An updated tornado climatology for the UK: 1981–2010

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In 1974 the Tornado and Storm Research Organisation (TORRO), initially called the Tornado Research Organisation, was founded by Terence Meaden to study reports of previous and new tornadoes as well as to conduct site investigations to confirm or disprove reports across the UK. These site investigations also allow further details to be built up around events, such as estimated wind speed based on damage caused, track width and track length. Since its inception TORRO has been cataloguing tornado reports extending back as far as 23 October 1091, when the first recorded tornado was noted in central London (Brown *et al.*, 2012).

Tornadoes in the UK are always rated, where possible, using the T Scale as set out by Meaden in 1972 (Meaden, 1985), and included in Table 1 for reference. These ratings can span different scale numbers such as T4/5, where tornadoes are on the borderline between two strengths, or for older events, where less information is known. Figures for older events can also be appended with ? or + where these are the best estimates from historical accounts of the time and indicate that damage is believed to have possibly reached a certain level or exceeded a certain level, respectively. The scale also includes track length (L Scale), track width (W Scale) and track area (A Scale) categories, which require a full site investigation to ascertain. These site investigations are all carried out by volunteers, many of whom are members of TORRO. Tornado totals collected by TORRO cover the UK as well as the Channel Islands and Isle of Man, as per previous studies (Reynolds, 1999), the latter due to their historical connection to the UK as Crown Dependencies, out to a distance of 30km offshore: chosen because that distance can be seen from land on a clear day. For convenience this combined area is referred to as the United Kingdom in this paper.

Tornado totals include all confirmed (where there is conclusive evidence of a tornado from observations or damage characteristic of a tornado) and probable (where there is reasonable evidence of a tornado but not enough to be certain), but not those that are merely possible (where a tornado was reported but there is insufficient evidence to count as such) reports. A Tornado Day is defined as a day in which a tornado occurs, from 0000 to 2359 UTC. Once checked and verified, reports of tornadoes are published by TORRO in *The International Journal of Meteorology* (*The Journal of Meteorology* prior to 2006).

All tornado ratings referred to in this paper are the maximum intensity reached during the lifetime of a tornado. Confidence intervals of 95% are given with all mean figures, which indicates that the actual population mean is within the range calculated from the dataset with a confidence level of 95%.

During on-site investigations after a tornado the T-scale category can be estimated based on the general level of damage caused. The following descriptions are used as guidance during such investigations:

- T0 – Exposed tiles dislodged, trail visible through crops.
- T1 – Major damage to sheds, chimney pots dislodged.
- T2 – Sheds destroyed, general tree damage.
- T3 – Garages and weak outbuildings destroyed, house roof timbers considerably exposed.
- T4 – Mobile homes destroyed, entire roofs removed from some houses.
- T5 – Wall plates/entire roofs/several rows of bricks on top floors removed, older/weaker buildings collapse entirely.
- T6 – Strongly built houses suffer major damage or are demolished.
- T7 – Brick/wooden frame houses destroyed, debarking of trees.
- T8 – Cars/heavy debris carried great distances, steel framed factory units severely damaged or destroyed.
- T9 – Many steel framed buildings demolished, trees completely debarked.
- T10 – Destruction leading to an area largely devoid of vegetation and man-made structures.

Table 1

International Tornado Intensity Scale, where tornadoes can be rated on separate wind speed, track length, track width and track area categories. For instance the 7 December 2006 Kensal Rise, London, tornado was found by the author following a site investigation to be rated T5, L4, W6 and A5.

Scale number	*Wind speed (T) (ms^{-1})*	*Track length (L)*	*Track width (W)*	*Track area (A)*
0	17–24	≤215m	≤2.1m	≤464m^2
1	25–32	216–464m	2.2–4.6m	465–2150m^2
2	33–41	465–999m	4.7–9.9m	2160–9990m^2
3	42–51	1.0–2.1km	10–21m	0.01–0.046km^2
4	52–61	2.2–4.6km	22–46m	0.047–0.21km^2
5	62–72	4.7–9.9km	47–99m	0.22–0.99km^2
6	73–83	10–21km	100–215m	1.0–4.6km^2
7	84–95	22–46km	216–464m	4.7–21km^2
8	96–107	47–99km	465–999m	22–99km^2
9	108–120	100–215km	1.0–2.1km	100–464km^2
10	121–134	216–464km	2.2–4.6km	≥465km^2

Annual mean number of tornadoes and tornado days

This paper updates the mean tornado totals for the UK to the 1981–2010 period. Previous studies for the period 1960–1989 found a mean number of tornadoes over land of 33.2 per year (Reynolds, 1999) and a mean number of tornadoes over water, colloquially known as waterspouts, of 11.1 per year (Reynolds, 1998). However, some of these events were

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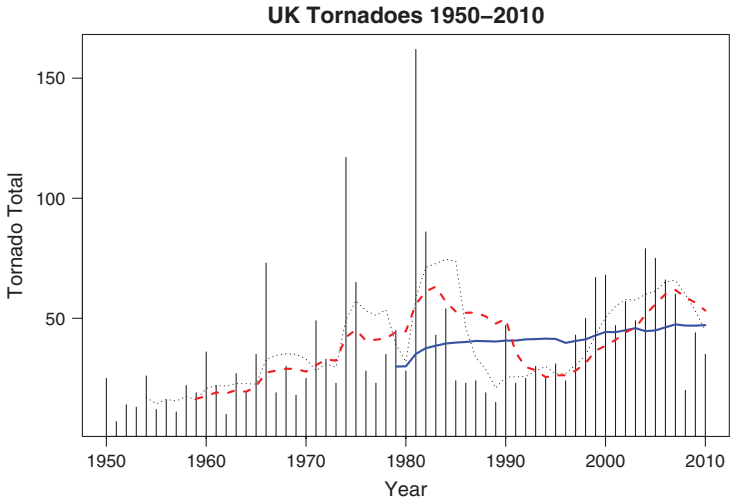

Figure 1. UK tornado totals from 1950 to 2010. Blue solid line is the running 30-year mean, red dashed line the running 10-year mean and the black dotted line the running 5-year mean.

counted twice if they had crossed from land to water or vice versa and so cannot be added to each other to find a combined total. A combined mean total of 40.3 tornadoes per year for this period can be calculated.

The total numbers of tornadoes over land and over water extending out into coastal waters of the UK have since been combined by TORRO. Using these combined figures between 1980 and 2004 there was found to be a population mean of 51.4 ± 12.8 tornadoes per year on 24.2 ± 2.0 days a year (Kirk, 2007). A review of this study following personal communication with P. Brown and T. Meaden has found some events that should not have been included and so these have been removed from the analysis. Using these figures a revised population mean of 45.7 ± 12.2 tornadoes per year and 22.6 ± 3.6 tornado days for 1980–2004.

Using the tornado totals for 1981–2010, Figure 1 gives a population mean of 47.2 ± 10.5 per year. A population mean of 24.3 ± 3.3 for tornado days where the day is known is also determined from these figures. Figure 1 shows how much of an outlier the total of 162 tornadoes recorded in 1981 is in relation to the totals recorded in all the other years. When these figures are broken down into events which for at least some of their lifetime occurred over land then population estimates are found to be 36.5 ± 10.1 per year occurring on 18.9 ± 3.0 days per year. For events over water these same figures come out as 12.7 ± 2.8 per year occurring on 8.1 ± 1.5 days per year. The individual figures for land and water do not add up to the combined figure as some events crossed between the two surfaces.

The number of tornadoes per year is highly variable, and during the period 1981–2010 ranged from a low of 15 in 1989 to a high of 162 in 1981. The second highest yearly total of 86 tornadoes recorded in 1982 is substantially lower than the 1981 total. Tornado day totals over this period range from a low of 11 in 1991 and 1996 to a high of 46 in 2004. It should be noted that the tornado day total for 1981 is just 19, reflecting the very large tornado outbreak on 23 November 1981.

Season and month of occurrence

Of the 1399 tornadoes for which the month of occurrence is known, 16.9% were recorded during winter (December–February), 14.7% during spring (March–May), 28.1% in summer (June–August) and 40.4% in autumn (September–November). For these data, November was the most active month at 15.1% (Figure 2). The figure for November is, however, a little skewed with nearly half of all events (104) occurring in a single day on 23 November 1981. The other most active days in this period were 20 October 1981 with 29 tornadoes and 21 September 1982 with 26 tornadoes. In terms of tornado days per month a similar profile is found to that of tornadoes per month, except the large outbreaks are filtered out with a peak of 14.8% in August (Figure 2).

The 23 November 1981 remains by far the most active day on record, with 104 tornadoes recorded on a squall line running ahead of a cold front in a little over 5h in an area north of a line running from North Wales to South Essex and south of a line running from Blackpool to Hull. Of these there were seven rated T0, 24 at T1, 47 at T2, 18 at T3 and three at T4 (Meaden and Rowe, 1985). It should be noted that one tornado has since been discounted from this day since the original paper was published and that all events in the TORRO database are subject to ongoing review.

Over the period 1960–1989 Reynolds (1998) found that for tornadoes over land the most active time of year was autumn (37.3%) followed by winter (30.8%). Of these the most active months were August to January (72.8%). Tornadoes over water were most common from July to October (70.5%).

Hour of occurrence

Of the tornado events in the database there is a known hour of occurrence for 950 of them. The most active time of day was 1400–1459 UTC at 11.7% and 1500–1559 UTC at 10.5%, with a general peak from 1100 to 1759 UTC accounting for 57.5% of all tornadoes (Figure 3). The least active time of day is 2000–0459 UTC, accounting for just 11.8% of known events. It should be noted that tornadoes over water are only likely to be seen during daylight hours, which is seen to be the case, with all but one of those in this period that remained over water for their entire existence being reported from 0500 to 2059 UTC, although the time for this event is questionable.

For 1960–1989 Reynolds (1998) found that tornadoes over land were most frequent between 1200 and 1659 UTC accounting for 42.0% of all events with 1400–1559 UTC totalling 21.1%. For tornadoes over water a sharp peak of 22.4% was found for 1000–1059 UTC although this is influenced by the fact there is a fairly small sample size in this case.

Location

The locations of events have been mapped based on the initial point of touchdown (Figure 4). Tornadoes are most common across southern and eastern parts of

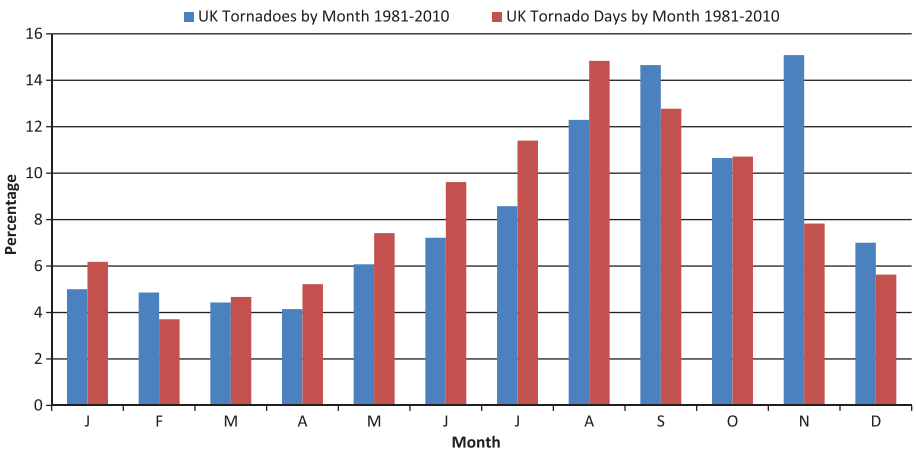

Figure 2. Percentage of UK tornadoes and tornado days by month from 1981 to 2010.

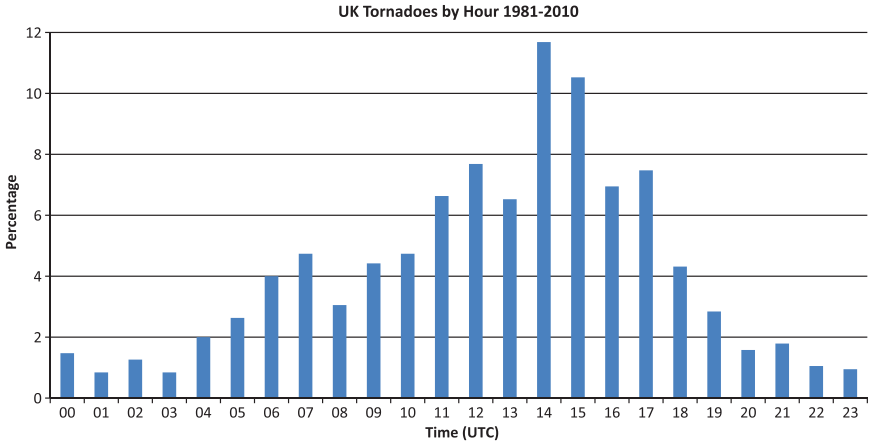

Figure 3. Percentage of UK tornadoes by hour from 1981 to 2010.

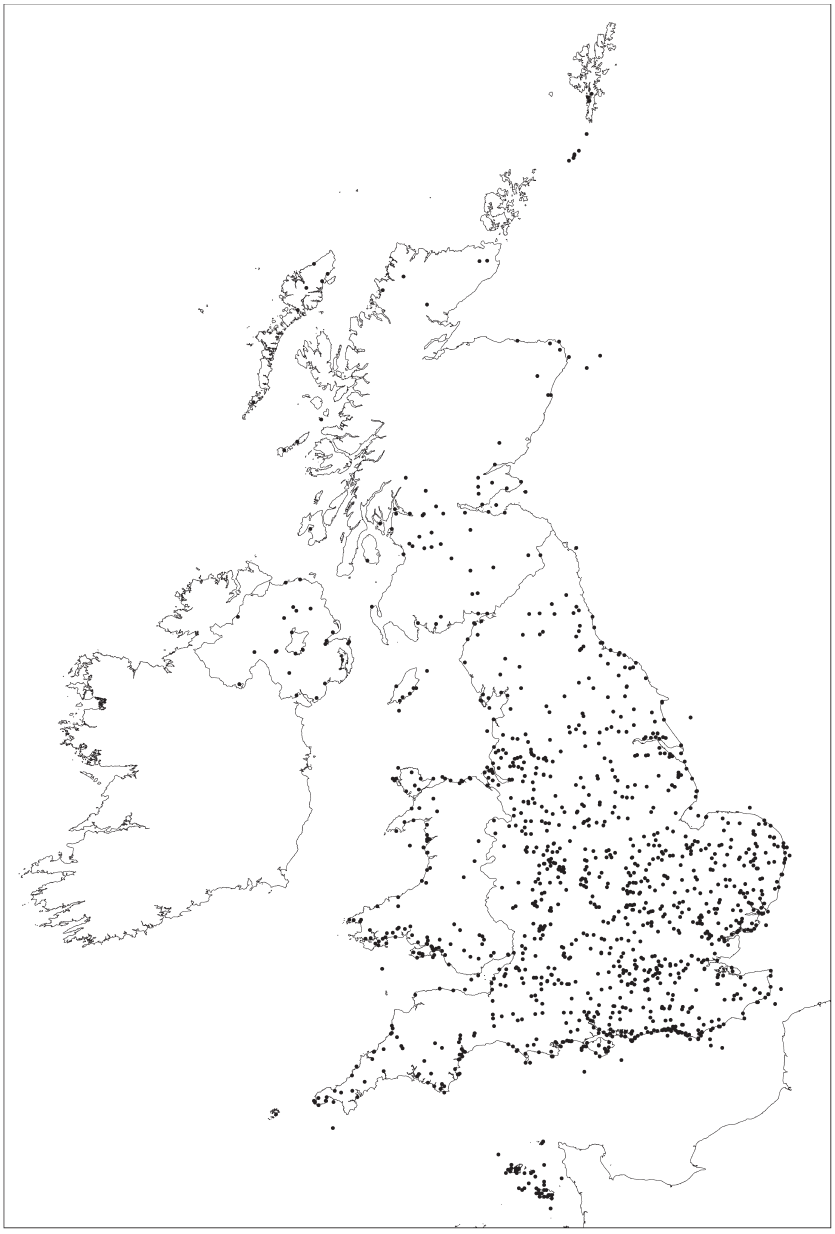

Figure 4. Location of UK tornadoes 1981–2010 based on initial touchdown.

England as well as in the vicinity of the Channel Islands. It has been noted previously that there is a high incidence of tornadoes in the vicinity of the Isle of Wight and eastwards from this location along the coast of southern England, hypothesised to be due to vortex shedding off the Isle of Wight, which can lead to tornadoes in an unstable atmosphere (Meaden *et al.*, 2005), and this is also shown to be the case here.

Reynolds (1998) found the most active areas for tornadoes over land from 1960 to 1989, in order of most active, were the counties of Norfolk, Lincolnshire, Essex, Suffolk and Kent: the most active areas for tornadoes over water were Kent, East Sussex and the Isle of Wight.

Intensities

Of the total number of 1415 tornadoes over this period, 767 have been assigned T ratings, with a peak of 38.2% at T2 (Figure 5). The strongest tornado, which reached an intensity of T5/6 on 28 July 2005 at Birmingham, West Midlands (Kirk, 2006) is shown in Figure 6. Another six tornadoes reached a maximum intensity of T5. These were on 21 September 1982 in Bicester (Oxfordshire), 7 December 1982 at Shobdon (Herefordshire), 12 November 1991 at Westley Waterless (Cambridgeshire), 17 May 1993 at St Harmon (Powys), 7 December 2006 at Kensal Rise, London, and 31 December 2006 at Ardmore (County Armagh). For 1960–1989 Reynolds (1998) found the majority of tornadoes were rated from T1 to T3 (90.2%).

It should be noted that at T0 it is difficult to rate tornadoes, due to the lack of damage usually caused and it is also difficult to rate tornadoes above T5 due to the nature of the damage caused. The last T7 occurred on 8 December 1954 in Gunnersbury, London, and the last T8 on 14 December 1810 at Old Portsmouth (Hampshire: rated T7/8). Following a recent review the 23 October 1666 tornado at Welbourn (Lincolnshire) has been upgraded to T8/9 and is now believed to be the strongest on record for the UK (Brown *et al.*, 2012). Information of these older events is, however, much more limited than that of more recent events.

Track lengths

Of the 1415 tornadoes, 255 have been assigned L (length) ratings, with a peak of 26.7% at L3 (Figure 7). Of the three with L7 ratings the longest track was recorded by the 31 December 2006 Ardmore (County Armagh) to Loanends (County Antrim) T4/5 tornado at 30.2km. Reynolds (1998) found that for the period 1960–1989 the majority of tornadoes over land were rated from L3 to L5 (76.5%).

The longest track tornado on record occurred on 21 May 1950 from Little London (Buckinghamshire) to Coveney (Cambridgeshire) covering a total distance of 107.1km, reaching a rating of L9. It was then observed to continue as a funnel cloud for a further 52.6km to Shipham (Norfolk) before moving out across the North Sea. There are no L8 rated tornadoes on record.

Maximum track widths

Out of the 1415 tornadoes, 164 have been assigned a W (maximum width) rating, with

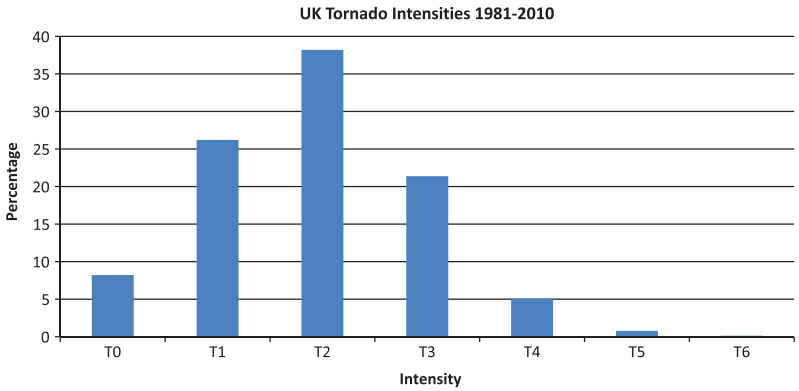

Figure 5. Percentage of UK tornado intensities from 1981 to 2010.

Figure 6. 28 July 2005 Birmingham tornado taken around maximum intensity when the track width was 500m. (© Ian Dunsford, Birmingham City Council.)

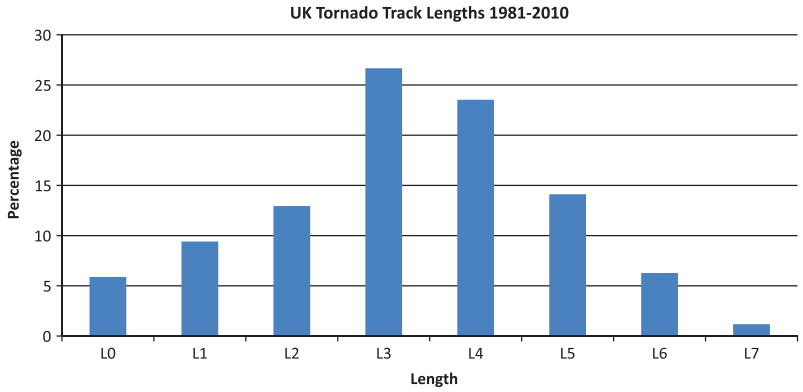

Figure 7. Percentage of UK tornado track lengths from 1981 to 2010.

a peak of 29.3% at W5 (Figure 8). Of the three rated at W8, two shared the record for the maximum width of 900m: the 7 January 1998 Selsey (West Sussex) T3 tornado (Matthews, 1999) and the 14 July 2005 Burton Joyce (Nottinghamshire) T1 tornado. There are no records of W0 tornadoes in the entire database, and given that these have maximum track widths of 2.1m they are very hard to detect and so can be easily overlooked.

There are two W9 tornadoes on record, occurring on 22 September 1810 at Fernhill Heath (Worcestershire) with an approximate width of 1600m and on 4 July 1946 at Fairlight (East Sussex) with an approximate width of 1200m.

Directions of travel

Directions of travel are known for 312 of the 1415 tornadoes, which is taken as the direction they arrive from at the initial point of touchdown (Figure 9). The most common direction is for tornadoes to move from the southwest towards the northeast (23.1%), and movement in from the south clockwise round to the northwest makes up 84.9% of all reports. Reynolds (1998) also found a sharp peak clockwise between south and west, peaking at 26.4% for south-southwest for tornadoes over land, and a peak of 23.3% for west for tornadoes over water for the 1960–1989 period. There are no tornadoes known to have moved in from the north-northeast since 1915, with just 10 on record from this direction.

Changes to reporting over time

Figure 1 shows that in recent years the 30 year mean generally increases with time. Initially, reports were mainly gathered from newspaper articles, but public awareness has gradually increased with time. This has been helped by major events, such as the 7 January 1998 Selsey (West Sussex) T3 tornado and 28 July 2005 Birmingham (West Midlands) T5/6 tornadoes, making national news headlines. Other things that have made it easier to report tornadoes include the rise of the internet, allowing easy reporting via the TORRO website, and social media such as Facebook and Twitter, as well as mobile phones equipped with cameras allowing more photographs of events to be taken. An unfortunate result of this, however, is that media reports sometimes refer to incidents of straight-line (non-tornadic) winds or land devils as tornadoes. There are also incidents of images being faked before being sent to the media, so vigilance has to be maintained to verify reports. This type of behaviour demonstrates how site investigations are especially helpful in determining whether or not a tornado has occurred.

Tornadoes are likely to remain under-reported over less populated areas, although Doppler radars such as the new dual-polarisation Doppler radars currently being installed by the Met Office are able to detect areas of rotation within storms, including mesocyclones and mesovorticies, as was shown for the 7 December 2006 Kensal Rise, London, tornado. Here a mesovortex was observed by Doppler radar in the lowest-elevation-angle radar scan at 500m above ground level or lower, just before the tornado occurred (Clark, 2011). In another case, tornadoes across Essex and Suffolk on 14 November 2009 were found to be associated with a long-lived mesocyclone within a supercell storm, which twice split into left-moving and right-moving cells (Clark, 2010). There is potential for further events, which otherwise are unreported, to be identified this way in these areas. Indeed such a tornado was picked up west of Odstock Down (Wiltshire) on 3

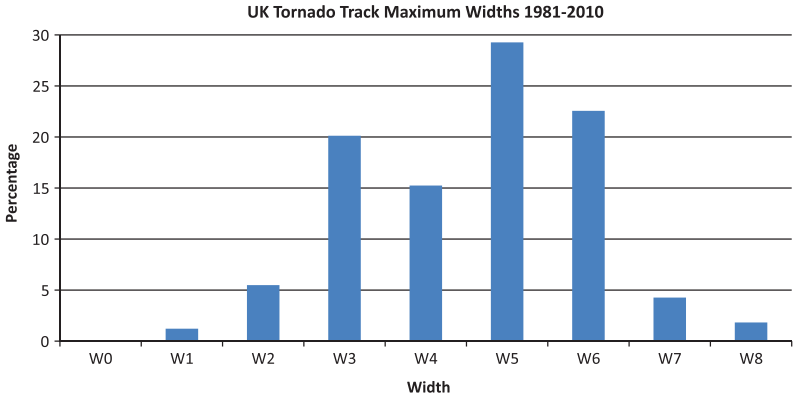

Figure 8. Percentage of UK tornado track maximum widths from 1981 to 2010.

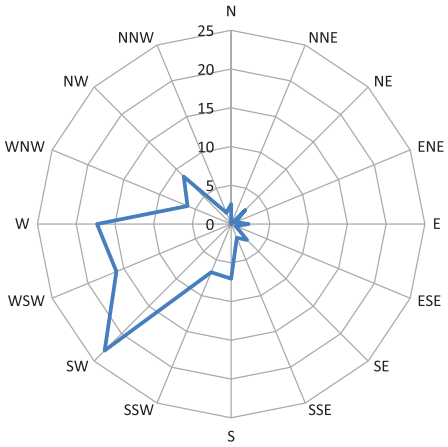

Figure 9. Percentage of UK tornado directions from 1981 to 2010.

November 2009 when several months later it was noticed on radar that a bow-shaped echo with embedded mesovortices had developed in this area. Site investigation then found that a T1 tornado had travelled along the path of one of the radar-detected mesovortices (Brown and Meaden, 2011). Analysis of Doppler radar observations showed the ten tornadoes that occurred on 3 November 2009 were associated with two of the five mesovortices observed (Clark, 2012). More recently, with the upgraded radar network, it was possible to carry out a dual-Doppler analysis on a tornadic supercell observed on 7 May 2012 that spawned three separate tornadoes (two of T2 strength and another of T4) to the northeast of Oxford (Westbrook and Clark, 2013).

Events that occur offshore close to the coast rarely do any damage and so are reported only if anyone sees them occurring. As a result these are generally reported only in daylight hours, as is seen in the data from this period, when there is good visibility and people are looking out to sea and therefore are most likely underreported.

The future

It has been anticipated that the mean number of tornadoes will fall as 1981 (162 tornadoes) and 1982 (86 tornadoes) drop off the rolling 30-year average. Using the total for 2011 and provisional figures for 2012 produces a provisional 1983–2012 population mean of 41.1 ± 6.5 for the number of tornadoes per year and 24.1 ± 3.3 for tornado days per year. The number of known tornadoes from the 1950s through to the 1970s may also increase due to a current review of newspaper reports from the time.

Conclusions

The long quoted figure of 33 tornadoes per year for the UK has now been superseded by the updated figure of 47.2 ± 10.5 for 1981–2010. Similarly the tornado days figure has been updated to 24.3 ± 3.3 for the same period. It should be noted these figures could be subject to slight revisions should further information be received by TORRO on additional tornadoes not currently known. Tornadoes are most common in summer and autumn, particularly between July and November, although they do occur year round, with a peak occurrence in mid-afternoon. Tornadoes are most frequent across southern and eastern England, particularly along the south coast east of the Isle of Wight, and in the vicinity of the Channel Islands. The majority of tornadoes investigated have intensities from T1 to T3, track lengths are quite variable but peak at L3 to L4 and maximum track widths are mostly from W3 to W6. The majority of tornadoes are found to move in from between the southwest to the west.

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