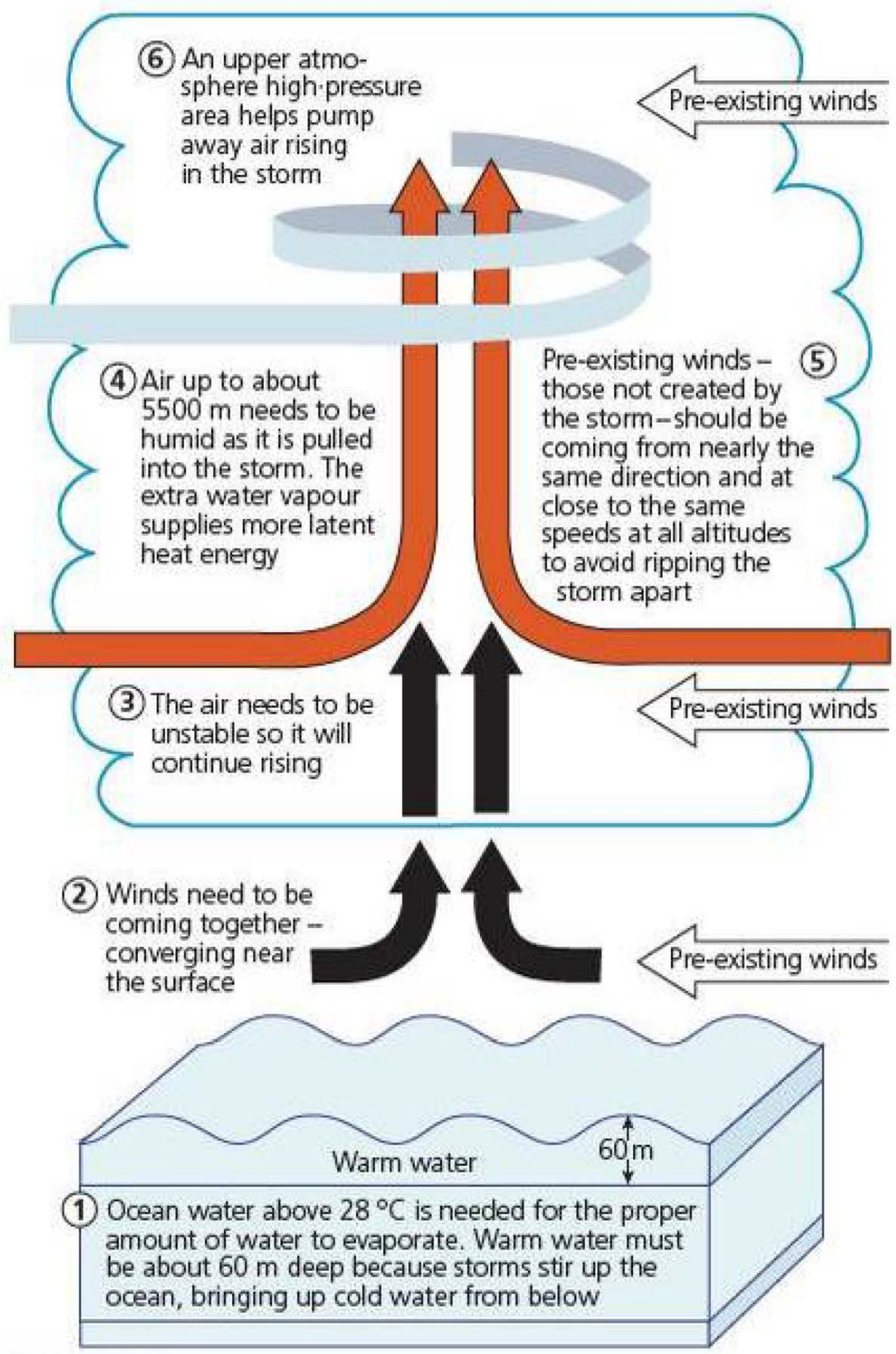

Figure 9.35 Formation of a tropical storm

- Sea temperatures must be over 27 °C to a depth of 60 metres (warm water gives off large quantities of heat when it is condensed – this is the latent heat that drives the tropical storm).
- The low-pressure area has to be far enough away from the equator so that the Coriolis force (the force caused by the rotation of the Earth) creates rotation in the rising air mass – if it is too close to the equator, there is insufficient rotation and a tropical storm would not develop.
- Conditions must be unstable – some tropical low-pressure systems develop into tropical storms (not all of them), but scientists are unsure why some do and others do not.

Tropical storms are the most violent, damaging and frequent hazard to affect many tropical regions (Figure 9.36). They are measured on the Saffir–Simpson Scale, which is a 1–5 rating based on the tropical storm's intensity (Table 9.14). It is used to give an estimate of the potential property damage and flooding expected along the coast from a tropical storm landfall. Wind speed is the determining factor in the scale, as storm surge values are highly dependent on the slope of the continental shelf and the shape of the coastline in the landfall region. Tropical storms can also cause considerable loss of life. Hurricane Georges (1998) killed more than 460 people, mainly in Dominican Republic and Haiti.

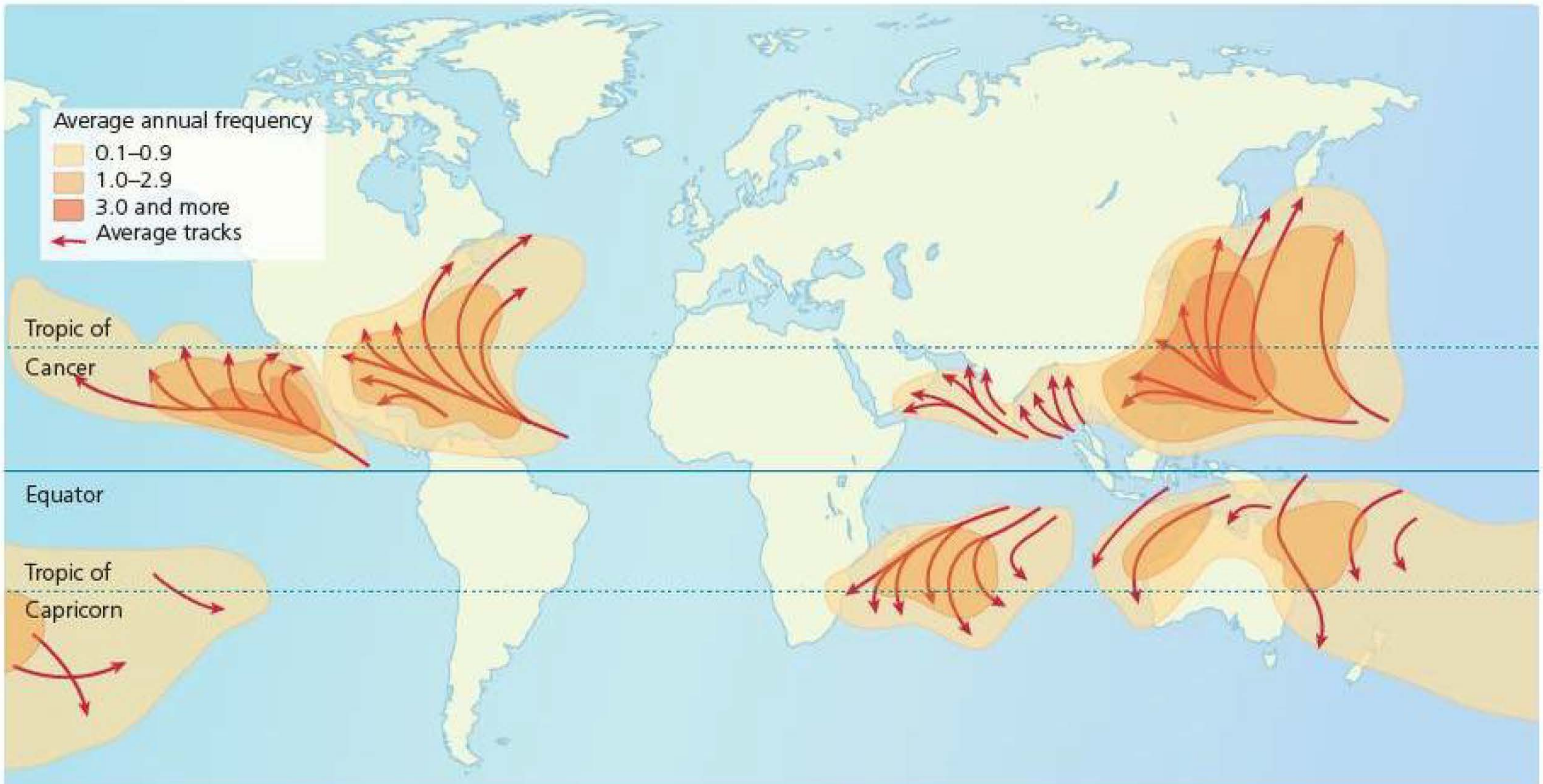

Figure 9.36 Distribution of tropical storms

Table 9.14 Saffir–Simpson Scale of tropical storm strength

Category 1	**Winds 119–153 km/hour; storm surge generally 1.2–1.5 m above normal**	No real damage to building structures. Damage primarily to unanchored mobile homes. Also, some coastal road flooding and minor pier damage.
Category 2	**Winds 154–177 km/hour; storm surge generally 1.8–2.4 m above normal**	Some damage to roofing materials, doors and windows. Considerable damage to vegetation, mobile homes and piers. Coastal and low-lying escape routes flood 2–4 hours before arrival of the tropical storm eye. Small craft in unprotected anchorages break moorings.
Category 3	**Winds 178–209 km/hour; storm surge generally 2.7–3.6 m above normal**	Some structural damage to small residences and utility buildings. Mobile homes are destroyed. Flooding near the coast destroys smaller structures, with larger structures damaged by floating debris. Land below 1.5 m above mean sea level may be flooded inland 13 km or more. Evacuation of low-lying residences close to the shoreline may be necessary.
Category 4	**Winds 210–249 km/hour; storm surge generally 3.9–5.5 m above normal**	Some complete roof structure failures on small residences. Complete destruction of mobile homes. Extensive damage to doors and windows. Land below 3 m above sea level may be flooded, requiring massive evacuation of residential areas as far inland as 10 km.
Category 5	**Winds greater than 249 km/hour; storm surge generally greater than 5.5 m above normal**	Complete roof failure on many residences and industrial buildings. Some complete building failures, with small utility buildings blown over or blown away. Complete destruction of mobile homes. Severe and extensive window and door damage. Low-lying escape routes are cut by rising water 3–5 hours before arrival of the centre of the tropical storm. Major damage to lower floors of all structures located less than 4.5 m above sea level and within 500 m of the shoreline. Massive evacuation of residential areas on low ground within 8–16 km of the shoreline may be required.

There are a number of significant factors that affect the impact of tropical storms:

- Tropical storm paths are unpredictable, which makes effective management of the threat difficult. It was fortunate for Jamaica that Hurricane Ivan (2004) (Figure 9.37) suddenly changed course away from the most densely populated parts of the island where it had been expected to hit. In contrast, it was unfortunate for Florida's Punta Gorda when Hurricane Charley (2004) moved away from its predicted path.
- The strongest storms do not always cause the greatest damage. Only six lives were lost to Hurricane Frances in 2004, but 2000 were taken by Jeanne when it was still categorised as just a 'tropical storm' and had not yet reached full hurricane strength.
- The distribution of the population throughout the Caribbean islands increases the risk associated with tropical storms. Much of the population lives in coastal settlements and is exposed to increased sea levels and the risk of flooding.
- Hazard mitigation depends upon the effectiveness of the human response to natural events. This includes urban planning laws, emergency planning, evacuation measures and relief operations such as re-housing schemes and the distribution of food aid and clean water.
- LICs continue to lose more lives to natural hazards, due to inadequate planning and preparation. By way of contrast, insurance costs continue to be greatest in American states such as Florida, where multi-million-pound waterfront homes proliferate.

Figure 9.37 Damage in Grenada after Hurricane Ivan

Tropical-storm management

Information regarding tropical storms is received from a number of sources including:

- satellite images
- aircraft that fly into the eye of the tropical storm to record weather information
- weather stations at ground levels
- radars that monitor areas of intense rainfall.

Preparing for tropical storms

Housing is particularly vulnerable to tropical storms. Hurricane Luis (1995) caused damage to 90 per cent of Antigua's houses, while Hurricane Gilbert (1988) made 800 000 people temporarily homeless in Jamaica. To limit damage to houses, owners are now encouraged to fix tropical storm straps to roofs and put storm shutters over windows. Houses built on stilts allow flood waters to pass away safely.

There are a number of ways in which national governments and agencies can help prepare for a tropical storm. These include **risk assessment**, land-use zoning, floodplain management and reducing the vulnerability of structures and organisations.

Risk assessment

The evaluation of risks of tropical cyclones can be shown in a hazard map. Particular information may be used to estimate the probability of cyclones striking a country:

- analysis of climatological records to determine how often cyclones have struck, their intensity and locations
- history of winds speeds, frequencies of flooding, height, location and storm surges over a period of about 50–100 years.

Land-use zoning

The aim is to control land use so that the most important facilities are placed in the least vulnerable areas. Policies regarding future development may regulate land use and enforce building codes for areas vulnerable to the effects of tropical cyclones.

Floodplain management

A plan for floodplain management should be developed to protect critical assets from flash, riverine and coastal flooding.

Reducing vulnerability of structures and infrastructures

- New buildings should be designed to be wind and water resistant. Design standards are usually incorporated into building codes.
- Communication and utility lines should be located away from the coastal area or installed underground.
- Areas of building should be improved by raising the ground level to protect against flood and storm surges.
- Protective river embankments, levees and coastal dikes should be regularly inspected for breaches due to erosion and opportunities should be taken to plant mangrove trees to reduce breaking wave energy.
- Vegetation cover should be increased to help reduce the impact of soil erosion and landslides, and facilitate the absorption of rainfall to reduce flooding.

Before a tropical storm

- Know where your emergency shelters are.
- Have disaster supplies on hand:
  - Flashlight and extra batteries
  - First aid kit
  - Non-perishable (canned) food and water
  - Essential medicines
  - Cash and credit cards.
- Protect your windows.
- Permanent shutters are the best protection. A lower-cost approach is to put up plywood panels.
- Trim back branches from trees.
- Trim branches away from your home and cut out all dead or weak branches on any trees on your property.
- Check your home and car insurance.
- Make arrangements for pets and livestock.
- Develop an emergency communication plan.

During a tropical storm

- Listen to the radio or television for tropical storm progress reports.
- Check emergency supplies.
- Make sure your car is full of fuel.
- Bring in outdoor objects such as lawn furniture, toys and garden tools, and anchor objects that cannot be brought inside.
- Secure buildings by closing and boarding up windows.
- Remove outside antennas and satellite dishes.

After a tropical storm

- Assist in search and rescue.
- Seek medical attention for persons injured.
- Clean up debris and effect temporary repairs.
- Report damage to utilities.
- Watch out for secondary hazards: fire, flooding, etc.

Figure 9.38 What to do before, during and after a tropical storm

There are many other things that individuals can do to prepare for a tropical storm, and to learn how to act during and after a storm (Figure 9.38).

A tropical storm watch is issued when there is a threat of tropical storm conditions within 24–36 hours. A tropical storm warning is issued when tropical storm conditions (winds of 120 kilometres per hour or greater, or dangerously high water and rough seas) are expected in 24 hours or less. A tropical storm warning is issued when there are risks of tropical storm winds within 24 hours. A tropical storm watch is issued when tropical storm winds are expected within 36 hours.

The emergency relief offered after a tropical storm can take many forms – food supplies, clean water, blankets and medicines. Much of this is provided in tropical storm shelters. In some communities, emergency electricity generators may be needed. The community normally becomes involved in the clean-up operation, and electricity and phone companies work to restore power lines and communications.

Long-term redevelopment may include construction of new buildings in areas away from the coastline and on high ground. Long-term reconstruction in Grenada following Hurricane Ivan concentrated on housing and community projects, water supply and sanitation, transport and communications, agriculture, fisheries and small businesses, schools and government expenses.

Section 9.3 Activities

1. In what ways is it possible to prepare for tropical storms?
2. How can governments help prepare for tropical storms?
3. What are the main actions that should be taken during a tropical storm?

Case Study: Cyclone Nargis, 2 May 2008

Cyclone Nargis was a strong tropical cyclone (Figure 9.39). It formed on 27 April 2008, made landfall by 2 May and died out by 3 May. It involved winds of up to 165 kilometres per hour (sustained for 3 minutes) and winds of over 215 kilometres per hour (sustained for over 1 minute). At its peak, air pressure dropped to 962 millibars. Around 146 000 people were killed and it caused damage estimated at $10 million. As well as Burma (Myanmar), parts of Bangladesh, India and Sri Lanka were affected. However, it was the Burmese government's actions – or rather their lack of them – that caused widespread anger and disbelief.

The Burmese government identified 15 townships in the Irrawaddy delta that had suffered the worst. Seven of them had lost 90–95 per cent of housing, with 70 per cent of their population dead or missing. The land in the Irrawaddy delta is very low-lying. It is home to an estimated 7 million of Burma's 53 million people. Nearly 2 million of the densely packed area's inhabitants live on land that is less than 5 metres above sea level, leaving them extremely vulnerable. As well as the cost in lives and homes, there is the agricultural loss to the fertile delta, which is seen as Burma's 'rice bowl'.

It was the worst ever natural disaster in Burma. There were over 80 000 deaths in Labutta and a further 10 000 in Bogale. The UN estimated that 1.5 million people were severely affected by Cyclone Nargis. Thousands of buildings were destroyed; 75 per cent of the buildings in the town of Labutta collapsed and a further 20 per cent had their roofs ripped off. Up to 95 per cent of buildings in the Irrawaddy delta were destroyed.

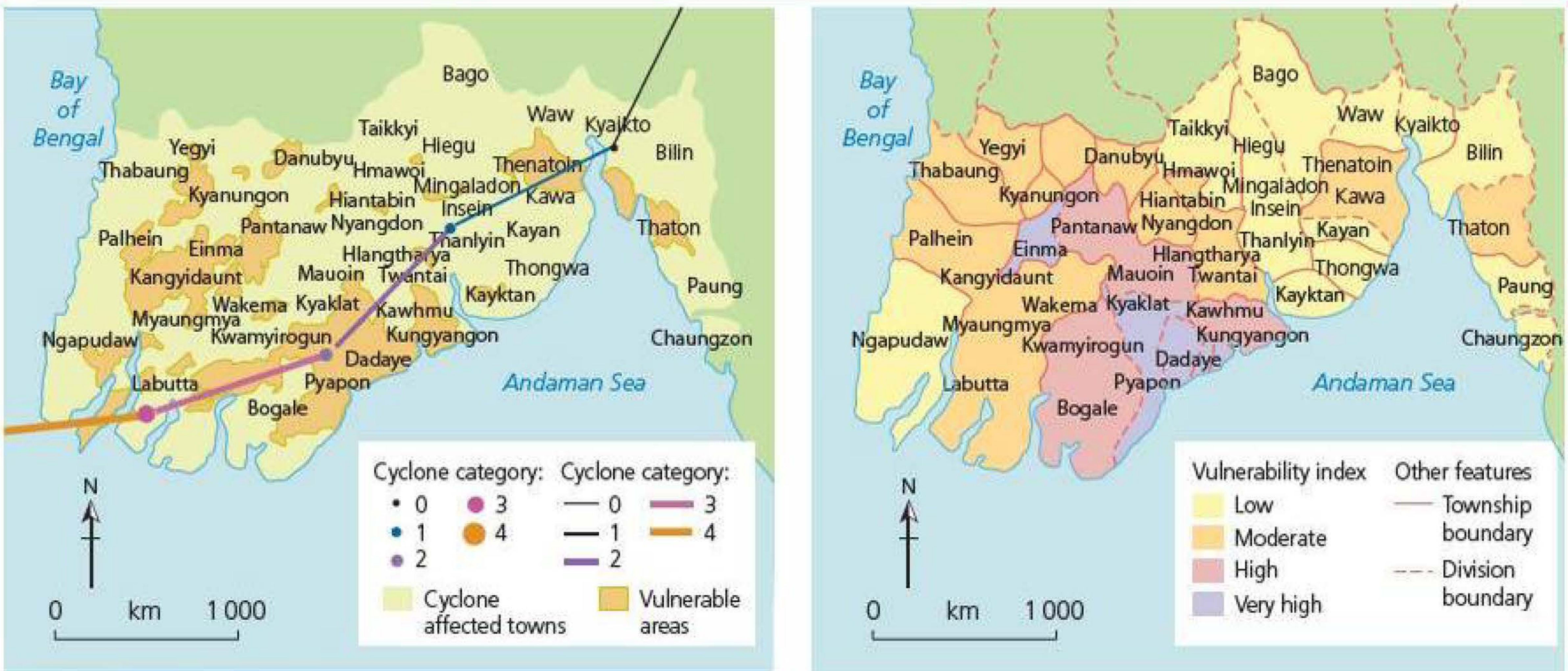

Figure 9.39 Cyclone Nargis

According to aid agencies trying to get into Burma, up to 1 million people could have died from the cyclone due to lack of relief. Relief efforts were delayed for political reasons. Burma's political leaders declined international aid; the World Food Programme said the delays were 'unprecedented in modern humanitarian relief efforts'. Within two weeks, an earthquake in China had deflected aid and sympathy away from Burma.

On 6 May, the Burmese junta (military government) finally asked the UN for aid, but accepted it only from India. Many nations and organisations hoping to deliver relief were unable to do so – the Burmese government refused to issue visas to many of them. On 9 May, the junta officially declared that its acceptance of international aid would be limited to food, medicines and some other specified supplies as well as financial aid, but would allow additional foreign aid workers to operate in the country.

India is one of the few countries to maintain close relations with Burma. It launched Operation Sahayata, under which it supplied two ships and two aircraft. However, the Burmese government denied Indian search and rescue teams and media access to critical cyclone-hit areas. On 16 May, India's offer to send a team of 50 medical personnel was accepted. Cyclone survivors needed everything – emergency shelter to keep them dry, all basic food and medicines.

Many Burmese people were displeased with their government, which had provided no warning of the cyclone. According to some reports, Indian meteorologists had warned Burma of Cyclone Nargis 48 hours before it hit the country's coast. People also believed the mayhem caused by the cyclone and associated flooding was further exacerbated by the government's unco-operative response.

The delays attracted international condemnation. More than a week after the disaster, only 1 out of 10 people who were homeless, injured or threatened by disease and hunger had received any kind of aid. More than two weeks later, relief had only reached 25 per cent of people in need. Some news stories stated that foreign aid provided to disaster victims was modified to make it look as if it came from the military regime, and state-run television continuously ran images of General Than Shwe ceremonially handing out disaster relief.

Uninterrupted referendum

Despite objections raised by the Burmese opposition parties and foreign nations in the wake of the natural disaster, the junta proceeded with a previously scheduled constitutional referendum. However, voting was postponed from 10 to 24 May in Yangon and other areas hardest hit by the storm.

☐ Small-scale tropical disturbances – tornadoes

Tornadoes are small and short-lived but highly destructive storms. Because of their severe nature and small size, comparatively little is known about them. Measurement and observation within them are difficult. A few low-lying, armoured probes called 'turtles' have been placed successfully in tornadoes. Tornadoes consist of elongated funnels of cloud that descend from the base of a well-developed cumulonimbus cloud, eventually making contact with the ground beneath. In order for a **vortex** to be classified as a tornado, it must be in contact with the ground *and* the cloud base. Within tornadoes are rotating violent winds, perhaps exceeding 100 metres per second. Pressure gradients in a tornado can reach an estimated 25 millibars per 100 metres (this compares with the most extreme pressure gradients of about 20 millibars per 100 kilometres in a larger-scale cyclone).

How tornadoes form

Moisture, instability, lift and wind shear are the four key ingredients in tornado formation (Figure 9.40). Most tornadoes, but not all, rotate *cyclonically*; that is, anticlockwise in the northern hemisphere and clockwise south of the equator. The standard explanation is that warm moist air meets cold dry air to form a tornado. Many thunderstorms form under these conditions (near warm fronts and cold fronts), which never even come close to producing tornadoes. Even when the large-scale environment is extremely favourable for tornado-type thunderstorms, not every thunderstorm spawns a tornado. The most destructive and deadly tornadoes develop from **supercells**, which are rotating thunderstorms with a well-defined low-pressure system called a **mesocyclone**.

Tornadoes can last from several seconds to more than an hour. The convectional activity that creates the source cloud is itself highly variable, and a single cloud can spawn a number of different tornado vortices, either simultaneously or in sequence, beneath different areas of the cloud, as parts of it develop and decay. Movement is generally with the parent cloud, perhaps with the funnel twisting sinuously across the ground beneath. Once contact with the ground is made, the track of a tornado at ground level may frequently extend for only a few kilometres, though there are examples of sustained tracks extending over hundreds of kilometres. The diameter of the funnel is rarely more than 200 metres; track length and width are therefore limited.

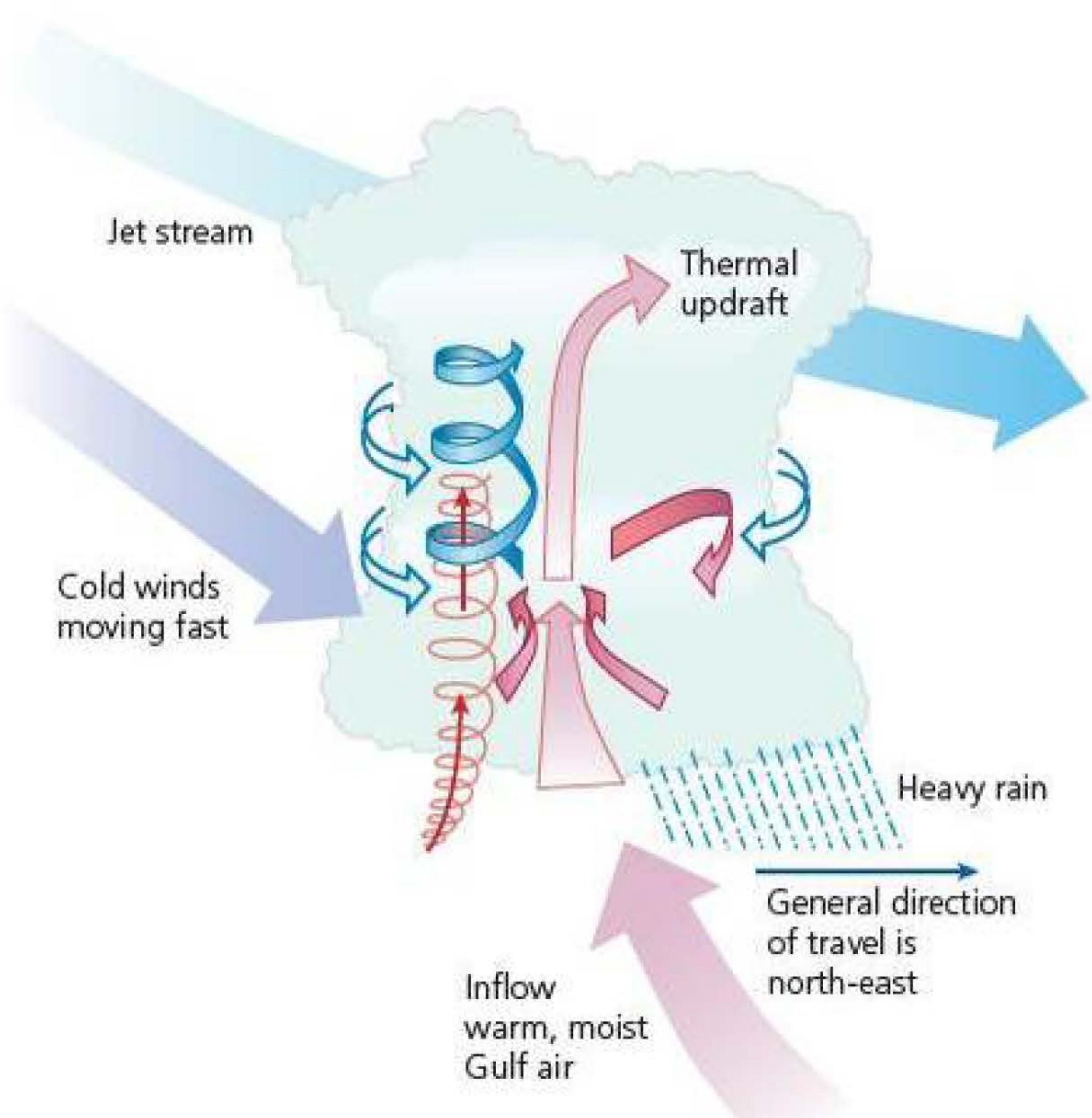

Figure 9.40 Formation of tornadoes in the USA

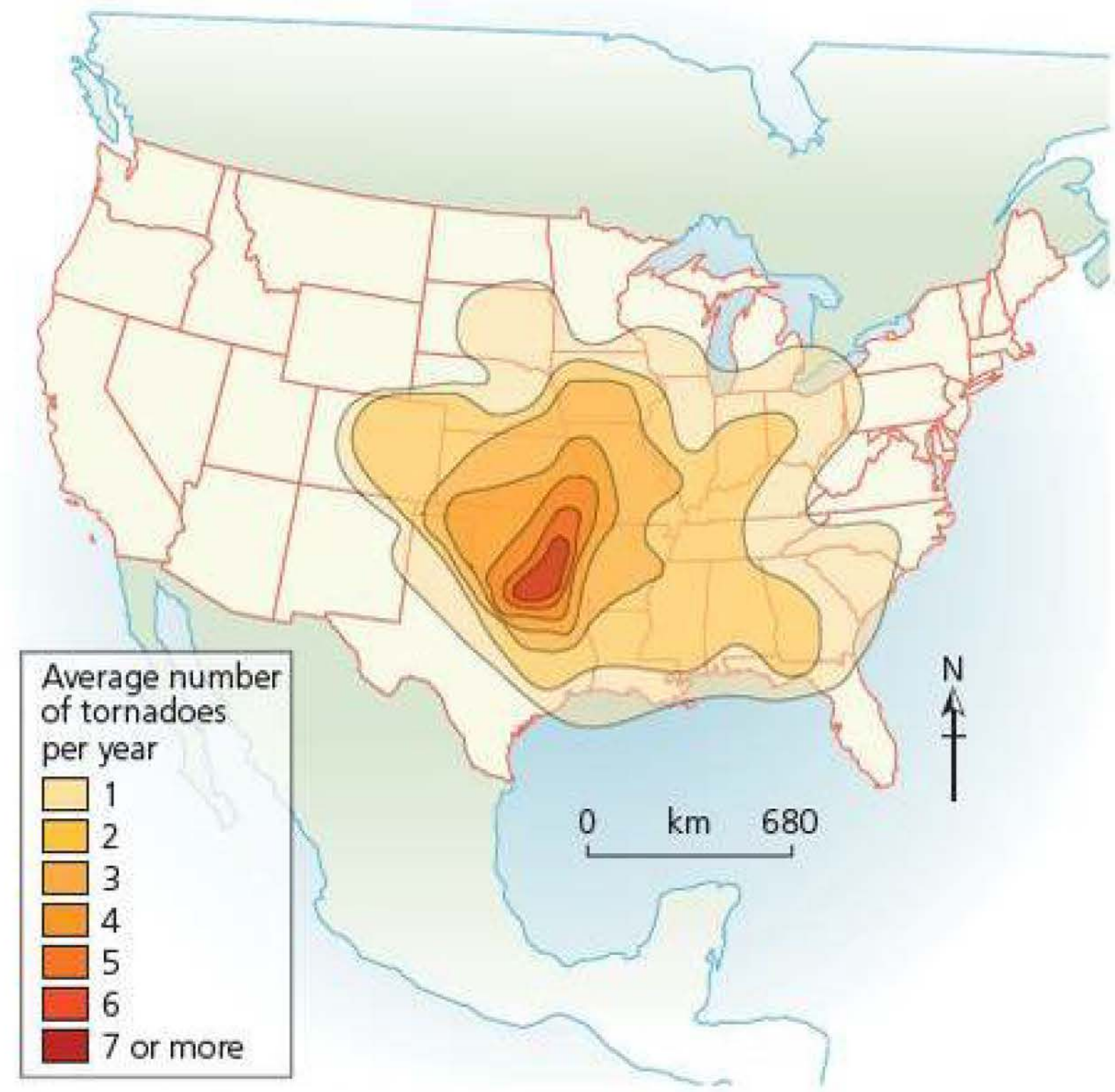

Figure 9.41 Tornado Alley, USA

Tornadoes, being associated with extreme atmospheric instability, show both seasonal and locational preference in their incidence. 'Favoured' areas are temperate continental interiors in spring and early summer, when insolation is strong and the air may be unstable, although many parts of the world can be affected by tornado outbreaks at some time or another. The Great Plains of the USA, including Oklahoma, Texas and Kansas, have a high global frequency (Figure 9.41), and tornadoes are particularly likely to be experienced here at times when cool, dry air from the Rockies overlies warm, moist 'Gulf' air. Some areas of the USA experience tornadoes from a specific direction, such as north-west in Minnesota or south-east in coastal south Texas. This is because of an increased frequency of certain tornado-producing weather patterns, for example tropical storms in south Texas, or north-west-flow weather systems in the upper Midwest.

Some tropical storms in the USA fail to produce any tornadoes, while others cause major outbreaks. The same tropical storm may produce none for a while, and then erupt with tornadoes – or vice versa. Hurricane Andrew (1992), for example, spawned several tornadoes across the Deep South after crossing the Gulf, but produced none during its rampage across southern Florida. Katrina (2005) spawned numerous tornadoes after its devastating landfall.

The size and strength of tropical cyclones is not related to the birth of tornadoes. Relatively weak tropical storms like Danny (1985) have spawned significant supercell tornadoes well inland, as have larger, more intense storms like Beulah (1967) and Ivan (2004). In general, the bigger and stronger the wind fields with a tropical cyclone, the bigger the area of favourable wind shear for supercells and tornadoes. But supercell tornadoes (whether or not in tropical cyclones) also depend on instability, lift and moisture. Surface moisture isn't lacking in a tropical cyclone, but sometimes instability and lift are too weak. This is why tropical systems tend to produce more tornadoes in the daytime, and near any fronts that may become involved in the cyclone circulation.

Tornado damage

About a thousand tornadoes hit the USA each year. On average, tornadoes kill about 60 people per year – most from flying or falling (crushing) debris. A tornado's impact as a hazard is extreme. They bring intense precipitation (heavy rainfall or hail), very high wind speeds and gusts of wind, and large-scale changes in pressure gradients (pressure imbalances).

There are three damaging factors at work. First, the winds are often so strong that objects in the tornado's path are simply removed or very severely damaged. Second, strong rotational movement tends to twist objects from their fixings, and strong uplift can carry some debris upwards into the cloud. Third, the very low atmospheric pressure near the vortex centre is a major source of damage. When a tornado approaches a building, external pressure is rapidly reduced, and unless there is a nearly simultaneous and equivalent decrease in internal pressure, the walls and roof may explode outwards in the process of equalising the pressure differences.

Most tornado damage is due to multiple-vortex tornadoes or very small, intense single-vortex tornadoes. The winds in most multiple-vortex tornadoes may only be strong enough to do minor damage to a particular house. But one of the smaller subvortices, perhaps only a few metres across, may strike the house next door with winds over 300 kilometres per hour, causing complete destruction. Also, there are great differences in construction from one building to the next, so that even in the same wind speed, one may be flattened while the other is barely touched.

Although winds in the strongest tornadoes may far exceed those in the strongest tropical storms, tropical storms typically cause much more damage individually and over a season, and over far bigger areas. Economically, tornadoes cause about a tenth as much damage per year, on average, as tropical storms. Tropical storms tend to cause much more overall destruction than tornadoes because of their much larger size, longer duration and the variety of ways they damage property. The destructive core in tropical storms can be tens or hundreds of kilometres across, last many hours and damage structures through storm surge and flooding caused by heavy rain, as well as from wind. Tornadoes, in contrast, tend to be a few hundred metres in diameter, last for minutes and primarily cause damage from their extreme winds.

Tornado damage scale

Dr T. Theodore Fujita developed a damage scale for winds, including tornadoes, which is supposed to relate the degree of damage to the intensity of the wind. Work on a new **Enhanced F-Scale** started in 2006 (Table 9.15). The Enhanced F-Scale is a much more precise way to rank tornado damage than the original, because it classifies damage F0–F5 calibrated by engineers across more than 20 different types of buildings. A team of meteorologists and engineers has worked on this for several years. The idea is that a 'one size fits all' approach does not work in rating tornado damage, and a tornado scale needs to take into account the typical strengths and weaknesses of different types of construction. This is because the same wind does different things to different kinds of buildings. In the Enhanced F-Scale, there are different, customised standards for assigning any given F rating to a well-built, well-anchored wood-frame house compared with a garage, school, skyscraper, unanchored house, barn, factory, utility pole or other type of structure. In a real-life tornado track, these ratings can be mapped together more smoothly to produce an accurate damage analysis.

Table 9.15 Enhanced Fujita Scale

EF number	3-second gust (mph)
0	65–85
1	86–110
2	111–135
3	136–165
4	166–200
5	200+
Note: this scale was created in the USA, so measurements are imperial.	

Managing tornadoes

The main problem with anything that could realistically stand a chance of affecting a tornado (for example an atomic bomb) is that it would be even more deadly and destructive than the tornado itself. Lesser things (like huge piles of dry ice) would be too hard to deploy in the right place fast enough, and would probably not have a significant effect on the tornado.

Nor is there any proof that seeding can or cannot change tornado potential in a thunderstorm. This is because there is no way of knowing that the things a thunderstorm does after it has been seeded would not have happened *anyway*. This includes any presence or lack of rain, hail, wind gusts or tornadoes. Because the effects of seeding are impossible to prove or disprove, there is a great deal of controversy among meteorologists about whether it works and, if so, under what conditions and to what extent.

Case Study: Tornadoes in Indiana

Indiana is in what is considered to be 'Tornado Alley' (see Figure 9.41 and Table 9.16), a swathe of states extending from the south-east USA to the interior plains. Although the state lacks the high frequency of tornadoes seen in places like Kansas and Oklahoma, it makes up for it in the intensity of its tornadoes.

Table 9.16 Indiana tornado disasters

Date	Place	Damage
13 April 1852	New Harmony	16 killed
14 May 1886	Anderson	43 killed
23 March 1913	Terre Haute	21 killed
11 March 1917	New Castle	21 killed
23 March 1917	New Albany	45 killed
28 March 1920	Allen through Wayne counties	39 killed by three tornadoes
17 April 1922	Warren through Delaware counties	14 killed
18 March 1925	'Tri-State Tornado': Posey, Gibson and Pike counties	74 killed
26 March 1948	Coatesville destroyed	20 killed
21 May 1949	Sullivan and Clay counties	14 killed
11 April 1965	'Palm Sunday Outbreak': 11 tornadoes, 20 counties	137 killed
3 April 1974	'Super Outbreak': 21 tornadoes hit 39 counties	47 killed
2 June 1990	37 tornadoes hit 31 counties	8 killed

Tornadoes can occur in any month, but March–June is considered tornado season in Indiana. Historically, the most destructive tornadoes strike in March and April. June holds the record for the most tornadoes in Indiana on any given day (37), and for the most in a single month (44). Both records were set in 1990, which is also the year when the state experienced the most tornadoes (49).

From 1950 to November 2001, 1024 tornadoes caused more than $1.7 billion in damage in Indiana, and killed 223 people.

Indiana was one of three mid-western states in the path of the deadliest tornado in American history. On 18 March 1925, the Tri-State Tornado travelled a record 352 kilometres on the ground from Missouri through Illinois and into Indiana, where it struck Posey, Gibson and Pike counties. The town of Griffin lost 150 homes, and 85 farms near Griffin and Princeton were devastated. About half of Princeton was destroyed, with losses totalling nearly $2 million. The funnel finally dissipated just outside Princeton, 3½ hours after it had begun. Nearly 700 people died, 74 of them in Indiana. Murphysboro in Illinois lost 234 people, a record for a single community.

In April 1965, 11 tornadoes struck 20 counties in central and northern Indiana, killing 137 people. More than 1700 people were injured and property damage exceeded $30 million. It was Indiana's worst tornado disaster. The tornadoes that devastated Indiana were part of an outbreak in which nearly 50 tornadoes struck the Great Lakes region on 11–12 April, causing 271 deaths and more than 3400 injuries.

The most destructive tornado outbreak of the twentieth century was the 'Super Outbreak' of 3–4 April 1974. During a 16-hour period, 148 tornadoes hit 13 states, including Indiana. The path of destruction stretched over 4000 kilometres. More than 300 people died and more than 5000 were injured. The most notable tornado in this group destroyed much of Xenia, Ohio. In Indiana, 21 tornadoes struck 39 counties, killing 47 people. Seven produced damage rated F5, the maximum possible, and 23 more were rated F4. This was one of only two outbreaks with over 100 confirmed tornadoes, the other being during tropical storm Beulah in 1967 (115 tornadoes).

Section 9.3 Activities

1 Briefly explain how tornadoes are formed.
2 Using examples, outline the factors that affect tornado damage.
3 To what extent is it possible to manage the risk of tornado damage?

9.4 Sustainable management of hazardous environments

Case Study: The use of geo-materials for erosion and sediment control

In Malaysia, early research on bio-engineering involved studies on plant selection for the re-vegetation of cut slopes along highways. Research in 2000–01 involved gully erosion control and vegetation establishment on degraded slopes. These techniques have incorporated the coppicing abilities of cut stems and the soil-binding properties of roots into civil designs, to strengthen the ground and to control erosion. Bio-engineering designs have great potential and application in Malaysia because in deforested upland sites landslides are common, particularly during the wetter months between November and January. Post-landslide restoration works involving conventional civil designs are costly and sometimes not practical at remote sites. Due to cost constraints, the remoteness of the sites and low risk to lives and property, bio-engineering was the option taken for erosion control, slope stabilisation and vegetation establishment.