Geo Factsheet

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TORNADOES

What is a tornado?

A tornado is a violent windstorm often associated with severe thunderstorms or tropical cyclones (hurricanes). It is characterised by a narrow, twisting funnel-like column of cloud that reaches the ground ('touches down') from a towering cumulonimbus cloud. Whilst a tornado may only touch down for 30 seconds or so, it may do so several times as a storm moves across an area. Once on the ground, tornado tracks rarely exceed 5km in length, although there is some evidence to suggest that tracks can exceed 50km in exceptional circumstances.

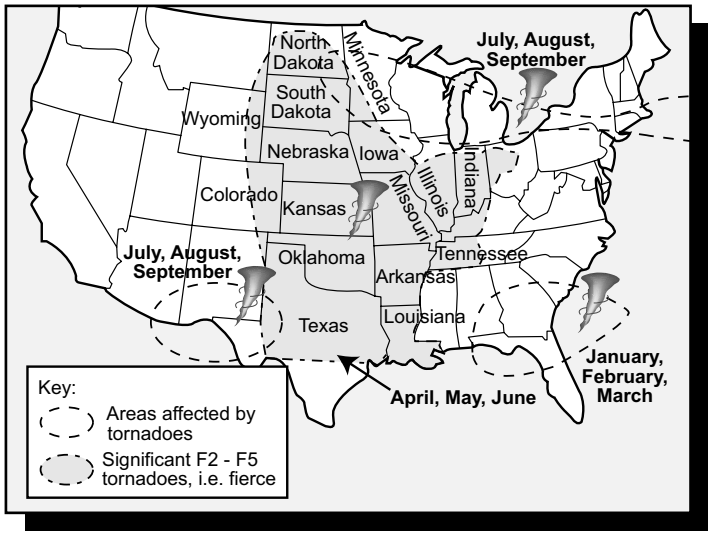
What is the tornado hazard?

Tornadoes are one of the most intensely violent of all natural phenomena. They are capable of causing tremendous destruction with winds often exceeding 400kph (250mph). One of the features of a tornado is its very narrow path of destruction, often only a matter of a few hundred metres. However, within this narrow belt, the destruction to property can be absolute. The winds and powerful updrafts are capable of lifting cars and mobile homes, uprooting trees and removing roofs from houses. Farm animals and people can be lifted off the ground. One of the greatest dangers associated with tornadoes is the frenzy of loose materials scything through the air, such as sheets of corrugated iron and pieces of wood picked up by the turbulent winds.

Where in the world do tornadoes occur?

Tornadoes are most commonly associated with the United States of America. In an average year, about 1,000 tornadoes are reported across the USA, resulting in 80 deaths and over 1,500 injuries. The bulk of USA tornadoes occur in a broad north-south belt known as 'tornado alley, which runs from Texas and Louisiana in the south, through Oklahoma and Kansas and on to North Dakota *(Fig. 1)*. The peak tornado season in the USA is from March through to mid-summer.

Fig. 1 'Tornado Alley' in the USA.



In the USA, the deadliest tornado event on record was the so-called 'Tri-State Tornado Outbreak', which killed 689 people in Missouri, Illinois and Indiana on 18th March 1925. *Fig. 2* lists the top 25 deadliest US tornadoes. Notice how the majority occurred within 'tornado alley' between the months of March and June. The largest known single outbreak in the USA occurred on April 3-4, 1974, when 148 tornadoes were reported in 11 states, killing 315 people, injuring more than 5,300 and causing $600 million in damage.

Fig. 2 The 25 deadliest tornadoes in the United States.

	Date	Location	Deaths
1	18 March 2005	Tri-State (Mo., Ill., Ind.)	689
2	6 May 1940	Natchez, Miss.	317
3	27 May 1896	St. Louis, Mo.	255
4	5 April 1936	Tupelo, Miss.	216
5	6 April 1936	Gainesville, Ga.	203
6	9 April 1947	Woodward, Oklahoma	181
7	24 April 1908	Amite La., Purvis, Miss.	143
8	12 Jun 1899	New Richmond, Wis.	117
9	8 June 1953	Flint, Michigan	115
10	11 May 1953	Waco, Texas	114
11	18 May 1902	Goliad, Texas	103
12	23 March 1913	Omaha, Nebraska	103
13	26 May 1917	Mattoon, Illinois	101
14	23 June 1944	Shinnston, W. Va.	100
15	18 April 1880	Marshfield, Mo.	99
16	1 June 1903	Gainesville, Holland, Ga.	98
17	9 May 1927	Poplar Bluff, Mo.	98
18	10 May 1905	Synder, Oklahoma	97
19	24 April 1908	Natchez, Miss.	91
20	9 June 1953	Worcester, Mass.	90
21	20 April 1920	Starkville, Miss., Waco, Ala.	88
22	28 June 1924	Lorrain, Sandusky, Ohio	85
23	25 May 1955	Udall, Kansas	80
24	29 Sept. 1927	St. Louis, Mo.	79
25	27 March 1890	Louisville, Kentucky	76

Tornadoes do occur elsewhere in the world, although Bangladesh is the only other country prone to violent tornadoes on an annual basis. In fact, the world's deadliest tornado is believed to have occurred in Bangladesh on 29th April 1989. The tornado that occurred in Manikganj killed approximately 1,300 people, injured 12,000 people, and made 80,000 people homeless. Most recorded tornadoes in Bangladesh - and there are probably a great many unrecorded - occur from late-March through to mid-May. April is a particularly active month, with 80% of the tornadoes that killed over 100 people occurring during the first 20 days of April. Most of the tornadoes occur in a relatively small area of central, south central and southeast Bangladesh.

In Japan, there are an average of 20 tornadoes a year, although they rarely cause fatalities. Perhaps surprisingly, tornadoes even occur in the UK. On average there are 33 tornadoes reported each year, although they are rarely powerful enough to cause widespread destruction or loss of life.

Tornadoes can be categorised using the Fujita Scale *(Fig. 3)*.

Fig. 3 Fujita Tornado Damage Scale

Category	Damage caused
F0	**Light Damage (<73 mph);** Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged.
F1	**Moderate Damage (73-112 mph);** Peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos blown off road.
F2	**Considerable Damage (113-157 mph);** Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.
F3	**Severe Damage (158-206 mph);** Roofs and some walls torn off well-constructed houses, trains overturned; most trees in forest uprooted; heavy cars lifted off ground and thrown.
F4	**Devastating Damage (207-260 mph);** Well-constructed houses levelled; structure with weak foundations blown off some distance; cars thrown and large missiles generated.
F5	**Incredible Damage (261-318 mph);** Strong frame houses lifted off foundations and swept away; automobile sized missiles fly through the air in excess of 100 metres; trees debarked; incredible phenomena will occur.

IMPORTANT: *Do not use F-scale winds literally. These wind speed numbers are estimates and have never been scientifically verified. Different wind speeds may cause similar-looking damage from place to place - even from building to building. Without a thorough engineering analysis of tornado damage in any event, the actual wind speeds needed to cause that damage are unknown.*

How are tornadoes formed?

Tornadoes are highly complex atmospheric phenomena and their precise formation is still not fully understood. Whilst they are known to be associated with conditions of extreme instability, as is associated with thunderstorms and tropical cyclones, their precise trigger mechanisms are uncertain. However, scientists have identified a number of factors that seem to be important:

- The presence of moist and potentially very unstable air. Unstable air is air that has a tendency to rise, either because it is warmer than the surrounding air (warm air rises) or because it is forced to rise by being undercut by cooler air.

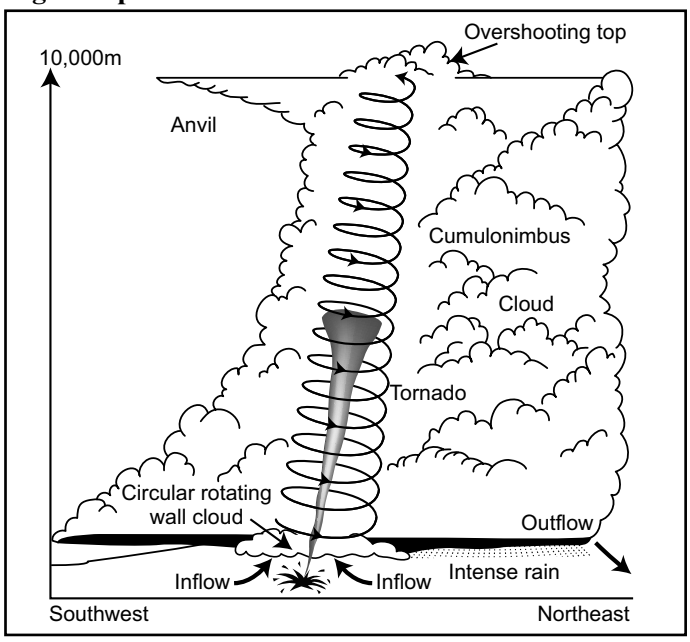
- A significant temperature gradient at altitude with colder air beneath much warmer air. These conditions are often associated with a cold front, where denser cold air undercuts warmer air, forcing it to rise. In the US, intense thunderstorms often form when cold air from the north or west converges with moist tropical air from the south. A great number of the springtime tornadoes in 'tornado alley' occur in this way.

- Intense convection (rising warm air) caused by the rapid warming of the ground surface during a summer's day

- The presence of cumulonimbus (thunderstorm) clouds with their powerful updrafts.

Most tornadoes in the US are spawned by intense thunderstorms known as 'supercells'. A supercell thunderstorm is an unusually large and intense weather system characterised by an exceptionally strong updraft, often in excess of 240kph (150mph). When this vertical updraft interacts with the larger scale horizontal winds a strong vertical wind shear results. This in turn causes the air to rotate to form a 'tube' of spinning air – this is the familiar funnel-shape associated with a tornado. Tornadoes typically appear near the central updraft and towards the rear of a supercell, usually behind the most intense belt of rain *(Fig. 4)*.

Fig. 4 Supercell thunderstorm and associated tornado.



Often associated with a tornado is a localised lowering of the cumulonimbus cloud known as a wall cloud. This results from humid air being drawn into the base of the main updraft. Cooling rapidly as it ascends, the moist air readily condenses to form cloud at a lower altitude than the base of the main cumulonimbus cloud. The cloud wall itself is roughly circular and typically about 3km in diameter. It is often clearly rotating and may spawn tornadoes if it is relatively long-lived (10-20 minutes).

After a tornado touches down, a downdraft develops near the rear of the supercell. This begins to wrap itself around the tornado and starts to cut off the inflow of the warm humid air that is sustaining it. Consequently the tornado weakens and dissipates. This sequence of events - an excellent example of a negative feedback - accounts for the short-lived nature of tornadoes.

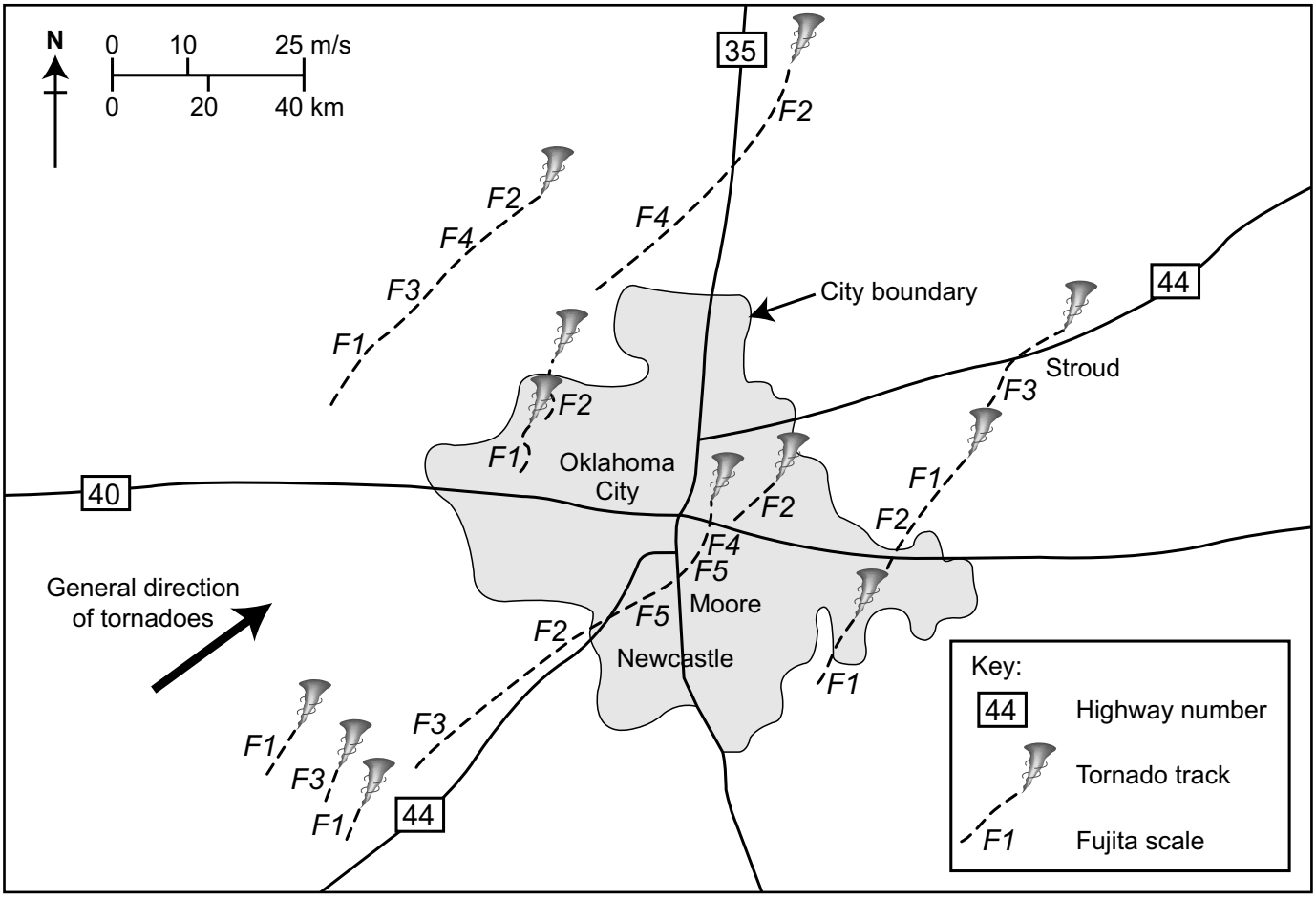
Tornadoes also form at the edges of hurricanes, which explains their occurrence in the south-eastern United States. In Bangladesh, tornadoes are formed from supercell thunderstorms, resulting from the complex mixing of different air masses (usually a hot and dry air mass from India and a moist air mass from the Bay or Bengal), as well as being associated with tropical cyclones. In the UK, they are most commonly associated with intense, often small depressions (areas of low atmospheric pressure) that move rapidly across the country.

Case Study 1: Oklahoma City/Wichita, USA, 3 May 1999

On 3 May 1999 there was a major outbreak of tornadoes in Oklahoma and Kansas in the heart of 'tornado alley' in the USA. Almost 70 tornadoes, many of them rated F3 or stronger, were spawned by a dozen supercell thunderstorms across Oklahoma and southern Kansas. One particularly intense F5 tornado tracked just east of Oklahoma City centre through densely populated suburbs killing 42 people and injuring 675 people (Fig. 5). Record wind speeds were recorded at 318mph and hailstones over 10cm across caused considerable damage to vehicles. Over $1.2bn of damage was caused by this single event. Elsewhere on the same day, an F4 tornado tore through Haysville suburb in Wichita killing 6 people, injuring 150 and causing £140m worth of damage.

This particular event resulted from the collision of low-level warm air from the Gulf of Mexico and a higher altitude pocket of cold air from the west. The mixing of the two very different air masses led to considerable instability with the warm air rising rapidly to form intense thunderstorms. Severe wind shear resulting from winds blowing in different directions at different altitudes created spinning corkscrew updrafts. The deadly tornadoes were spawned. The weather service had been tracking the progress of the storms and issued tornado warnings giving people about 30 minutes to prepare. However, despite these warnings, a considerable number of people lost their lives or were injured.

Fig. 5 Damage paths and Fujita scale ratings for tornadoes that occurred during 3rd May 1999 outbreak in central Oklahoma.



Case Study 2: Kansas/Missouri, USA, 4th May 2003

A major tornado outbreak occurred across the Kansas City area during the late afternoon and evening of May 4th 2003. It was one of the deadliest tornado outbreaks for years with 37 people killed. As many as 80 tornadoes touched down in eight states, many of which were unusually wide and long-tracked. In southeast Kansas hundreds of homes, dozens of farms, and several entire towns were wiped out. Significant tornado damage occurred in Kansas City, Kansas, as well in Gladstone and Parkville, Missouri. The deadliest tornado of the outbreak swept across Madison County, Tennessee, devastating the downtown area of Jackson. Eleven people were killed in the county, two at Jackson, and 9 in the town of Denmark, 12 miles southwest of Jackson.

Case Study 3. Tornadoes associated with Hurricane Ivan, Florida, USA, 15 September 2004

Hurricane Ivan was the most powerful of four hurricanes to strike Florida in quick succession during August and September 2004. The category 5 storm killed 34 people in the Cayman Islands before making landfall in the USA in western Florida. It spawned nearly 100 tornadoes, four (possibly five) of which caused deaths. Two people died in Panama City, Bay County, Florida, one person died in Panama City Beach, and four died in mobile homes north of Blountstown, Calhoun County, Florida. In Franklin County, Georgia, there was one death near Carnesville when a tree fell onto a car. In a possible killer tornado, two women were killed in Cecil County, Maryland, when a house was hit by a tree.

Case Study 5. Birmingham, West Midlands, UK 2005

Twenty people were injured, some seriously, when an unusually powerful tornado tore through south Birmingham on 28th July 2005. The tornado caused significant damage in the Sparkbrook and Small Heath areas of the city, ripping off roofs, uprooting trees and hurling debris through the air. One of the areas most seriously affected was the so-called 'Balti-Belt, a concentration of over 40 Indian restaurants. Here many properties were damaged and business fell by some 60% in the weeks immediately following the event.

The Association of British Insurers estimate that insurance companies will receive claims exceeding £25m. However, as many people in this relatively poor part of the city did not hold valid insurance, the real cost of the tornado will be far higher.

In common with tornadoes worldwide most of the injuries to people resulted from flying glass and masonry. Over a hundred people had to be accommodated temporarily in a sports centre and a community centre as their homes were too badly damaged to return to. It will take several months to repair the damage to buildings.

The tornado - an F2 category storm - packed winds in excess of 130mph. It was associated with a band of extremely unstable weather and thunderstorms that had formed at the boundary of warm humid air moving up from the south meeting colder dry air from the north. This is exactly the scenario that accounts for the formation of most of the tornadoes in the USA and Bangladesh. The Birmingham tornado occurred at 3pm, which is also a prime time for tornadoes to strike.

4. Tangail, Bangladesh, 13th May 1996

One of the most devastating tornado outbreaks of recent times occurred in the Tangail district of northern Bangladesh on 13th May 1996 (Fig. 6). Massive thunderstorms - probably supercells - had developed at the boundary of two distinctly different air masses. These storms spawned a number of violent tornadoes that killed between 500 and 1,000 people, injured more than 30,000 and left 100,000 people homeless. More than 80 villages were destroyed and some people were buried alive as their homes collapsed. Telephone lines were snapped, trees uprooted and crops flattened.

Fig. 6 Location of Tangail in Bangladesh.

A rough plot of the villages that were destroyed indicated that there were at least two separate tracks, about 10 miles north and south of Tangail. The northern track is estimated to have been at least 50 miles in length, which is exceptionally long.

Ironically, the extraordinary death and injury total may have been enhanced by a recent increase in prosperity. The growth of the textile industry had allowed the people in this region to move out of homes of mud and straw and into frail sheet metal structures. It tossed homes, buildings and trees as if they were feathers. The air became filled with the loose sheet metal, literally acting like an enormous blender. Hundreds of paramedics and volunteers rushed to the affected areas, but their efforts were hindered by poor weather. Of the patients visiting one of the clinics set up to care for the injured, 99% had multiple injuries due to flying corrugated iron sheets that had been used as roofs and walls. Head injury was the cause of death in a majority of cases. Seven per cent of the hospital deaths due to the tornado in Tangail district resulted from sepsis after-wound infections.

The horrendous death and injury total seems likely to be repeated in the future. An east-west corridor lying north of the capital (Dhaka) has a long history of killer tornadoes.

Responding to the tornado hazard

Tornadoes are such powerful and localised phenomena that little can be done to modify them. It is impossible to prevent them from occurring so scientists have no option but to try to predict when and where they are likely to occur and ensure that people who are at risk know how to minimise their losses.

To some extent tornadoes are predictable:

- They have a tendency to occur in certain regions, for example, 'tornado alley' in the USA.
- They are more likely to occur at certain times of year. In the southern states of 'tornado alley' they are more likely to occur from March through to May. Those associated with hurricanes will occur during the hurricane season, from July to October. In Bangladesh, April is the main month when tornadoes occur.
- Tornadoes are more likely to occur during the heat of the day, between 3 - 9pm when conditions favour convection from the warmed ground surface.
- They are associated with violent thunderstorms. Therefore, if violent thunderstorms are forming, tornadoes may well be spawned.

Whilst there are always exceptions to the rules, the predictable nature of tornadoes in time and space favours a mitigation approach involving monitoring and forecasting.

Financial resources and levels of development in general have a huge impact on a country's ability to initiate and run a coordinated and effective warning system. The experience in the USA contrasts markedly with that in Bangladesh and goes some way to explain why Bangladesh suffers so much loss of life from tornadoes.

Case Study 6: USA

On 25th March 1948 a tornado roared through Tinker Air Force Base, Oklahoma. Whilst it caused considerable damage, there were no fatalities. This was because the event was anticipated following the identification of unstable atmospheric conditions. This was the first time that a tornado had been correctly predicted using scientific information and it was the forerunner of the present system of tornado forecasting.

The US has invested huge amounts of money into researching the genesis of tornadoes and, with the help of a national network of Doppler radar stations (which can detect air motion within a weather system) and forecasting technology, the National Oceanographic and Atmospheric Administration's (NOAA) National Weather Service issues more than 15,000 severe storm and tornado alerts every year. Viewers to the Weather Channel can see up to the minute radar reports for their local area and can actually watch as storms develop and move. When conditions favour tornado formation, televisions at home, at work and in public places will all be tuned to the Weather Channel!

The length of the warnings given to the public has increased significantly as NOAA laboratories have continued to study the development of tornadoes. Between 1994 and 1998, the average warning time increased from 6 minutes to almost 12 minutes. Whilst this does not seem very long, if communities are already aware of the threat of tornadoes, it is long enough for people to go to safe locations and prepare themselves and their property. Fig. 7 describes in more detail the forecasting network in the USA.

Fig. 7 Tornado forecasting in the USA.

NOAA's Storm Prediction Centre (SPC), in Norman, Oklahoma, provides predictions of hazardous weather over the United States. The Centre coordinates with National Weather Service (NWS) field offices around the country to predict hazardous weather such as flash floods, thunderstorms, tornadoes, winter storms, blizzards and freezing precipitation.

The Centre makes maximum use of observations, numerical forecast models, Doppler Radar and geostationery satellites to generate forecasts. The Centre also enhances its operations and trains meteorologists and customers to use SPC products.

Source: Storm Prediction Centre http://www.spc.noaa.gov/faq/tornado

If hazardous weather is considered to be possible a tornado watch is announced. People in a watch area need not alter their behaviour other than to remain alert for changing weather conditions and to keep the television or radio (or computer) on for further advisories. A tornado warning is issued when hazardous weather is occurring somewhere in the region. The public is advised to take all necessary safety precautions. A tornado watch area is likely to be larger than a tornado warning area.

People in the USA are very much aware if they live in a tornado prone area. They are given advice about precautions they should take if a tornado warning is issued. Such advice includes the following:

- *Take shelter in a tornado cellar, basement or a substantial steel-framed or reinforced concrete building. Mobile homes offer little protection - nearly a third of all fatalities between 1985 and 1990 were people in mobile homes.*
- *At home head for the basement or a small room in the centre of the house.*
- *In an office or school take shelter in an interior hallway on the lowest floor.*
- *Lie flat on the floor and protect your head from falling or flying debris*
- *Stay away from windows and outside walls.*
- *If in a car, do not attempt to out-run a tornado. Take shelter indoors or, if in the open, lie flat in a ravine or ditch.*

Research by scientists at the University of Oklahoma in 2005 of some 15,000 tornadoes before and after Doppler radar was introduced has shown that fatalities have dropped by about 50%. Since the Doppler radar was introduced, tornado warnings were issued for about 85% of all F3+ category storms with an average warning lead-time of 15 minutes. The research, published in 'Weather and Forecasting' in June 2005 suggested that without Doppler, the death toll from tornadoes would be much higher than it is today.

For full article see:
www.detnews.com/2005/nation/0506/14/A04-213628.htm

Case Study 7: Bangladesh

Tornado forecasting and warning is in its infancy in Bangladesh despite the fact that systems are in place to warn of flooding and cyclones. There is no national network of Doppler radar stations and no integrated warning system. However, a group of volunteers run a worthwhile website 'Bangladesh Tornadoes', which does involve the use of meteorological maps to make forecasts.

In 2004, scientists from Kansas State University and the University of Dhaka studied the impact of a powerful tornado that affected north-central Bangladesh on 14th April 2004 killing 111 people and injuring many thousands. It was the deadliest tornado to occur in Bangladesh since the 1996 Tangail tornado. The tornado ripped through 38 villages destroying everything in its path. After conducting questionnaires in the local communities affected by the tornado, they made the following conclusions and recommendations:

- *Despite the many devastating tornadoes that have affected Bangladesh, there is a virtual absence of tornado warning systems.*
- *A tornado forecasting and warning system should be established together with a communications network to warn citizens of approaching tornadoes. Given the financial constraints, this should be targeted at the area most prone to tornadoes.*
- *Bangladesh needs more weather stations - at present there are only 28 in operation, which is inadequate for the detailed meteorological information required to predict tornadoes.*
- *All weather stations should be equipped with Doppler radar and forecasters should be trained to use this equipment. Donor governments and aid organisations such as the World Meteorological Organisation may be able to help.*
- *Once the radar stations have been established warnings should be issued via the media and through local government and community leaders. Television and radio ownership has increased in recent years and this form of dissemination could be very effective. Trained emergency personnel in local communities could visit people door-to-door to disseminate warnings.*
- *Hazard literature should be produced to enable people to know how to react to a tornado warning.*
- *Tornado warning sirens could be used to warn of a tornado.*
- *Tornado shelters need to be constructed. Many homes are flimsy and the use of tin sheets is a major hazard during a tornado.*

Bangladesh is affected by a huge variety of meteorological events including monsoon rains, tropical cyclones and tornadoes. With its predominantly poor rural population and flimsy housing, the death toll from extreme weather events is often very high. Unlike the USA with its highly advanced warning systems and procedures, the people of Bangladesh are often unaware and unprepared.

Conclusion

Tornadoes are amongst the most dramatic and evocative of all natural phenomena. They are extremely powerful and can cause tremendous destruction. However, they do exhibit some characteristics of predictability, occurring at certain times of the day and during certain months of the year. They occur when atmospheric conditions favour their formation and scientists are now able to identify tell-tale signs of impending tornadoes. People living in tornado prone areas can be made aware of the potential hazards and can help to reduce their own vulnerability.

Yet, tornadoes still represent a significant natural hazard across the world killing hundreds of people annually and causing huge amounts of damage. For people living in the wealthy USA, the tornado hazard has been minimised by the use of technological improvements in forecasting and the adoption of widespread public awareness programmes. For people living in poorer Bangladesh, the challenge for the future lies in trying to reduce their vulnerability by enabling the authorities to adopt many of the innovations that have been so successfully deployed in the USA.

Useful websites

- The Storm Prediction Center at: *www.spc.noaa.gov/faq/tornado*
- Tornado Project *www.tornadoproject.com/recent/recentts.htm*
- TORRO at: *www.torro.org.uk/TORRO/index.php*
- National Oceanographic and Atmospheric Administration at: *www.noaa.gov/tornadoes.html*
- Nebraska Weather and Climate website at: *www.hprcc.unl.edu/nebraska/may3outbreak.html*
- *http://bangladeshtornadoes.org/bdfcsts04/outlooks.html*
- Bangladesh Meteorological Department at: *www.bmd.gov.bd*

Further research

Hazards and Responses (2nd Edition), Bishop, V. (2001) Collins
Natural Hazards, Ross, S. (1998) Nelson Thornes

Student Activities

1. In Bangladesh there are an average of 6.4 tornadoes a year, whereas in the USA, there are about 1,000. However, the average annual death toll in Bangladesh is 179, whereas in the USA it is only 80. Examine the reasons why tornadoes are more deadly in Bangladesh than the USA.

2. Research the tornado that struck Bangladesh on 14 April 2004. A good starting point on the event is the detailed report published by the University of Colorado at *www.colorado.edu/hazards/qr/qr169/qr169.html*. Further information can be found at the major media websites, such as CNN and the BBC.

3. Study the information in *Fig. 8*.
   (a) Represent this information in the form of a graph.
   (b) Describe and explain the pattern shown by your graph
   (c) To what extent does the information support the assertion that tornadoes are predictable hazards?

Fig. 8 Average number of tornadoes in the USA, 1950-99.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
20	22	54	109	180	171	96	60	41	29	30	17

4. Attempt to answer one of the following A2 exam essay questions.
(a) To what extent are tornadoes predictable hazards? How does this affect the level of hazard that they represent?
(b) To what extent does the damage caused by tornadoes reflect the level of public preparedness?

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