The
JOURNAL of METEOROLOGY

TORNADOES AND STORMS, 5

Proceedings of the Seventh TORRO Conference

Part 2

OXFORD BROOKES UNIVERSITY
16TH OCTOBER 1999

Volume 24, number 243 **November 1999**

THE JOURNAL OF METEOROLOGY
LE JOURNAL DE MÉTÉOROLOGIE
Published in association with
The Tornado and Storm Research Organisation
a privately supported research body, serving the national public interest
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http://www.torro.org.uk

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Published by the Artetech Publishing Co., 54 Frome Road, Bradford-on-Avon, Wiltshire, BA15 1LD, England.

Printed by Heron Press, West Wilts Trading Estate, Westbury, Wiltshire. Tel: (01373) 825602

ISSN 0307-5966

JOURNAL OF METEOROLOGY

"An international magazine for everyone interested in climate and weather, and in their influence on man."

Editor: Dr. G.T. Meaden — Vol. 24, no. 243 November 1999

PROCEEDINGS OF THE SEVENTH TORRO CONFERENCE: TORNADOES AND STORMS 5, part 2

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CONFERENCE HELD AT
OXFORD BROOKES UNIVERSITY, OXFORD
16th OCTOBER 1999

Sponsored by
The Tornado and Storm Research Organisation, TORRO, OXFORD

Published by the
Artetech Publishing Company, QED House, Frome Road, Bradford-on-Avon, Wiltshire, England

' WORK OF THE DEVIL': 'TORNADOES IN THE BRITISH ISLES TO 1660

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Abstract. A total of 35 tornadoes are known from the British Isles up to the year 1660. The earliest was in the Irish Republic in 1054, while the earliest in the United Kingdom, and one of the most violent, was in London in 1091. There are three cases from Wales, the earliest a rather doubtful case in 1173, but none from Scotland in the period under review. These early tornadoes were generally in the summer months. Most of the well-known characteristics are reported, such as funnel clouds, twisting of trees and the levitation of objects. Most tornadoes were associated with thunderstorms, often accompanied by severe hail. Several cases are attributed to the Devil; others are described as God's punishment for sins.

INTRODUCTION

In 1976 I gave an account in this journal of the tornadoes that were recorded in Britain before the year 1500 (Rowe 1976). This paper has long needed substantial revision. Most of the data in it was taken from Britton's *A Meteorological Chronology to AD 1450* (Britton 1937), which presents the texts in translation; only a few of the original Latin texts had been seen. Now most of the primary sources have been traced, which in some cases has changed the assessment of the tornado. Many of these tornadoes are interesting enough to deserve more detailed treatment than was possible in the 1976 paper. Finally, it seemed desirable to cover in one paper all the tornadoes recorded in the pre-scientific period, here regarded as ending in 1660. The Royal Society was founded in 1662 and a number of tornadoes are reported, in a noticeably more scientific way, in its *Philosophical Transactions* from 1671 onwards.

In this paper the 35 tornadoes known for the period ending in 1660 are individually described, with less attention being given to the less definite cases. Finally I examine the tornado characteristics reported in these early sources. All dates have been converted to the Gregorian (New Style) calendar.

SOURCES

For the period up to 1450 nearly all known British tornadoes can be found in Britton's *Chronology* mentioned above. Britton's sources were the medieval chronicles, most of which were published in the 19th century, generally in the Rolls Series (abbreviated in this paper to R.S. in the references for each case). Britton does not always quote from the source nearest in time to the event; his translation is very occasionally faulty; and he sometimes omits details which help to clinch the tornadic nature of a storm (such as the "angels of Satan" seen during the tornado of 1234). Nevertheless his work represents a colossal effort and remains very useful.

After 1450 we rely on the early printed chronicles by Holinshed (1586) and Stow (1615, 1631), and on pamphlets issued shortly after the events they describe.

THE TORNADOES

TN 1054 April 30. *Rosdalla, County Westmeath, Irish Republic*

Although several earlier possible tornadoes are known from the British Isles, especially Ireland (Meaden 1975), this is the first definite example. The *Chronicum Scotorum* (ed. W.M. Hennessy, R.S., 1866: 280-28 1) describes a "tower of fire" surrounded by many "black birds" which went into and out of the "tower". When they came out they lifted a greyhound and dropped it, killing it; they also lifted three garments. When the birds perched on trees the trees fell, and an oak was shaken.There seems no doubt that the "tower of fire" was a funnel cloud and the "birds" debris circling the funnel. For a fuller account of this incident see Rowe 1989.

The earliest known tornado in Northern Ireland was at Termonomungan, County Tyrone, on 11 October 1752 (Henry 1753).

TN 1091 October 23. *London (c TQ 3381)*

Britton calls this event a "great gale", but his account, from Roger de Hoveden (end of the 12th century), clearly indicates a tornado. Roger's version is identical with that given by the earlier chronicler Florence of Worcester, which if actually written by Florence himself (there is some doubt) must date from before 1118, when Florence died. "A very powerful whirlwind, coming from the south, knocked down more than 600 houses and a considerable number of churches. It also struck the church called St. Mary le Bow, killed two people in it and, lifting the roof with the timbers aloft, carried them back and forth in the air for a long time. Finally it fixed six of the timbers, in the same position in which they had been fixed in the roof, so deep in the ground that only a seventh or eighth part protruded; yet they were 27 or 28 feet long" (*Florentii Wigorniensis Chronicon*, ed. B. Thorpe, 2. 29, 1849). A very similar account is given by William of Malmesbury, writing about 1125, who comments that the tornado was "a great spectacle for those watching from afar, but a terrifying experience for those standing near" (William of Malmesbury, *Gesta Regum Anglorum*, 4: 505). This appears to be possibly the most violent tornado on record in the British Isles, perhaps force T8.

TN 1141 May 19. *Wellesbourne, Warwickshire (SP 2755)*

This is the first recorded tornado to be associated with a severe summer thunderstorm. "A powerful whirlwind (*ventus turbinis*) arose, and a most foul darkness (*caligo teterrima*) reached from the earth to the sky. Striking the house of a priest called Leofred it razed his outbuildings to the ground and smashed them to pieces. It also removed the church roof and threw it across the River Avon. It also threw down in a similar way almost 50 houses of the peasants and left them uninhabitable. There also fell hail up to the size of pigeons' eggs, by the blows of which a woman was killed" (John of Worcester, *Florentii Wigorniensis Chronicon*, ed. B. Thorpe, 2. 131, 1849). Britton, who gives John's account, states that the text gives the date as May 1140, but that a later writer gives 1141. However, Thorpe's edition of John clearly dates the tornado "on the fourth day before the octave of the Ascension," 1141, which means 19 May by the Gregorian calendar (Rowe1975). This was clearly another very severe tornado, at least force T5. The "most foul darkness" is probably a reference to the tornado funnel.

tn 1149. *England; exact location not known*

The *Waverley Annals* describe a "terrible whirlwind" which destroyed houses and woodland. In this storm "devils in the form of hideous beasts" were said to have fought each other (*Annales Monasterii de Waverleia*, in *Annales Monastici*, ed. H.R. Luard, R.S.: 233, 1865). The severity of the damage strongly suggests a tornado (force at least T5), and the "demons" are probably a reference to the funnel.

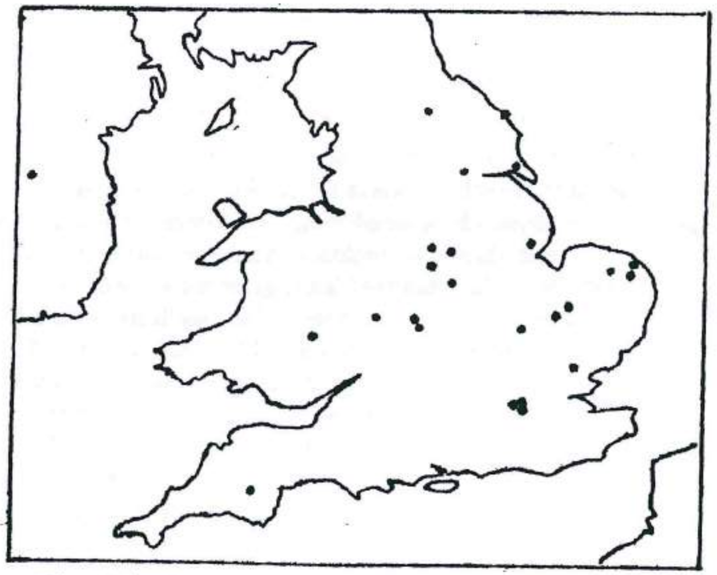

Fig. 1 Distributon of tornadoes in the British Isles to 1660

TN 1165 August. *Scarborough, North Yorkshire (c TA 0388)*

In this storm "many people saw the old enemy taking the lead...he was in the form of a black horse of large size, and always kept hurrying towards the sea, while he was followed by thunder and lightning, and fearful noises and destructive hail. The footprints of this accursed horse were of a very enormous size, especially on the hill near the town of Scardeburch, from which he gave a leap into the sea; and here for a whole year afterwards, they were plainly visible, the impression of each foot being deeply graven in the earth." Is the "black horse" a tornado funnel, and, even more intriguingly, are the "footprints" the impressions of suction vortices? Would such impressions remain visible for a whole year? I now feel that this is a probable rather than a definite tornado, but have here retained it as definite, in line with the TORRO Tornado Database. Unfortunately I only have Britton's translation of this text, from *Chronicle of Melrose*: 130 (Church Historians of England, 1856).

tn 1173 May 24. *Wales?*

On Ascension Thursday a thunderstorm, with hail and a"whirlwind" broke branches off trees and threw trees to the ground (*Brut y Tywysogion* ed. J. Williams ab Ithel, R.S.: 220-221, 1860). This case must be considered rather doubtful, especially as the text is a translation (the original is in Welsh). However, the TORRO Database assessment is again followed here.

TN 1205 August 4. *England; exact location not known*

On this date Ralph of Coggeshall records a severe thunderstorm, with hail damage (the hailstones were said to have been as big as goose eggs). Some of the damage was clearly tornadic: 'Trees were pulled up by the roots and carried away; some were twisted like ropes; some were visibly snapped across the middle"(*Radulphi de Coggeshall Chronicon Anglicanum*, ed. J. Stevenson, R.S.: 155-156, 1875). This is the earliest reference to the characteristic twisting of trees by a tornado. Ralph also discusses some "monstrous footprints" found the next day, "which people said were the "footprints" of demons". (Vestigia may mean "signs" rather than "footprints.") Force: perhaps T3-4.

TN 1222 December 7. *Pillerton Priors (SP 2947) or Pillerton Hersey (SP 3048), Warwickshire*

Here we have the first reference to a tornado sucking up water. The storm "struck the buildings of a certain knight, crushing (opprimens) his wife and eight people of both sexes." It then hit "a turf pit ... surrounded by deep water and a marsh, and in the twinkling of an eye dried it up, leaving neither plants nor mud in it, only the dry stones" (Roger of Wendover, *Flores Historiarum*, ed. H.O. Coxe, 4: 83, 1842). If the nine people injured all died this would perhaps be the highest death toll in any British tornado. Force: T5, possibly higher.

2WS 1233 June. *South coast of England*

This, by far the earliest known waterspout sighting in Britain, is briefly described by Roger of Wendover (for reference and translation see Rowe 1976).

TN 1234 July 23. Abbotsley, Cambridgeshire (TL 2256)

During a thunderstorm with heavy rain and hail there was a "whirlwind whipped up by a blast from hell" (*flatu diabolico*). Roger of Wendover (*op.*cit., *4*: 321-322) goes on to say, in a passage which Britton omits: "Angels of Satan were seen flying around in the air." Matthew Paris, even more interestingly, describes "angels of Satan in the form of black satyrs" (Matthew Paris, *Chronica Majora* , R.S., *3*: 302-303). There can be little doubt that this is a description of a tornado funnel.

TN 1244 June 18. *England; exact location unknown*

"A violent whirlwind levelled many trees and houses," according to John de Taxter's continuation of Florence of Worcester's *Chronicon*: 323 (Bohn, 1854). Britton calls this a gale, but the severity of the damage clearly indicates a tornado, of force T5 or perhaps more.

TN 1246 July 26. *England; exact location unknown*

Matthew Paris (*4*, 568) describes a severe thunderstorm which "twisted oak trees, destroyed buildings" and caused other damage, some of it clearly attributable to floods and some probably to the hail, which was larger than almonds. The twisted trees, however, should indicate a tornado.

FC 1251 May 26. *Saint Albans, Hertfordshire (TI, l 507)*

This was given as a tornado in iny 1976 paper, but the primary text has no reference to damage (except by lightning). It does, however, give a very clear description of a funnel cloud. "When they had left the town they saw meeting them a torch like a drawn sword, 'but *plicabilis*, with thunder and a terrible roaring sound (*murmure horribili*)" (Matthew Paris, *5*: 263-264). Britton does not translate the word plicabilis, but it probably refers to the rotation of the funnel, since plicare can mean "to coil". He takes *murmure horribili* to mean "a dreadful murmuring"; but Latin *murmur* can mean "roar", which seems to accord better with the adjective *horribilis.*

tn 1257 January 4. *England; exact location unknown*

"A fierce whirlwind darkened the air "as if it were night," with thunder, lightning and violent hail (Matthew Paris, *5*: 607). No conclusive evidence of a tornado is given.

TN 1262 July 1 (approx.). *Grimley (SO 8360) and Henwick (SO 8354), Hereford and Worcester*

A severe thunderstorm "about the feast of St. John the Baptist" (24 June, Old Style) threw down the granges at Grimley and Henwick and uprooted large trees, according to the Worcester Annals (*Annales Prioratus de Wigornia* , in *Annales Monastici*, 4: 447, ed. H.R. Luard, R.S., 1869). Such severe damage (T5?) to buildings in summer is unlikely to be ordinary wind damage. If both places were struck by the same tornado it had a 6kin track from south to north (north to south is much less likely).

tn 1271 July 11. *England; exact location unknown*

The same source (p. 460) mentions a violent wind which blew down trees and rooted up crops. This may have been simply a thunderstorm squall, though the uprooting of crops is usually a sign of a tornado. The event probably occurred in the Worcester area.

TN 1279 May. *England; exact location unknown*

Another local chronicle, the *Dunstable Annals*, describes "a terrible thunderstorm; in many places trees were uprooted and carried to other places; people were carried off in clouds; buildings collapsed., lakes were dried up; crosses were reduced to small fragments" (*Annales Prioratus de Dunstaplia*, in *Annales Monastici*, *3*.: 280, ed. Luard, R.S., 1866). The drying up of lakes and the carrying of trees and people, even if exaggerated, undoubtedly indicate a tornado. Instead of trees being "carried to other places" Britton has "at other places borne down", but this seems a less obvious translation of *ad alia loca transportatae*. The force was perhaps T4.

q 1286 May 9. *England; exact location unknown.*

The Worcester Annals (p. 492) record a thunderstorm, with hail as large as stones,

The Worcester Annals (p. 492) record a thunderstorm, with hail as large as stones, which levelled crops, penetrated houses, broke off branches and severed leaves and flowers, "and in many places various monsters were seen." This was regarded as a tornado in the 1976 article, on the strength of the "monsters", which were taken to be a possible reference to a tornado funnel. However, the case is best classified as a thunderstorm squall, especially as it is not certain what the writer intended by *monstra.*

tn 1291 August 18. *Boston, Linconshire (TF 3244)*

In a thunderstorm "at the market of St. Botulf .. a demon ... threw down the pillars of a gallery with his claws, and destroyed a mill outside the village and killed a woman in it, and killed three people in the countryside nearby," according to Bartholomew de Cotton's *Historia Anglicana* (ed. Luard, R.S., 1859, Appendix D: 430). Britton, in his translation, has "several mills" and "a number of women." In my 1976 paper 1 adopted Dr. Meaden's suggestion that "the market of St. Botulf 'was a village in Norfolk, which was plausible, as Bartholomew was a monk of Norwich. However, 1 have long felt that the correct location was Boston, a place-name which contains the name of St. Botulf. This seems to be confirmed by the late 13th-century poem *Dame Sirith*, in which it is said of one of the characters that "he was gon/ To the feire at Botolfston/ In Lincolneschire" (Bennett and Smithers 1968: 82, 308). This is the earliest record of 'fair" in this sense, and "the fair at Boston" corresponds exactly to the "market of St. Botulf" in Bartholomew's text. The "demon" is assumed to be a reference to a tornado, but there can be no certainty about this.

TN 1323 July 2 (approx.). *Cowick, Humberside (SE 6521)*

There can be no doubt that this was a true tornado. Matthew of Westminster (*Flores Historiarum*, *3*: 216-217, ed. Luard, 1890) tells how "an evil spirit ... in a furious storm and dark whirlwind" struck Cowick while Edward II was dining there. The storm covered the place with "a darkness like night ... it tore up by the roots oaks of wonderful size, and other trees, twisting some in two at the middle; some it split from the top downwards." Debris was carried aloft, and water lifted and carried "beyond the houses of the manor." Britton, who used a different edition of this chronicle, has only one tree twisted and one tree split (p. 134).

TN 1396 July 3. *Keyingham, Humberside (TA 2425)*

The Melsa Chronicle has a very long account of the damage caused by "a whirlwind coming from the south," accompanied by a thunderstorm. Stones from the church were thrown into or onto the rectory (*Chronicon Monasterii de Melsa*, *3*: 193-195, cd. E.A. Bond, 1868). The description of the damage is very similar to that in the Widecombe tornado of 1638; in both cases it is very difficult to know how much of the damage was due to the tornado, and how much to lightning. This tornado occurred at night (the villagers were asleep at the time). Britton gives the location as "Kanyngham", which in the 1976 article was identified as "Caynham, Yorkshire"; but no place of this name is listed for Yorkshire in the Ordnance Survey's *Gazetteer* to the 1; 50 000 map series (though there in one in Shropshire), or by Ekwall (1960).

to the 1; 50 000 map series (though there in one in Shropshire), or by Ekwall (1960). The original text has "Kayngham", which the editor identifies as "Kayingham". Other evidence in the book makes it clear that this is Keyingham.

tn 1402 June 3. *Danbury, Essex (TL 7805)*

Britton (p. 153) mentions a thunderstonn at about 3pm, and says that there follows an account of a devil appearing to a man at Danbury and injuring him." There was also damage to the church. His source is the *Annales Henrici Quarti*: 340 (R.S., 1866), which I have not seen. Holinshed, however, mentions the event, and says that the devil was " in the likenesse of a Gray frier", and that there was a "tempest of whirlewind" at the same time.

tn 1402 July 3. *Hereford, Herefordshire (c S0 5139), or Hertford, Hertfordshire (c TL 3212*

The *Annales Henrici Quarti* (p.342) record another thunderstorm in which a devil appeared. This time it did damage to a church at Hereford or Hertford; Britton (p.153) gives both places, and unfortunately 1 have not managed to find the original text.

TN 1402 *September 16. Wales*

This is another report from the Annales Henrici Quarti (p.343). Henry IV was in Wales when, during the night, heavy rain fell, followed by "such a whirlwind that this same king's tent was broken, tom and dashed to the ground and the king's lances were violently thrown and transfixed in the royal armour" (translated by Britton). Britton dates the event vaguely as having occurred in "August or September", though the chronicle states quite clearly that the date was "the vigil of the nativity of St. Mary" (see Rowe 1975).

tn 1438 December 2. *London (c TQ 3281)*

"A great wind" almost destroyed "one side of the old Exchange ... all housing with great long trees" (*Chronicles of London*, ed. C.L. Kingsford: 145, Oxford, 1905; spelling modernised). The severity of the damage suggests a tomado, although we are told that the storm "did much harm in many places," so there was probably a general gale as well.

TN 1545 June 30. *Duffield to Heage, Derbyshire (SK 3343 - 3650)*

This tornado was supposed to be the work of the Devil - hence the title of this paper. At Belper 40 houses were damaged, while at Belper Wood "he hath pullyd down a wonderous thyng of wood and kylled many beaste." He then moved on to Heage, where he pulled down "the chappyl and the moste part of the towne" (F.A. Barnes and C.A.M King, A tornado at Tibshelf, Derbyshire, *Weather*,.*7*: 214, 1952). The authors say. "A reference to the upward explosion of a house indicates that this was a tornado." It is the first one for which we can reconstruct the track, which was 8km long and from S.S.W. The force was about T6.

TN 1558 July 17 or 21. *Sneinton, Nottinghamshire (c SK 5838)*

A severe thunderstorm with hail allegedly 15 inches (38cm) in circumference

destroyed houses and churches; the bells were thrown to the outside of the churchyards, and some sheets of lead were carried 400 feet (122 metres). Water and mud from the River Trent were carried a quarter of a mile and thrown against trees. Trees were uprooted and carried "twelve score" (240 - yards, or feet?). A child was carried 100 feet (30 metres) and dropped; his arm was broken and he died of the injury; five or six men were killed in the same area (Holinshed, 1586; Stow, 1615 ed.: 634). The earliest sources indicate that the date was 7 July, Old Style, but Short (1749) gives 11 July. Force; about T6.

TN 1563 January 19. *Leicester, Leicestershire (cSK5804)*

A "great tempest of wind and thunder uncovered 42 bays of houses and overthrew many, renting and tearing them to pieces" (Holinshed, 3: 1198). This tornado may also have been about T6.

TN 1577 March 27. *Patrick Brompton, North Yorkshire (SE 2290)*

A "strange tempest" destroyed "not only cottages, trees, barns, and haystacks, but also the most part of a church called Patrike Brumton...with most strange sights in the air both fearful and terrible" (Stow, 1615 ed.: 680; Holinshed, *3*: 1230). The "most strange sights in the air" suggest that the funnel was seen. This is another possible T6 tornado.

TN 1582 August 22. *Honing to East Ruston, Norfolk (|TG 3227 -3427)*

This tornado uprooted trees "or wound them like withes" (twisted them like willows). At Honing the church door, which weighed over 300 pounds, was lifted off its hooks and thrown over the font. At East Ruston many barns were blown down and houses unroofed (Holinshed, *3*: 1348; Stow, 1615 ed.: 695). The tornado was associated with a thunderstorm, and hail two to three inches in circumference. The track was at least 2km long, probably from west to east rather than the reverse. The force seems to have been T4.

TN 1585 October 5. *Hay-on-Wye, Powys (SO 2342)*

An anonymous pamphlet of 1585 (*A most rare and true report, of such great tempest, strange sightes, and wonderful accidents, which happened by the providence of God, in Herefordshire, at a place called the Hay ...*) gives a description of a "wonderfull and cruell tempeste" which caused great damage. In this "an innumerable companie of black Crowes and other Fowles ... were of divers credible persons visibly seen to rent and tear whole houses, barnes and stables, ye and to pull out whole and huge trees by the rootes ... yea and a most dreadful sight some of the rafters and peeces thereof, were carried up in the aire, and after that never sithens seene, with great store of corne which at that time was carried away." As for trees, "Some were pulled up by the roots and cast abouthe ... some cut as it were with a cross saw and ... some so straungely withern [twisted] as the like has not been seen." Much more puzzlingly, there was "a most huge great and ugly black dog, who running along in the presence of manne [many] beholders, rent, toare, and pulled up whole trees by the roots." The "dog" is presumably the funnel, but the description is certainly bizarre.

Moreover there are other references to "black dogs" in storms, the best known having occurred only eight years before the Hay tornado, at Bungay, Suffolk, on 14 August 1577. (The most accessible account of this incident is probably that given by Harvey (1951), who incorrectly dates the event 1557.) The "crows" (very reminiscent of the "black birds" in the tornado of 1054) are probably the debris raised by the tornado. The pamphlet is reproduced in full and discussed by G.L. Fairs, A tornado at Hay in Herefordshire in the year 1585, *J. Meteorology* 7: 187-191, July/August 1982. This is the first tornado which is clearly stated to be "an alarum to awake us from our sinfull and sluggish sleeping;" indeed the exhortations to repentance and other religious reflections occupy about half the pamphlet. A similar emphasis is found in most of the other cases between this one and 1660. The force was T4, perhaps more.

WS/TN 1626 June 22. *London (c TQ3079)*

At 2pm there was "a strange tempestuous whirle-wind upon the Thames ... much water was lifted up into the ayre" and it became so dark that passengers in boats could hardly see each other. This was in the Westminster area. There was then a severe thunderstorm with "extreme hayle", some of which took two days to melt. There was damage to churchyards at Holborn and Bishopsgate, but it is not clear whether this was tornadic; it may have been due to heavy rain (coffins were exposed). Nevertheless, it is unlikely that the waterspout's track was entirely over water. The report is in Stow, 1631 ed.: 1042.

TN 1638 October 3 1. Widecombe in the Moor, Devon (SX 7176)

This is probably the best known early tornado in Britain. It was brought to the attention of meteorologists by L.C.W. Bonacina, The Widecombe calamity of 1638, *Weather*, *1*: 122-125, August 1946. The storm was the subject of several pamphlets issued shortly after the event; two of these are reproduced by J.B. Rowe, *The Two Widecombe Tracts, 1638, giving a Contemporary Account of the great Storm, Reprinted with an Introduction; Devon Notes and Queries, 3* (2); Exeter, James G. Commin, 1905. There was a severe thunderstorm, and a great deal of damage to the church, some of it by lightning. The clearest evidence of a tornado is the lifting of a dog: two people were leaving the church when " at the Chancell doore, they saw the Dogg whirled up some height from the ground, taken up and let downe againe three times together, and at last fell downe stone dead, all the lightening being past, neither could they see any thing at all neare the Dogg." Large stones were thrown at least 100 yards from the church, and a house "was torne up, the covering carried off." Bonacina gives a fascinating and apparently contemporary woodcut depicting the storm, including what may well be a funnel cloud; but Rowe (1905) says that the origin of this picture is unknown. The number of dead and injured is given as about 60; but it is clear that the death toll was only five to seven (Rowe 1980). Again, as with the 1585 tornado, religious exhortation and comment loom large in the contemporary pamphlets. There was also damage to the church at "Norton" in Somerset, and very large hail, the size of turkeys' eggs, at Brixton (SX 5552), near Plymouth. Brooks (1954: 37, 39) identifies "Norton" as Norton Fitzwarren (ST 1925) and shows the track of the storm cell from

Brixton to Norton on his map of British tornado tracks, though strictly speaking we only know that the storm was tornadic at Widecombe.

TN 1646 May 31. *Thetford/ Newmarket, Cambridgeshire/ Suffolk Norfolk (TL 77?)*
TN 1646 May 31. *Brandon Parva, Norfolk (TG 0708)*
TN 1646 May 31. *Swaffham Prior, Cambridgeshire (TL 5764)*

The events of this date were discussed by several writers in the *Journal of the British Astronomical Association* in 1979-1980. The initial feeling was that there had been a meteorite fall, but the events are clearly tornadic. Besides funnel clouds at Cornberton, Cambridgeshire (TL 3856) there are three definite tornadoes. "Betwixt *Newmarket* and the town of *Thetford* ... there was observed a piller or a Cloud to ascend from the earth, with the bright hilts of a sword towards the bottom of it, which piller did ascend in pyramidall form, and fashioned it self into the forme of a Spire or broach steeple, and there descended also out of the sky, the forme of a Pike or Lance, with a very sharp head or point to encounter with it." At Brandon there was "a spire Steeple ascending up from the earth, and a Pike or Lance descending downwards from Heaven." At Swaffham there was "a dense pyramid-shaped cloud of smoke streaked with a reddish colour, which was pointed in shape at the top but had four thick stems at the bottom." The cloud reached the ground, made a lot of noise and lifted two stones. Rotation was clearly observed. It was "a violent hot Day"; in various places there were severe thunderstorms, with rain, and hailstones of "extraordinary" size, "and some hollow within like rings." Not surprisingly after almost four years of civil war the texts ask for God's mercy in preventing 'further conflicts and effusion of blood," and the people are admonished to take heed of this "warning Trumpet ... that we may speedily awaken out of our sins." For the full texts of the reports see M. Rowe, The supposed East Anghan meteorite of 1646, *J. Brit. astron. Assoc., 90*: 478-479, August 1980, and references given there.

TN 1656 July 30. *Norwich, Norfolk (c TG 2308)*

A violent thunderstorm with large hail took place during the afternoon. There was also "a black Cloud of Smoke, like unto the Smoke of a Furnace, and ever and anon it did cast forth Flames of Fire." When it reached Norwich "there arose a sudden Whirlwind," but this only seems to have raised dust in the city, though trees were uprooted in the countryside. Enormous damage was caused by the "stupendious" hail, which was five inches (13cm) or more in circumference. The tornado is described in an anonymous pamphlet, *The most lamentable and dreadful Thunder and Lightning the County* of Norfolk, *and the City* of Norwich .... London, 1656. I have used the reprint in *The Harleian Miscellany, 2*: 272-274, 1744. The writer takes the storm to be an example of "the Anger of the Almighty, for our great and crying Sins."

TN 1660 June 12. *Worthington to Tonge, Leicestershire (SK 4020 - 4123)*

About 3 or 4pm "there arose a mighty whirlwind, which untiled and unthatched many of the houses in Worthington." At Worthington Hall "it took away, or cast down several bays of a building there, bringing down the great barn. Also it took up a great log of wood from a mill-pond, whirling it out." After blowing down many large trees in a wood, taking the bark off some of them, it reached Tonge, where more trees were uprooted; a beehive was removed and never found. Source: an anonymous pamphlet, *The Lords Loud Call to England*, London, 1660; the meteorological sections are in G.T. Meaden, A tornado in Leicestershire and a severe hailstorm in Kent in the summer of 1660, *J. Meteorology 4*: 148-150, May/ June 1979. The force was about T4, and the track was 3km long, from S.S.W.

DISCUSSION

By 1660 almost all the tornado characteristics familiar from modern reports had been described, though often in ways that seem strange to us. The funnel is referred to as a "tower of fire" (1054), as resembling smoke (1626, 1656) or simply as a "dark whirlwind" (1323). The word *caligo*, used in 1141, may mean "dark mist or cloud". In 1646 we have the funnel described as a pyramid, spire or steeple. The "angels of Satan in the form of black satyrs" (1234) undoubtedly refer to a funnel, and the same is probably true of at least some of the "demons" of 1149, 1291 and June and July 1402. This may also be true of the "black horse" of 1165, and possibly the "black dog" of 1585. Debris circling the funnel accounts for the "black birds" of 1054 and the "crows" of 1585. The characteristic tornado roar is possibly referred to in 1165, 1251, 1585 and 1646.

Rotation is not definitely mentioned until 1646, though it is probable that the word *plicabilis* refers to it in 1251. However, rotation and shear effects are clearly implied by the twisting of trees (1205,1246,1323,1582,1585).

A variety of objects were lifted by the tornadoes: a greyhound and three garments (1054); another dog (1638); a church roof (1091); a church door (1582); water (1222, 1279, 1323, 1558, 1626), rafters (1585); a log (1660); even people (1279, 1558). Objects carried and dropped some distance away include, besides the cases just mentioned (where the emphasis was on vertical motion): a church roof (1141); trees (1205, 1279, 1585); stones (1396, 1638, 1646); a beehive (1660).

For six of the tornadoes the track direction is given (the first in 1091) or can be deduced. The tracks were all from between south and west, as is normal today, though it is conceivable that the 1582 tornado moved from the east. Three track lengths are known, none from the original sources: 8km in 1545, 2km in 1582 and 3km in 1660. These are minimum lengths: there may well have been other damage not recorded. None of the texts before 1660 specifically mentions a narrow track: the earliest is 20 yards near Macclesfield, Cheshire, on 9 August 1662 (Short, 1749, *1*: 337), which is also the first report to specify a track length.

Of the 34 tornadoes for which the month of occurrence is given, 24 were between May and August, with nine in July, six in May (but three of these were on one day), five in June and four in August. The only other months to record more than one were October (three) and January and December (two each). No tornadoes were noted in February and November until 1731 and 1669 respectively. The marked summer peak is because most of these tornadoes were associated with violent summer thunderstorms. We now know that many tornadoes occur in autumn and winter; these were rarely recorded, probably because wind damage at that time of year is less newsworthy, and also because the damage was not distinguished from general gale damage. Most of the tornadoes occurred, by implication, during daylight hours; ten are stated to have occurred in the afternoon. Three took place at night (1205, 1396 and September 1402).

The overwhelming majority of the tornadoes were reported in England, with one from Ireland and three from Wales, but none from Scotland, where, the earliest record is for 1767 (Rowe 1999). Of the 22 tornadoes that can be assigned to an English county (Fig. 1) Norfolk and Greater London had three each; North Yorkshire, Cambridgeshire, Warwickshire, Humberside and Leicestershire two each. The concentration of tornadoes in the Midlands and East Anglia is noteworthy, and the absence of cases in the counties near the south coast of England is quite a surprise: in modern times most of these counties have been roughly as tornado-prone as the Midlands and East Anglia. There may be a slight recording bias, in that several of the local chronicles in medieval times were from the Midlands. But severe tornadoes - and most of these early cases were severe - appear to have a different distribution from tornadoes in general, more closely resembling the pattern shown in Fig. 1 (see Meaden 1976: 249, Fig.3, which shows the distribution of tornadoes of force T4 or more). Severe hailstorms have a fairly similar distribution, being most frequent in a zone stretching from Kent across the Midlands to Lancashire (Webb, Rowe and Elsom 1994: 336, Fig. 1). Finally, and not surprisingly, these are also the most thunder-prone areas.

Of the 35 tornadoes up to 1660, 20 were associated with thunderstorms and 12 with hail, in both cases usually severe. It is not always clear whether the thunderstorm and hail actually occurred at the same place as the tornado. The circumference of the hailstones was given as two to three inches (1582), five inches (1656), and even 15 inches (1558). Other reports mention hail as large as pigeons' eggs (1141), goose eggs (1205) and almonds (1246). The hail as big as turkeys' eggs which fell at Brixton, Devon, on the date of the 1638 tornado was probably from the same storm cell that later produced the tornado.

The strength of the tornadoes reported in these early years is well above the modern average, but this merely means that only the most severe tornadoes were recorded. The indications of strength on the TORRO scale given in this paper must be regarded as very approximate.

How did knowledge of tornadoes grow during these early centuries (assuming that the reports could have been collated at the time)? By 1100 tornadoes were known from both Ireland and England; it was known that they could destroy well-constructed buildings and lift heavy objects into the air, and that they could resemble a "tower of fire" (column of smoke). By 1200 it was beginning to appear that England had more tornadoes than other parts of the British Isles, though there was now a possible example from Wales; it was clear that they were often accompanied by thunderstorms and large hail; all the cases so far had been between April and October. By 1300 the great majority of known cases were in England, and there were accounts of trees being twisted and water sucked up. Two winter tornadoes had been reported, as well as the first waterspout case. Little more was added by 1400, with only two cases reported in the 14th century. Wales had its first definite tornado in the 15th century. By 1660 it was becoming clear that tornadoes generally move from between south and west, and that several could occur on one day.

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IRISH TORNADOES: SECOND THOUGHTS ABOUT THE IRISH CLIMATE

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TORRO

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Abstract: A tornado that occurred on 6th August 1999 was probably more important for its impact on the Irish awareness of tornadoes as a legitimate part of their climatic environment than the physical impact of the event which was minimal. The results of a site survey are summarised together with the meteorology of the event. These are compared with the characteristics of 'typical' tornadoes reported in Ireland since 1970.

SIGNIFICANCE OF THE EVENT

The summer of 1999 may prove to be an important threshold for the study of tornadoes in Ireland. There have been many tornadoes over the years in Ireland, three or four being reported each year. But 1999 has been important, not just because there have been more reported tornadoes than usual, but that for the first time one particular tornado was recorded on video and broadcast nationally. The tornado occurred on Friday 6th August near Ballysadare, about five miles south of Sligo and the video record was made by Keith Sleater of Knocknahur, County Sligo.

THE METEOROLOGICAL BACKGROUND

The tornado developed at approximately 7pm BST (1800 UTC) when a shallow low pressure system of about 1000hPa was located about 350 miles west of Mizen Head, Southwest Ireland. As a result a southeasterly airflow was crossing most of Ireland that became increasing easterly further north (Fig. 1). This was part of a trough of low pressure that extended across southern Britain and northern France within which pressure gradients were slack and wind-speeds were light. This situation was changing only slowly. As the depression edged eastwards the pressure was falling most rapidly over Southeast Ireland.

At 7pm (BST) the air temperatures were relatively high for Ireland. They were at 21.1°C close to Sligo, although the typical values for most of County Mayo were between 17.4°C and 16.3°C. The high surface air temperatures were associated with the build up of cumulonimbus clouds during the afternoon over most of the country except for the east and south-east. The surface chart shows little rain north of the River Shannon, although some rain showers are recorded in the Northwest, at Bellmullet. But this is a rather incomplete picture as the radar shows (Fig. 2).

The radar imagery is helpful because it has a complete geographical coverage for about 200 km from its source . It shows both the geographical and vertical extent and rate-of-fall of precipitation. This information helps to locate very active thunder cells that are often in close association with the development of whirlwind phenomena. The Sligo area is about equidistant from the Dublin and Shannon radars and both have the lower part of their range over northwest Ireland blocked by the high terrain. The highest vertical velocities of precipitation are, therefore, lost as these will increase

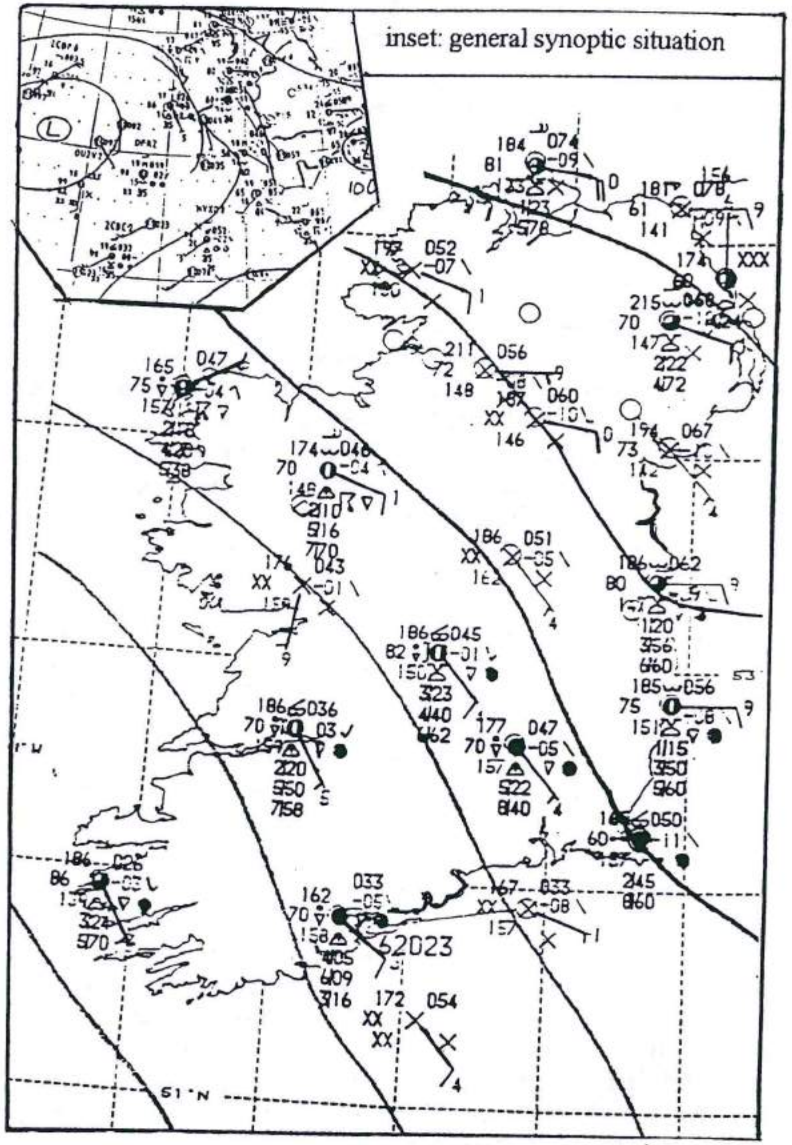

Fig. 1 The synoptic situation over Ireland for 7pm 6th August 1999. (Information kindly supplied by Met Eireann)

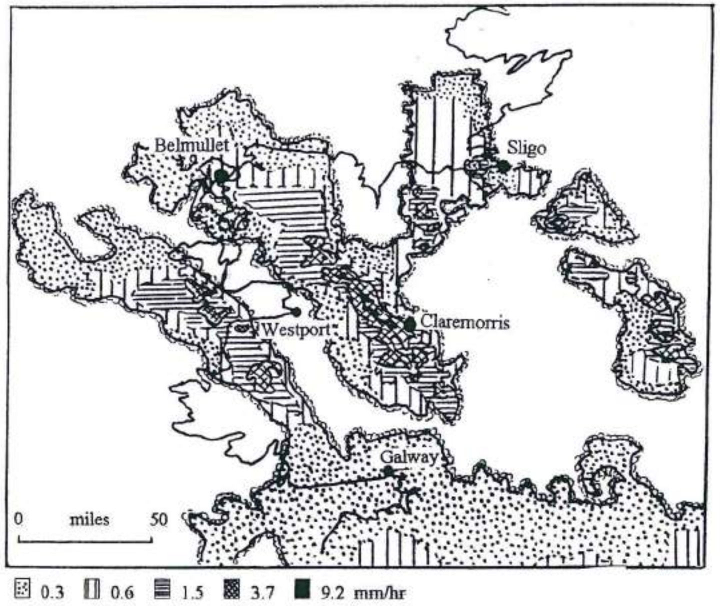

Fig. 2. Rainfall intensities across Connacht, Ireland at 7pm 6th August, 1999. (Based on information supplied by Met Eireann)

towards the ground. However, they do show the maximum rate of rainfall within the air columns and the active cells can be compared in terms of their rates of precipitation. In this case the images define three separate storms over northwest Ireland. One is in the Sligo area, the second from Claremorris to Bellmullet and finally an area to the southwest of the town of Westport. The second of these has the highest precipitation rates, exceeding 9.2 mm/hr and possibly approaching 23 mm/hr in the air column that can be 'seen' by the radar. The only two meteorological stations that reported thunder are located within this second belt of intense rain, one at Claremorris and the other at Belmullet. But the tornado was elsewhere. It developed beneath the storm near Sligo, where a much smaller area of intense precipitation was recorded on the radar images. The highest precipitation intensities in this storm also appear to have been less than in the Claremorris-Bellmullet storm. However, the intense radar echo near Sligo is exceedingly close to the position where the tornado developed. It matches the witness reports of intense rain occurring just before the tornado was observed.

Another helpful indicator of what was happening is provided by the 500 hPa pressure surface. The two times of day for which these maps are available are 1200 on 6th August and the following midnight. The time of the tornado is almost equidistant between the two. However, since there was little change in the pressure patterns between the two times at this level, we can safely assume that it was the same for the times in between as well. At first sight the 500hPa map looks very similar to the pressure pattern at the surface. While there is little difference in wind direction over the south and east of Ireland, there is quite a dramatic difference over the northwest, particularly over County Mayo and County Sligo, by about 45 degrees. At the surface the direction is largely within a few degrees of being easterly or even north of east. At the 500hPa level the winds are within a few degrees of being southerly (Fig. 3). Another feature of note is that despite its southerly direction the temperature of this upper air was relatively cold (the temperature over Valentia was - 18°C, Malin Head -17°C, but further north at latitude 60°N it was only 12.9°C). If that is considered with some of the high surface temperatures, the result is a particularly steep thermal lapse rate between the two levels. This is a strong indication of a very unstable atmosphere that would be ideal for the strong development of cumulonimbus clouds.

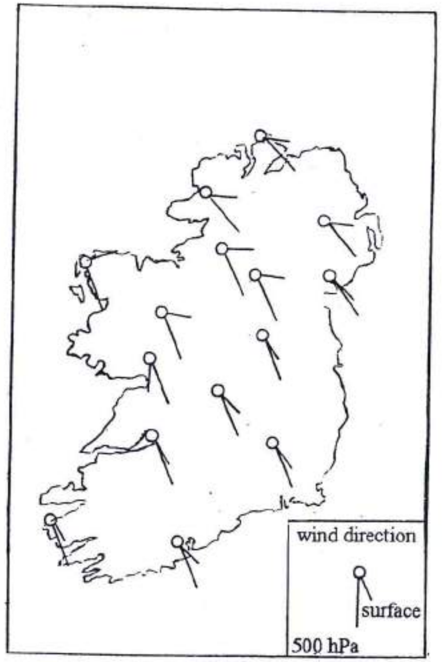

Fig. 3. Vertical wind sheer over Ireland.

Thus, between the surface and the 500 hPa level there are a series of marked discontinuities that were particularly strong over the part of Ireland where the tornado developed. The steep temperature lapse rate, the vertical increase in windspeed and the marked sheer in wind direction at middle levels are all classic environmental features for whirlwind development.

THE TORNADO ON THE SURFACE

The tornado was first seen to develop approximately 500 metres inland from the road that passes through Streamstown, Ballysadare. This is a very rural area on the

edge of a small village with a scatter of new bungalows. Here the chances of the tornado being observed were relatively high compared with most of rural Ireland (Tyrrell, 1999). While much of the tornado was recorded on video, its initial development was not. But there was a clear observation of this by two witnesses who described a black, boiling, raging cloud about a mile away that caught their attention as it moved towards their homes. It developed a 'smoke-like' funnel cloud and had barely touched the ground by the time it passed between the houses lining the road. It travelled about half a mile before it touched down (Fig. 4). During this time, and subsequently, the rotation was quite clear to the naked eye. But it did no damage. The exposed coastline is largely bare of trees and built structures are few. The probability of a tornado between three and eight metres wide missing any of these is very high. The lack of damage makes the determination of the track possible only from witness statements and video evidence. Fortunately both are available. Video evidence is from Knocknahur on the opposite side of Ballysadare Bay, a distance of 3 miles away. It is useful in a general way as far as the track is concerned. But the details had to depend on witness evidence.

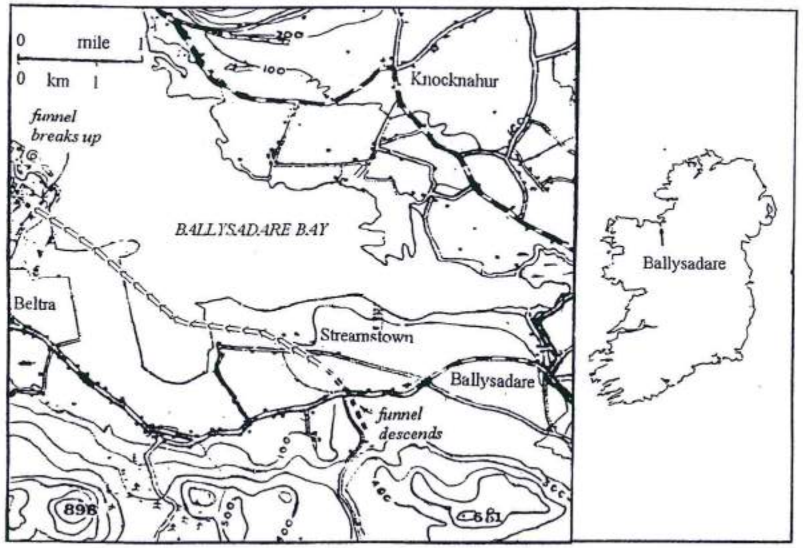

Fig. 4. The track of the Ballysadore tornado 6th August, 1999.

The publicity of the event has raised public awareness of some major characteristics of Irish tornadoes and their differences compared with the large tornadoes of the USA that are taken as models for the phenomenon. The 'representative' nature of this tornado in comparison to the 38 recorded in Ireland from 1970 to August 1999 is demonstrated by the following data:

	Modal value	Ballysadare
Track width	30ft (10 metres)	25ft (8 metres)
Track length	1.5 miles (2.4km)	3 miles (4.8 km)
Duration	10 mins	7 mins
Direction	SW	SE
Thunder present	30%	no
Hail present	32%	no
Intense rain present	52%	yes
Loud noise present	53%	no
TORRO scale	T4 (T0 - T5)	T0 (no final assessment)

CONCLUSION

Every tornado is unique. This one was close to what has 'typically' been recorded in Ireland although it was slightly towards the larger end of the spectrum, except for its assessment on the TORRO scale (Meaden, 1994). The indicators for windspeed used in the scale may require further development to accommodate the lack of wind impact information in many Irish events. These tend to be small and localised and, one suspects, often unreported. However, this may change. In an ongoing survey that will be reported at a later date, interview information indicates that the showing of the video evidence on national television had a significant educational impact and dispelled the rather rigid common perception of what a tornado must be like 'to be real'. Given some of the negative impacts of the information published by the media in recent months, this is welcome (Elsom et. al.,1999).

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A POSSIBLE SOURCE OF KAPITZA WAVES AS A GENERATION MECHANISM FOR BALL LIGHTNING

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Abstract: Several investigators, including Lodge, Marchant and Cerrillo, suggested that ball lightning might be caused by electromagnetic standing waves, and Kapitza developed this suggestion more formally. Kapitza's model required standing waves with frequencies of several hundred megahertz. These were formed by reflection from the ground of radiowaves generated by lightning. Powell and Finkelstein described experiments in which long-lived luminous regions were produced by radio frequency electromagnetic waves. Ohtsuki and Ofuruton reported the experimental production of plasma fireballs in air at atmospheric pressure by microwave interference.

Until recently, radio emissions from natural lightning in the required range of frequencies were considered to be very weak. Twenty years ago, unusual lightning discharges called 'superbolts' with exceptionally high optical powers were discovered. These may have been extreme examples of positive cloud-to-ground lightning. Soon afterwards, Le Vine reported the discovery of very strong sources of radio frequency emission from lightning in the frequency range required by Kapitza's model, known as narrow positive bipolar pulses (NPBP's). Recently, Massey and Holden reported the detection of exceptionally intense pairs of brief noise-like very high frequency pulses in a passband from 25 to 100 megahertz. Although these pulses are thought to originate from thunderstorm regions, they are significantly more intense than the atmospherics produced by normal lightning activity and may represent the 'tail' of the frequency distribution for 'normal' very high frequency emissions from lightning. Jacobson, Knox, Franz and Enermark confirmed that the signals were consistent with the second pulse being generated by a ground reflection. These observations offer evidence for the existence of more intense, albeit transient, radio frequency signals close to the 'Kapitza range' than had hitherto been detected, and for the existence of both transmitted and reflected signals as required for the formation of the appropriate stationary wave configuration.

THE MODEL

P. L. Kapitza (1955, 1961) used the analogy with the radiation time of a cloud from a nuclear explosion to deduce that a sphere of typical ball lightning dimensions (~10 cm) with an internal energy source would glow for no more than 10 ms. He thus concluded that ball lightning must be fed by an external source of energy, and proposed that it absorbed this energy by resonance with intense radio standing waves in the microwave region. Standing wave patterns can be formed when reflected waves superpose with transmitted waves, and under appropriate conditions regular patterns consisting of regions of maximum and minimum energy may be formed. Similar suggestions that ball lightning was caused be stationary waves had been made previously by Lodge (Jans 1912a-c), Marchant (1930), Cerrillo (1943, 1960) and others, although it was Kapitza who developed the suggestion much more formally.

In developing a model based on this proposal, Kapitza tried to explain the constant size and the absence of convective behaviour of ball lightning. Ordinarily, a body of hot gas would rise by convection because it is less dense than its surroundings. He showed that the condition for resonance depended solely on the external dimensions of the ball. He derived a relationship between the wavelength and the ball diameter using the characteristic oscillations of a sphere. The initial scenario was the excitation of a small volume of weakly ionised plasma by absorption of radio waves according to the resonance condition. This excitation increased the degree of ionisation and the volume of the region grew until the diameter of the ball stabilised. Expansion due to increase of temperature would cause a deviation from the resonance condition, which would reduce the efficiency of absorption, hence the ball would cool and contract to resonance diameter. This negative feedback process could thus maintain the constant size of the ball. Typical reported diameters of ball lightning (10 cm to 50 cm) indicate that wavelengths would lie in the range 37 to 183 cm, hence frequencies would lie in the approximate range 160 to 820 megahertz, which I will call the Kapitza range. Kapitza argued that ball lightning would be formed at antinodes (high energy regions) of a standing wave pattern where electric field would be greatest. Motion of the ball would follow motion of the antinode and would not exhibit convection or depend on wind direction. Were the standing waves set up by reflection along a normal to the earth's surface, antinodes would occur on surfaces parallel to the earth at different heights. Near these surfaces the raised electromagnetic field intensity would provide the necessary initial conditions and conditions to maintain the ball. Kapitza argued that the ball would most often be formed close to the earth's surface at a height of one quarter wavelength, i.e. a distance from the reflecting surface and the edge of the ball equal to its radius. If similar effects were also produced at higher antinodes, bead lightning might be formed. Silent decay of the ball would occur if the energy supply to the ball was terminated and the ball radiated its energy slowly. Explosive decay would occur if rapid cooling produced a weak shock wave as the sphere filled with air.

Watson (1960), using a different analysis, predicted that the particles would be bound near the nodes because there was no solution of the equations at the antinodes. Tonks (1960), on the other hand, demonstrated that, although initial ionisation would be at an antinode, the ball would find an equilibrium position at a node because of radiation and atmospheric pressure. Electrons in the node region would cause further ionisation by collision provided the field strength was of the order of 1 MV m-1.

Experimental studies by Babat (1947) had already demonstrated the possibility of producing spherical plasma discharges, without an electrode, both at nodes and antinodes. Tonks (1960) and Singer (1971) discussed the difficulty of radiation pressure from an external electromagnetic wave preventing convection of a ball 10 cm in diameter with a temperature of several thousand degrees kelvin, because the buoyancy force would be about 6 mN It was suggested that the additional electrostatic force on a charged ball attracting it to a grounded conductor might provide an additional force to stabilise against buoyancy. Tonks pointed out that the model required a substantial input power of about 0. 1 MW together with a very high stability in the frequency of the generating radio frequency radiation were the ball to be maintained stationary for some time.

PENETRATION OF BALL LIGHTNING INTO ENCLOSURES

Many ball lightning models run into severe difficulties when attempting to explain reports of ball lightning within enclosures such as buildings, and especially within conducting enclosures (Faraday cages) to which predominantly metal aircraft form a very good approximation. Kapitza attempted to explain the appearance of ball lightning into buildings by the suggestion that an aperture such as a chimney could serve as a waveguide. It was not explicit in his paper whether Kapitza considered that a similar explanation could apply to the appearance of ball lightning inside aircraft. After referring to such an observation he wrote: "In term of our hypothesis, all these effects are explained thus: lightning balls penetrate into closed buildings by virtue of the fact that they follow the path of short-wave electromagnetic oscillations which can propagate through apertures or along a chimney or conductor as along a waveguide."

He did not develop the question of ball lightning in aircraft further (Kapitza 1955). Altschuler, House and Hildner (1970) commented that models based on focusing of microwaves or of electric currents into a small volume could not explain ball lightning that enters metallic enclosures such as aircraft. However, aircraft are not entirely closed metal contamers - many are partly made of composites - and there are apertures such as windows and radio antennae, and cables pass through the fuselage. (Indeed, many radio operators have received severe shocks when attempting to disconnect antennae). Military and commercial airlines have coated windshields composed of a sophisticated sandwich of material comprising bulk or surface electrical conductors so it is very unlikely that DC fields could penetrate the windshield and produce discharge phenomena. Side windows on the fuselage are not coated, so DC fields can penetrate the fuselage here. The electric field induced inside the fuselage from this type of aperture is, however, very low compared with the field outside so an aircraft fuselage is a good Faraday cage (Laroche, P. 1998, personal communication).

Nonetheless, very high frequency and ultra high frequency radio frequency fields, possibly in the frequency range of interest can penetrate aircraft through such apertures. While the main resonances within the aircraft will probably occur at lower frequencies, lower intensity resonances at higher frequencies are possible. 'Continuing currents' of 100 amperes or more may flow through the aircraft feeding the leader for periods of up to hundreds of milliseconds. These currents can produce substantial magnetic fields, with rapid rates of change that can in turn induce large voltages and currents in nearby conductors, The lightning strike couples sufficient energy into the aircraft structure in this frequency range to excite electromagnetic resonances. For an F-106B aircraft, for example, these are in the high frequency range of about 7 to 23 megahertz, the lowest frequency corresponding to the fuselage half-wavelength resonance and the highest corresponding to that of the wings, with intermediate frequencies probably corresponding to a combination of the wings and tail. In laboratory scale-model tests there was also a component at 39.8 megahertz that was thought to be the second harmonic of the wing resonance (Trost and Pitts 1982). However, these measured frequencies fall short of those in Kapitza's model by a factor of at least 4, Furthermore, corona discharges from the extremities of aircraft, often visible as 'St Elmo's fire', may generate radio interference in the gigahertz range. (Boulay & Laroche 1982) The majority of strikes to aircraft follow observations of corona and/ or high-voltage streamers, which may then develop into leaders enabling electrical connection between charge centres in clouds.

EVIDENCE FROM LABORATORY EXPERIMENTS

It has been known for some time that plasmas can absorb energy by a variety of resonance mechanisms with radio-frequency waves in the range 100 kilohertz to 200 gigahertz (Cairns, R. A Chapter 15 in Dendy 1993). Powell and Finkelstein (1970) describe experiments by Manwaring (Powell, Finkelstein, Zucker & Manwaring 1966) in which long-lived (0.5 s), bright regions of luminosity were produced in a 250 cm resonant cavity by radiofrequeney electromagnetic waves at a frequency of 75 megahertz. Powell and Finkelstein remarked that an aircraft fuselage provides a natural resonant cavity for radio frequency radiation. In repeating these experiments, Powell and Finkelstein produced luminous regions in a 15 cm Pyrex tube whose luminosity persisted for about 1 s after the power was switched off. In open air, they persisted for only about half as long, probably owing to convective mixing, The properties of these regions of luminosity depended on gas pressure, electrode composition and gas composition, the latter having the most significant effect. The experiment was only successful with nitrogen, oxygen, with mixtures of these, and with nitrous oxide. Colour ranged from dull blue with nitrogen, through yellow white with intermediate brightness in air, through pure orange with nitrous oxide, to white and very luminous with oxygen. Luminosity with nitrous oxide persisted for up to 2 s and may have resulted from decomposition. In the other cases, the persistence of luminosity was attributed to metastable excitation of nitrogen and oxygen molecules. Decay of metastable molecular species of nitrogen and oxygen were considered to be responsible for the processes.

Kapitza related the formation of ball lightning near the end of a storm immediately after a flash of conventional lightning to the presence of ionised air that promoted the generation of radio waves and to the stimulation of oscillation by the lightning discharge. He suggested that the source of the oscillation was an oscillatory process accompanying the ionisation of the atmosphere near the ground or the earth. If it were the latter, the zone of intense radio emission would be of limited extent.

LIGHTNING AS A NATURAL SOURCE OF RADIO FREQUENCY RADIATION

Until recently, radio emissions from natural lightning in the 'Kapitza' range were considered to be very weak (Silberg 1961a, 1961b, 1962; Powell and Finkelstein 1970). Pierce (1977) stated that above 5 kilohertz, signal amplitudes radiated from lightning flashes have an approximately inverse dependency on frequency. Kapitza suggested that as ball lightning is a rare phenomenon, the occurrence of corresponding radio emissions might also be rare. Subsequent field investigations of electromagnetic radiation from lightning revealed relatively narrow-band radiation at frequencies of about 0. 1 to 0.2 gigahertz, occurring 0. 1-0.4 s after the appearance of a leader stroke.

The average duration of these oscillations was about 50 ns. The power spectral density (1 to 100 pW m-2 Hz-1 at a distance of 1 km from lightning) was too low to generate a plasmoid of the kind described by Kapitza, but the investigators speculated that the power might be much greater near the ionised lightning channel. The source of the radiation was speculated as transverse plasma resonances in the lightning channel, where the magnetic field of the lightning channel amplifies magnetic Bremsstrahlung and Cerenkov radiation from electrons in the channel. (Kapitza 1968a, 1968b; Kosarev, Vaganov, Zakirov, Luganskii, Natusbek and Samosyuk 1968, 1969; Ranjeloric 1969; Kosarev and Sereazlikin 1974a, 1974b.)

Since Kapitza's work in this field, investigators have discovered lightning discharges, called superbolts with exceptionally high optical powers (Turman 1977.) These may be positive discharges at the extreme end of the energy distribution. Their radio emissions are not known and there is at present no way to extrapolate radio emissions from optical emissions. They may, however, be possible generators for 'Kapitza waves' and it would therefore be interesting if radio special data could be obtained for superbolts. Uman (1987) states that (1) positive lightning occurs more frequently in winter thunderstorms; (2) positive lightning often occurs towards the end of a storm; (3) the median energy of positive lightning is about 7 times greater than that of negative lightning. Although Rayle's (1966) survey did not agree, Brand (1923, 1971) noted that (1) ball lightning occurs more frequently in winter than summer; (2) ball lightning frequently occurs towards the end of a storm.

Spectral data about electromagnetic radiation from lightning has been acquired by two methods: narrow-band receivers (NBRs) and, more recently, wideband waveform digitizers (WWDs).

The NBR method directly yields quantitative data on average and peak spectral amplitudes, on a relative scale between about 1 kilohertz and 1 gigahertz. Where the distance to the lightning is known, the NBR technique also provides quantitative data on spectral amplitudes, but it is not usually possible to relate this to specific processes within the lightning discharge, (e.g., cloud pulse, stepped leader, return stroke).

The latter WWD method enables electric and magnetic field impulses to be recorded. These records can then be subjected to Fourier analysis to provide spectral amplitudes. The characteristics of the waveforms in this technique enable identification of the type of discharge, i.e., cloud-to-ground (CG) or intracloud (IC) and of the particular component within a flash. WWD spectra of the larger lightning impulses now extend through most of the high frequency band (3-30 megahertz). Return strokes in CG flashes have been found to be the strongest sources of radiation at frequencies up to about 20 megahertz. Le Vine (1987) showed that there was generally good agreement between NBR and WWD below about 2 megahertz. Above this frequency, however, there was much scatter in the NBR data. At the limit of published data for WWD spectra (20 megahertz), NBR data were as much as 50 decibels higher. Some of these high values might be attributed to superposition of signals from multiple sources arriving almost simultaneously at the receiver, it is possible that other lightning processes, not previously detected or analysed by the WWD method, constitute significantly stronger sources of high frequency energy than return strokes.

Le Vine (1980) identified the sources of the strongest radio frequency emissions from lightning at 3, 139 and 295 megahertz as narrow bipolar pulses with an initial polarity opposite to that of return strokes lowering negative charge, which were thus known as narrow positive bipolar pulses (NPBPs). Willett, Bailey and Krider (1989) reported the first wideband recordings of these pulses and identified that they radiated much more strongly than first return strokes with more high-frequency content at frequencies from 10 megahertz to at least 50 megahertz. They generally occurred as relatively isolated and infrequent pulses in intracloud flashes, but they were not associated with K changes or other known phenomena.They sometimes occurred either before or after the first return stroke in a CG flash. The authors identified their potential risk to aerospace vehicles whose fundamental structural resonances, usually lie at high frequency frequencies. They also identified that these pulses could occur with the opposite initial polarity.

The 'Blackbeard' detector on the ALEXIS satellite detected exceptionally intense pairs of brief (a few microseconds) noise-like very high ftequency pulses separated by a few tens of microseconds in a passband from about 25 to 100 megahertz. Both pulses are equally dispersed, consistent with their propagation through the earth's ionosphere. These are called Trans-Ionospheric Pulse Pairs (TIPPs). (Massey and Holden 1995.) Although these pulses are thought to originate from thunderstorm regions, they are significantly more intense than the atmospherics produced by normal lightning activity, and may represent the tail of 'normal' very high frequency emissions from lightning. Four possible reasons were suggested why ground-based stations have not reported corresponding observations. (1) TIPPs are a rare phenomenon that has thus not been identified as a special class of radio frequency signal; (2) they are a rare but energetic phenomenon that is more easily detected from space than from the ground; (3) they have a different waveform when observed from space than when observed from the ground; (4) they are emitted by directional sources radiating more energy towards space than towards the ground.

TIPPs were among the signals later detected by the Forté satellite, launched in August 1997. Their instantaneous power was at least ten times greater than that of very high frequency signals normally associated with lightning. Although some investigators had hoped that TIPPs might provide supportive evidence for high-altitude, upward discharges related to sprites and similar phenomena, Jacobson, Knox, Franz and Enemark (1998) confirmed that these signals were consistent with the second pulse being generated by a ground reflection. Nonetheless, these experiments offer evidence for the existence of more intense, albeit transient radio frequency signals close to the Kapitza range than had previously been detected, and for the existence of both a transmitted and reflected signal as required by the Kapitza model.

While lightning-generated radio noise at low frequencies in the atmosphere is dominated by contributions from ground flashes, above 50 kilohertz the influence of cloud flashes becomes significant. Between 1.5 and 12 megahertz, the amplitude ratio of return stroke to cloud stroke is approximately 1:1. (Brook and Ogawa

1977).Thus, cloud flashes should also be considered a possible source of 'Kapitza radiation'. Many strikes to aircraft are apparently intracloud (IC) strikes rather than strikes from the more severe cloud to ground (CG) strikes. (Anderson, Kroninger & Smith 1982).

CRITICISMS OF THE KAPITZA THEORY

Silberg (1961a, 1961b, 1963) was critical of some aspects of Kapitza's model, chiefly the lack of specific detail about why this phenomenon would be selective in responding to specific radio frequencies from the broad band, damped emissions of a storm, and about mechanisms for plasmoid generation and containment However, Silberg considered Kapitza's model worthy of further development. In further evolving the model, he treated the earth as a perfectly conducting, extended plane surface and assumed that intracloud or inter-cloud discharges generated a radio frequency field with a flat discrete band spectrum, The assumption of a discrete band spectrum helped to circumvent the difficulty of frequency stability discussed by Tonks. Because of the dipole-like nature of the radiator, radiation from such a discharge would be linearly polarised and could be treated as plane waves in the region in question. His analysis demonstrated that, under rare conditions, the electric field thus produced could support a horizontal lightning streamer and possibly a localised corona discharge. However, he pointed out that the existence of a discrete band spectrum has not been experimentally verified. Shapiro and Watson (1963) demonstrated the possibility of using three, mutually perpendicular standing waves to confine particles. Berger (1973) remarked that Kapitza's theory should logically predict the generation of ball lightning type phenomena in the vicinity of short-wave radio transmitters. However, Singer (1977) pointed out that 'Kapitza waves' have short wavelength compared with normal transmission wavelengths, and that in the latter case waves would disperse and become too diffuse to produce such phenomena.

CONCLUSION

Kapitza's ball lightning model requires the formation of superposition patterns between transmitted and reflected radio frequency emissions from lightning in the approximate range 160 to 820 megahertz. Recent observations suggest that there are strong sources of electromagnetic radiation from lightning in the high frequency range, that these signals are reflected from the ground, and that lightning strikes to aircraft may stimulate resonances in the megahertz range. Kapitza's model predicts that apertures could act as wave-guides, channelling ball lightning into enclosures. Although metal aircraft serve as effective Faraday cages, there are circumstances in which radio frequency energy might penetrate the fuselage, or where radio frequency resonances can be stimulated by lightning strikes to the fuselage. It is possible that ball lightning is generated by radio frequency signals from positive cloud to ground lightning and from cloud flashes.

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LONDON'S TOP TEN THUNDERSTORMS IN THE TWENTIETH CENTURY

By BOB PRICHARD

Abstract: This was originally the subject of a talk given to the Royal Meteorological Society's History of Meteorology and Physical Oceanography Group in March 1999. The idea for the subject came from the current series of articles that the writer produces every week for *The Guardian*; over the last three years, these have featured a personal assessment of the 20th century's 150 top weather events, or series of events, in the British Isles. London's Top Ten Thunderstorms is an adaptation of that theme.

INTRODUCTION

It must be stressed that this is a personal assessment, and someone else with the same data set would be very likely to come up with a different ten - not least because there is not, and I suggest cannot be, a universally agreed definition of a severe thunderstorm. My approach is to go for fierce electrical activity as the decisive factor; the longer it lasts, the higher up the ranking order the storm will be.'Fierce' must mean a reasonable proportion of flashes to ground. Other effects, like squalls, tornadoes, hail may or may not be present. Then, aside from how you might define a bad thunderstorm, there is the question of assessing a storm you did not personally experience, as is the case with all but one of those in this list. However, I have, over many years, compiled a fairly comprehensive summary of British weather for every month of the twentieth century, which helps to provide some perspective about the British weather, including its thunderstorms.

Before discussing the ten chosen storms, a brief preamble about London's thunderstorms is apposite. Locally produced storms, that we might regard as arising out of London's heat island effect, are fairly rare. The heat island is more a night-time feature anyway, and London is not very often warmer than its surrounds on summer days. The higher ground around the capital is probably a more potent factor in storm development. Furthermore, such effects as there are tend to result in convection being initiated over London but the storm developing downwind - one of the reasons why the Epping Forest area to the northeast of London experiences more thunder than the capital itself. Nevertheless, when conditions allow a local development over London, they tend to be violent storms, and six of my list are local developers. The top three, though, are imports. The Top Ten spans the decades; there are two in the second decade, one in the twenties, two in the forties, two in the fifties, and one in each of the sixties, seventies and eighties. Four were in July, three in June, one in August and one in September - and one in December.

LONDON'S TOP TEN THUNDERSTORMS: FROM NUMBER 10 TO NUMBER 1.

10), 8 DECEMBER 1954: this was a fierce short-lived evening rush-hour storm in west London, including a tornado between Gunnersbury and Acton. Other summer storms not in this list were doubtless more severe, certainly electrically, but the surprise factor for December and the tornado (perhaps London's worst, with much damage to buildings) merit its inclusion. Over an inch of rain fell in much of London that day, with sharp thunderstorms and some large hailstones - associated with the secondary cold front of a deep depression off southern Ireland. (I even remember hearing about it on the news that evening - as a 6 year-old. It is not quite my earliest weather memory; that was the North Sea flood of January 1953).

9). 7 JUNE 1963: a heavy afternoon thunderstorm, centred on Kensington Palace, where 57 millimetres fell in 35 minutes. There was also 62 millimetres in 120 minutes at Mill Hill. It occurred during a warm, thundery start to the month; on this day, there was a slack airflow, and this is therefore a good example of a heat-island storm. Paddington and Victoria stations were flooded, as were many roads in west and northwest London.

8). 9 JULY 1981: a classic heat-island storm - the most recent one in the list and the only one I personally observed. The weather pattern was rather similar to that of the previous one, with very warm, stagnant air over London. Between 2 and 3pm, the sky took on a grey-yellowy hue as large cumulus forced its way through a sheet of altocumulus, and haze and smoke converged beneath the clouds. The temperature was 26 degrees. By 3.15pm, the sky was very dark (still with a yellow tinge) looking west from London Weather Centre (High Holborn); soon afterwards a shower of huge raindrops began there. After about five minutes of very heavy rain, the first flash of lightning was seen about a mile WSW. From 3.20-4pm, there was frequent close thunder and lightning (up to about six discharges a minute), intense rain, a spell of very large hail and a few minutes of very squally winds with a gust of 49 mph. At the peak of the rain, around 3.30pm, visibility looking west along High Holborn was reduced to about 50 metres. 58 millimetres fell in 50 minutes at the Weather Centre, but the storm centre was probably in the King's Cross area, where flooding was severe.

7). 16 JULY 1949: I have no personal memories of this one - I was a little too young! But I was intrigued, when reading the autobiography of the late Ray Moore, whom Radio 2 listeners may remember, to read that this was his wedding day in Chelsea, and he commented that it was warm with a brief shower. They were lucky - not far away, mayhem was the order of the day. Two boys were killed by lightning at Plumstead as were two men at Walthamstow. A depression lay off southwest England, and thundery troughs were drifting north in the weak southerly airflow. There was 62 millimetres of rain at Barking and 58 millimetres at Leyton.

6). 16 JUNE 1917: detail on this one comes from *British Rainfall*. On the afternoon of this day, "a thunderstorm of a highly localized character commenced over the north of London" and drifted southwest. From automatic gauges, at Camden Square 70 millimetres of rain fell in just over two hours, and over fifty millimetres fell between Finsbury Park and Richmond and as far northwest as Willesden Green. Non automatic gauges, some of them non-standard, suggest over 100 millimetres fell in a small area around Campden Hill, and 92 millimetres was recorded at Kensington Gardens. Not surprisingly, considerable damage was done by flooding, and heavy hail was reported in places. *British Rainfall* could find no parallel to these rainfall figures in previous years. In a survey of 'Summer Thunderstorms' in the April 1933 *Met Mag*, CKM Douglas commented that in the period 1916-1932, this was the only severe storm of diurnal convective type on a day when the temperature reached 80 F. "Thunderstorms on hot afternoons are never numerous" he wrote - and that has certainly been true in recent years, where above average summer heat has been accompanied by a decrease in summer thunderstorms in and around London. (See the writer's article on thunderstorms in Loughton, shortly to be published in this Journal.)

5). 14 JUNE 1914: again *British Rainfall* has been the source for the detail here. This time it was the turn of south London, again in the afternoon. Seven people were killed by lightning whilst sheltering under trees in the Wandsworth Common area, four of them under one tree. Giant hailstones were reported from Dulwich, Lewisham and Roehampton and much damage was done to plants. Many buildings and trees were struck by lightning across south London. 93 millimetres of rain fell in just under three hours at Richmond Park.

So, both these second decade storms were what we might call 'heat thunderstorms' - local developments in warm, slack airflows.

4) 14 AUGUST 1975: 'the Hampstead storm', another classic heat-island one, just slightly displaced from the centre of London, and including the largest-ever recorded rainfall total in one day in the capital. It struck between 5 and 8pm, during which time 170.8 millimetres of rain was recorded on Hampstead Heath. Cars floated along streets which resembled canals, torrents of water tore down walls, poured into basements, filled subways, burst sewers and brought the Underground railway to a halt. Dozens of families had to be evacuated from their houses. There was also a considerable fall of hail, giving a complete 'white-out' in the Cricklewood area, where it lay nearly a foot deep for a while. As near as Mill Hill, only 2.5 millimetres of rain fell. Later in the night, further thunderstorms, from France, moved across London.

3). 14/15 JULY 1945: this was a very severe thunderstorm, described, in *British Rainfall* as rivalling the one I have chosen as the number one storm. The storm system developed over eastern France and lasted all night over southeast England; lightning was reported as incessant. The heaviest falls of rain, which also included hail in places, were outside the capital, but over fifty millimetres fell around Watford and Waltham Abbey and 80 millimetres as near as Old Woking.

2). 5 SEPTEMBER 1958: the eastern and southern suburbs caught the worst of this storm, which was at its most severe over northwest Kent and south Essex; 130 millimetres of rain fell in the Sevenoaks area. This storm system, which continued through most of the evening, was undoubtedly one of the most severe ever experienced in this area, and came at the end of a spell of very humid southerly winds. However, the spectacular storms were not a French import; they developed initially over the

Isle of Wight and Hampshire. Cloud tops were reported to be in the region of 50,000 feet. As the storm crossed London, flash counter equipment registered 1690 flashes in one hour. Looking into this storm from Slough, it was reported that many of the flashes appeared to develop upwards and outwards from the cloud and spread across a clear sky with extensive branching, with some flashes lasting for several seconds. There was much flooding, with the main London to Southend roads impassable for some time during the night.

So, we come to London's Top Thunderstorm of the Century:

1). 9/10 JULY 1923: I extracted several days weather reports from *The Times* covering this period from the Library at the University of Keele. The first half of July was very warm, with high pressure predominantly to the east of the British Isles; the hottest weather actually came after this storm - 35 degrees was recorded in London on the 13th. Thundery outbreaks punctuated the heatwave, and London's turn - together with much of the southeast - came on the night of the 9th/ 10th. Quoting from *The Times:* "the thunderstorm which raged over London in the early hours was probably the greatest in living memory. It was remarkable both for its severity and extent, but above all for its duration, the lightning and rain continuing with almost unvarying intensity for from six to eight hours. The alarm caused by the storm was evident to persons who had to travel home in the early morning. In many houses lights were to be seen and it was obvious that many people were too frightened to go to bed. A journey through the streets of London between 1 and 5 am was a thrilling experience." And later in this report, describing the scene from Sydenham Hill: "as the lightning came nearer, with simultaneous thunder-claps, the rain became hail, known, when not seen, by its swifter rush and harder patter on the outstretched leaves. The earth was very still and hushed and timid. Children woke and light appeared - more than the common number of lights - to mitigate if not conceal the grand terrors of the night. Men thought of France and the war. The recollecting ears picked out those several sounds of musketry, machine guns, field artillery and bursting shells. Women thought of air raids and, partially reassured, made tea. A mist was thrown up by the steaming earth which delayed the dawn. The birds woke without song. The new day was heavy and oppressive, like the evening before. If the night had been like war, the new day was not like peace but only an uncertain armistice." Indeed, there was another sharp, but short-lived, thunderstorm that evening in London.

As with the 1958 storm, the major storm system apparently developed over the English Channel rather than France; this is not unusual - indeed, sometimes in these thundery southerlies the storms do not develop until the air has reached northern England or Scotland. 65 millimetres of rain was recorded at Hampstead and a lightning counter at Chelsea recorded 6924 flashes.

REFERENCES

The material from which this selection is compiled comes from a number of sources, but principally from *British Rainfall* and the *Weekly* and *Monthly Weather Reports* of the Meteorological Office - all, unfortunately, no longer published. Contemporary newspaper reports were also used in some instances. Volume 1 of the *Journal of Meteorology* provides some interesting accounts of 'the Hampstead storm'.

A 'GIANT HAND' SWEEPS THE TREES AS A TORNADO HITS SOUTHAMPTON

By PETER MATTHEWS
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Abstract. Site investigations often involve much work and travel, and in previous investigations I have journeyed up to 160 miles in order to survey an area for tornado damage. It was therefore with an element of surprise when I learnt that a tornado had approached within three quarters of a mile of my flat in Southampton. Fortunately for the residents of the area, it was a small tornado, and I was able to get to the scene soon after its occurrence. The tornado occurred at approximately 0400 GMT on 10 November 1998 on a trough moving ESE through the area. It seems that the tornado moved with the trough and not along its length, so that the direction of the tornado was the same as the surface winds.

INTRODUCTION

On the morning of 10 November 1998 at approximately 0400 GMT, I was awoken by the sound of heavy rain lashing the western-facing window of my flat in Southampton. It is not often that I am woken by the sound of rain so this must have been a significant shower. Six hours later I realised how significant it was. A tornado had occurred in the Highfield area 1200 metres to the north-east.

I went to do a site investigation at around 1100 GMT and had plenty of time to look at the damage. The Council contractors were still present clearing fallen branches from two roads . Little did the people of Southampton realise that morning that the main A33 road running northwards out of Southampton had been blocked by branches for two-and-a-half hours from 4 am onwards. If this tornado had struck five hours later at the morning rush hour, there would have been considerable disruption and maybe even fatalities.

THE TORNADO'S TRACK

The tornado moved on a bearing of 245 degrees across the eastern side of Southampton Common and on to the Oakmount Avenue estate damaging at least eight houses in the area (see Figure 1), As I collected reports, I realised that this tornado did not apparently descend below 40 feet in the Highfield area. This was confirmed by one of the contractors. I continued to do the site investigation from west to east and the following reports resulted.

HIGHFIELD ROAD AND THE AVENUE

A 15 ft maple tree was uprooted and brought down in a SE direction. The Avenue was blocked by four large branches from oak trees on the eastern section of the main road. The area was also littered with small branches. The main damage was on the eastern side of the A33 and on the north and south sections of Highfield Road.

Just to the north of Highfield Road a 25-metre oak tree of one-metre girth was brought down in an easterly direction. On the southern side three trees were brought down on to Highfield Road: an oak, a sycamore and a chestnut tree. Also a 25-metre beech tree was split into a number of branches. It was at this point that one of the contractors who had been clearing debris at treetop height informed me that the damage only occurred above 40 feet. "The whole event was weird', he reported. It was as if a giant hand came across the trees at 40 feet and wrecked all the branches above this height. There was no branch damage below 40 feet."

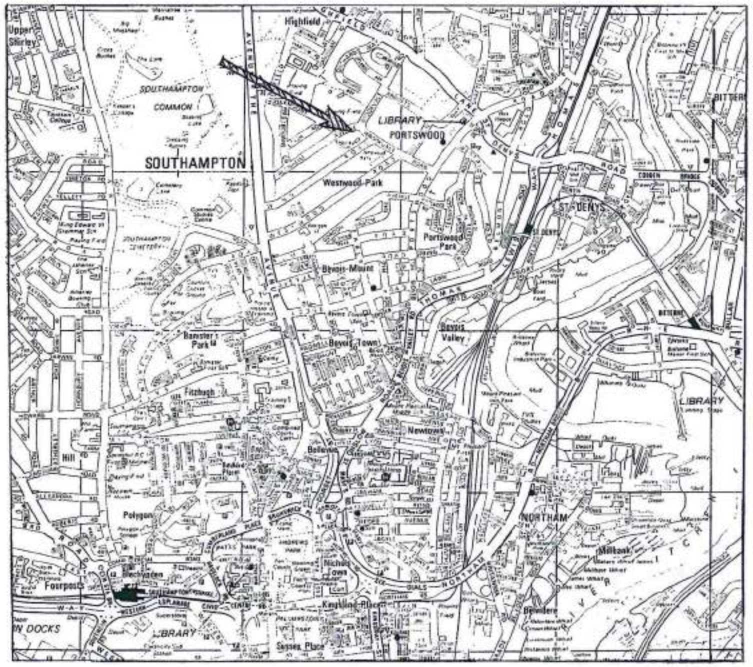

Fig. 1. A map os Southampton showing the tornado's path as determined from damage patterns.

Between Highfield Road and Oakmount Avenue there was little or no apparent damage. The tornado had either lifted slightly or become momentarily disorganised. It continued on a path almost parallel to Oakmount Avenue. As it moved ESE the first reported damage was at 30 Oakmount Avenue. From the top of Oakmount Avenue to the end of the road at No2 there is a decrease of 10m in altitude (from 41.1 to 31.7 a.m.s.l.). The tornado had started to move downhill and, as in previous cases, this seems to have had the effect of dragging the funnel towards ground level. Significantly this was the area of greatest damage.

OAKMOUNT AVENUE

Roof damage occurred at Nos 30, 28, 26, 24 and 22 Oakmount Avenue. By far the

worst damage was at No 24. The chimney was removed from the eastern side of the house and deposited into a neighbouring room. Mr. B. Barton, a teenage student studying geography, reported the incident as follows:
"I was woken at 3.52 am by rain on the south-facing window. There was a whirring sound and I thought the window was about to break. The foundations seemed to shake and then with a 'wooshing' sound and the chimney came down. Seconds later there was complete calm'. The chimney narrowly missed him and he was later interviewed on TV about his great escape.

His mother Mrs. L.G Barton gave her own independent report.: " I was woken up by heavy rain hitting the bedroom window. Immediately the wind got up and it became very loud for 30 seconds. I was aware that it was whirling like a helicopter and the whole house shook. Rain started to pour through the ceiling, but I was not aware of the damage. There was no thunder and lightning and the force seemed to be on the SE window'.

A 4ft wall was brought down in an easterly direction between No. 24 and 26 Oakmount Avenue, thus showing the strength of the winds at ground level (Figure 2). There was a similar report from Mrs. S Hart at No. 26 with "tiles clattering and rain swirling in waves, first going anti-clockwise, then vertical and finally horizontal like a wall of water. It was a cross between a waterfall and heavy rain". The five houses damaged were on the southern boundary of the tornado. Further damage was done on the northern boundary around Crofton Close.

Fig. 2. Looking NW towards 24 Oakmount Avenue. In the background the chimney was removed from No. 24 and deposited next to where the workman is standing. In the foreground a section of the double-skinned wall was brought down in an easterly direction showing the force of the winds (see also Fig. 3)

CROFTON CLOSE

Tile damage to roofs occurred at Nos. 6, 7, 8, 9, 10, 11 and 12. Fence panels around No. 10 were damaged and a small trampoline was lifted over the wall at No. 12. W. M Puckett at No. 11 was the only person in Crofton Close who saw the whole thing as he looked outside his window that morning. He said he was amazed: I saw leaves taking off down the passage in one huge gust (wind vectors are shown in Figure 3). This occurred for about one minute. The wind was terrible, although there was no thunder and lightning. A large 7 to 8-metre branch crashed through the Hyundai Accent car at No. 10 (Figure 4), and other large branches came down in the open area between Oakmount Avenue and Crofton Close'.

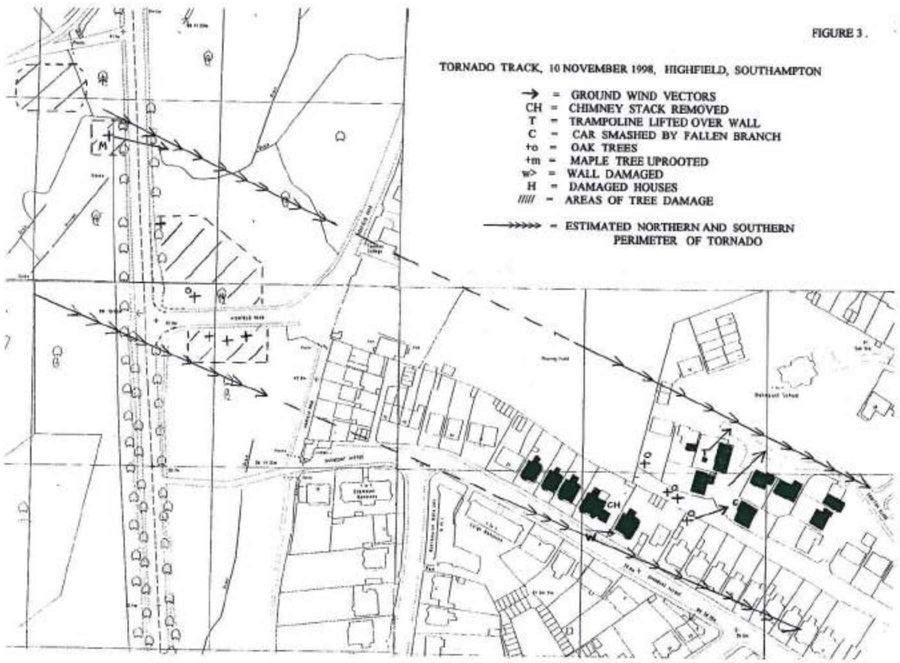

Fig. 3. The damaged areas ftom W to E. Note that the distance between each grid line is 100 m. Also, the wall damage at No. 24 (marked W) could have been due to a strong gust which swept through to Nos. 9, 10, 11 and 12 Crofton Close.

Apart from 24 Oakmount Avenue this was the area of greatest damage and the three large (50 ft) oaks were stripped of several of their large branches (Figure 5). In the small area of land between Oakmount Avenue and Crofton Close there are four 50-ft trees. It was interesting to note that three oak trees were significantly damaged whereas the horse-chestnut tree was unharmed. The gusts of wind in this area were generally from W to SW and this could have been caused by a swirl of wind as the tornado first approached. This 'swirl' may have brought down the wall at 24 Oakmount Avenue and also been the huge gust as seen by Mr. Puckett. As in previous tornadoes, though, pressure differences were probably responsible for the slate damage.

Beyond 5 and 6 Crofton Close there was no known damage. The road drops quite markedly in altitude so presumably the tornado either lifted or dissipated.

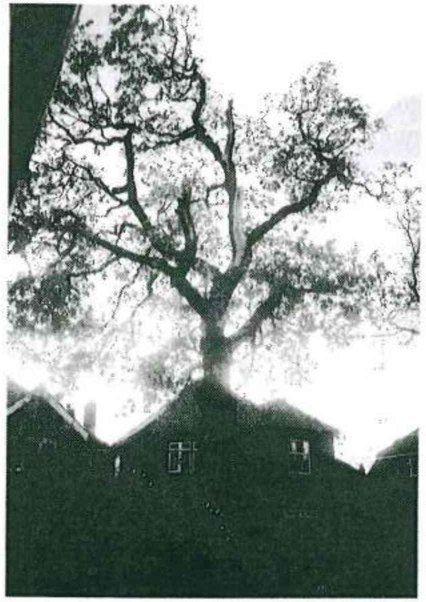

Fig. 4. One of the main branches of this oak tree was removed and deposited on to the Hyundai Accent car at No 10.

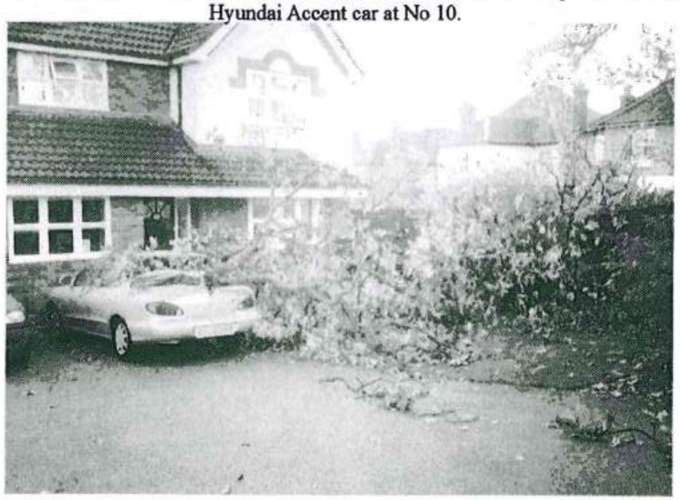

Fig. 5. The branch as it lay next morning with the rear end of the car smashed. The photograph was kindly taken by Mrs. Puckett at No. 11.

DAMAGE PATTERNS

Commenting on the damage patterns at ground level, it was difficult to see whether the tornado did descend below 40 feet around the Highfield Road area. It could be that the resistance caused by the thick undergrowth under 40 feet prevented surface winds from creating damage, although this would not explain why three trees were brought down on the south side of Highfield Road. Also the maple tree at the start of the tornado's damage path was brought down in the direction of the tornado. As in Selsey this seems to be a feature of investigations that I have done on tornado damage. There is a definite need for British tornadoes to be filmed at ground level (if the chance ever arises).

Summing up, the damage was restricted to two main areas. Only one tree was uprooted, the rest having their branches removed, although several of these branches were very large (7 - 8m). Discounting the wall damage at No.24, this would suggest a moderate tornado (intensity T2 on the TORRO scale). However at the time of writing, a further conversation with Blake Barton revealed that the wall was almost certainly brought down by the wind alone and not by any foreign object. The wind-speed would have to be calculated using engineering principles.

THE GENERAL SYNOPSIS

At approximately 0400 GMT on 10 November 1998 a trough moved ESE through the area, creating a line of organised heavy showers. There was no apparent thunder and lightning; but the rain was torrential. It seems, therefore, that the tornado moved with the trough and not along its length, so that the direction of movement of the tornado was the same as the surface winds

Acknowledgements: I would like to thank Arthur (Bob) Haseldon for the use of his computer as an aid in writing this report.

Book Reviews:

ORDEAL BY.TEMPEST: the story of the Great Storm of July 1968, by P.D. Rendall ISBN 0 9531331 0 9, 1997 pp 76 p.b *Past-Track publications, 79 Westerleigh Road, Pucklechurch, Bristol, BS16 9PW*

The floods that beset parts of the West Country after a prolonged, intense, slow-moving thunderstorm on 10 July 1968 were the worst in that area of England since 1952, and P.D. Rendall's little book is a timely memoir of an event which will never be forgotten by many of those who experienced it. The author concentrates on the effects of the deluge in Bristol, as well as the river valleys of the Avon and Chew where damage was most severe; Chew Magna, Pensford and Keynsham in particular suffered greatly as river levels rose to unprecedented heights with frightening rapidity. Sudden 'walls of water', released by the collapse of impediments to the onward rush of the floods, appear to have caused much of the havoc. The meteorology of the storm is briefly dealt with, and the weather enthusiast might wish for more statistics and diagrams to mull over; but such material has been published elsewhere. Otherwise, the book is concerned mainly with the response of people to the unexpected emergency, and many are the anecdotes of bravery and tribulation to be found in these pages. Some of the stories are amusing; I liked the account of the fireman at Chew Magna fire station, whose last call to headquarters at Weston Super Mare was to say that he would be unable to receive any more emergency calls that night, as his telephone was floating away on the flood!

ADRIAN JAMES

TORRO NEWS UPDATE: MAY-JUNE 1999
By JONATHAN WEBB

MAY 1999 was a predominantly warm month, while rainfall, typically showery in nature, was variable. Three severe thunderstorm events punctuated the last two weeks.

May 7th: 'Lightning struck a house in Macclesfield (Cheshire), and also hit a Boeing 767 aeroplane just after take-off from Manchester Airport, fortunately with no damage.

May 10th: For the second time in three days a plane was struck after take-off from Manchester airport; the plane landed back safely at the airport. Lightning also struck houses in the Atherton and Farnworth areas of Greater Manchester.

May 13th: A funnel cloud was reported at Banbridge (Co Down, Northern Ireland).
During a prolonged downpour at Drumburgh (Cumbria), a single lightning discharge struck the cottage of COL observer, Carl Matthews, fortunately without damage.

May 14th This was quite an eventful day with tornadoes occurring at Corby (Northants) and Southend (Bucks). At least seven other funnel clouds were observed: at Bracknell (Berks),Bury St Edmunds (Suffolk), Shipham (Norfolk), Barkway (Herts), Hampton (Surrey), and also (unspecified) in Oxfordshire and Essex.

May 19th: A large area of severe thunderstorms affected Sussex, Surrey, central Southern England, and the South Midlands in the evening. Lightning struck buildings in Epsom and Farnham (Surrey), Crowthorne and Poyle (Berks), Oxford, Buckland, Abingdon, Kennington, and Eynsham (all Oxon), Twyford (Bucks), and Redditch (Worcs) An unusual incident was reported at Ashford (Surrey), where lightning apparently struck the road in front of a car, igniting the engine; the driver climbed out unhurt. At Gatwick airport, a lightning strike disrupted the radar and landing system for an hour. Meanwhile, conversely, TORRO observer John Bird's electric anemometer, which had not functioned for over a year, burst into life during the storm!

A severe hailstorm (up to H4 on the TORRO scale) affected an area of Hampshire, between Alresford and Kings Worthy (near Winchester). At Itchen Stoke, the hailstones were up to golf ball size, damaging greenhouses and thatched roofs.

May 24th: A tornado swept through the Humberside village of North Ferriby (East Riding of Yorkshire).
May 27th/28th: Widespread thunderstorms followed the warmest day so far in the year, with some spectacularly violent storms across the West Country (see TORRO observer Shirley Cleave's account, in the Journal, of the event near Taunton), the Western Midlands, and the Welsh Borders. Numerous lightning incidents included the following:

Devon; The Torbay Gemini local radio transmitter was struck and put out of action, a building was struck in the Cullompton area, and 13 cows were killed near Chagford, Somerset; houses were struck in Burnham-on-Sea and Bath, the former resulting in serious damage.
Cardiff, two people received mild electric shocks while talking to each other on telephones at either end of a street.
Gloucestershire; a man suffered a minor shock when a pub was struck in Nailsworth, while a flat was struck in Gloucester, resulting in a small fire.
Worcestershire; houses were struck at Overbury (severe damage), and Worcester
Herefordshire. a house at Luston (Leominster) was severely damaged
Warwickshire: residents were treated for shock after lightning hit a pair of semi-detached houses in Water Orton.
West Midlands: Buildings were struck by lightning in Stechford, West Bromwich, and Bloxwich; a driver in Bilston hastily abandoned a Midland Metro train which had a hole blown by lightning in the roof, another strike set vent pipes alight at a petrol station in Cradley Heath. In Hall Green, a 25ft conifer was one of several trees reportedly set ablaze in the area.

An incident of ball lightning was reported from Moseley, Birmingham. In Derbyshire lightning struck buildings in Littleover and Hilton. At Cwmbran (Gwent), TORRO observer Simon Bedford witnessed a violent squall, accompanied by hail up to 20mm diameter. Elsewhere, lightning also struck and damaged houses in Westwood (Notts), Stevenage (Herts), and Wragby (West Yorkshire); also hit were a garage in Leigh (Manchester), and a fishery caravan in Stretton (Cheshire). In Arnold (Notts), TORRO's John Wilson witnessed "hissing/crackling" just before a massive, close electrical discharge. In Solihull, some similar close discharges were preceded by an eerie green glow, reminiscent of burning copper.

May 29th: This was another day of severe thunderstorms in the west and south of Britain. In Devon flash flooding closed much of Torquay town centre, while landslips blocked roads around Exeter. In Dawlish, hailstones up to about 25mm diameter (TORRO intensity H3) damaged plastic roofing (information from TORRO's John Goodger). There were also reports of marble sized hail in the Exeter area. Hail at least 10mm diameter was reported from several other places in Southern England, notably Dartford in Kent, where stones were up to 13 to 20mm across.

At least three tornadoes occurred; at Bracknell (Berks), Tong (Shropshire), and Hanworth (London). There were also three other reported funnel clouds: at Culverhouse Cross (west of Cardiff), Bath (Somerset), Bradford-on-Avon (Wilts). Possible funnels were also observed at Solihull (West Midlands) and near Tewkesbury (Glos).
Lightning incidents were again numerous: Portishead (Somerset) -a wicketkeeper was thrown to the ground (but unhurt) when a searing flash of lightning forked into a cricket ground, where some players were still on the pitch.
Bristol - Lightning was photographed striking Cabot Tower
Cardiff - The Wenvoe tv transmitter was struck over 30 times.
Bedwas (Caerphilly)A man suffered only a few singed hairs when lightning struck the metal clip of his cap.
Swansea - Lightning struck a chapel.
Surrey - Lightning struck houses in Ashstead, Epsom Wells, and Guildford. At Chiddingford, a woman survived after being struck on her doorstep.

Lightning also damaged a farmhouse at East Challow (Oxon), and a vicarage at Wolverley (Worcs). In Northleach (Glos), both the Leach and Windrush rivers overflowed. Flooding was described as the worst since 1947, the High Street resembling a river. A similar scene was reported from the main street in Wotton-under-Edge (also Glos).

A complex area of low pressure dominated the first week of

JUNE 1999. After the fourth severe thunderstorm event in two weeks on the 2nd, further heavy, locally thundery showers, affected much of the British Isles until the 8th, and eastern England until the 12th. The following fortnight was often anticyclonic and warm, before disturbed weather returned near the end of the month.

June 2nd: During overnight thunderstorms across southern England, lightning struck and damaged buildings in Petworth and Bexhill (West Sussex), Paddock Wood (Kent), Ealing and Barnet (London), Rayleigh (Essex), and at Caister-on-Sea and Bradwell (Norfolk). A house was also hit in Cambridge, while another "strike" of the lightning was on one of the Millienium Dome's supporting pylons.

There were reports of 72mm of rain at Freshwater (Isle of Wight), 65mm at New Milton (Hants), and 49.5mm at Lymington (Hants), where TORRO's Mike Rowe measured the wettest day since he first recorded rainfall there in 1986. Marble-sized hailstones were reported from Ryde (Isle of Wight). The ceiling of a Pharmacy store in New Milton collapsed. In Portsmouth, the University Students Union building was flooded in chalky water. In Hove (Sussex) the local museum was inundated. In the Bushey/Potters Bar area of Hertfordshire, two roads were rendered impassable from floodwater, and the council's drainage service attended 75 separate incidents.

During further violent afternoon storms,,especially in a broad swath from South-East Wales across the Midlands to Yorkshire, shoppers were evacuated when lightning struck and sparked a fire at a Tesco supermarket in Newport (Gwent). At Warwick, a race meeting was delayed as the judge considered it unsafe to go to his box, and then abandoned after lightning struck three spectators; fortunately they experienced no serious effects. A woman struck at nearby Allesley was unharmed.

At Leicester, a man was struck while walking his dog in a local park. He required treatment, but again not for any serious injury.

In York, lightning struck six children, aged between 11 and 15, who were sheltering under an umbrella in a playing field. Five of the children were allowed home after treatment. One 13 year old girl suffered burns to a hand and foot, and underwent precautionary medical checks. She had been holding the umbrella, and "her hand was completely frozen in the shape of the handle", the charge apparently going down the umbrella shaft. Her 12 year old friend said: "Suddenly there was this yellow flash and you could feel the force of it coming through you and we were thrown to the floor".

A furniture store in York was damaged by lightning during the storm Lightning also struck and damaged houses in Leicester and nearby Whitwick, as well as disrupting electricity, telephone and railway services in Gloucestershire, Northamptonshire, and Leicestershire. TORRO's Simon Bedford witnessed ten strikes on a power line in Coedkernew (Newport), as well as hailstones up to 16mm diameter..

Flash flooding affected the Midlands. The village of Norton, near Worcester, was virtually cut off by floodwater. In Coventry, where 47mm of rain was recorded, a hospital, council buildings, and a Register office were flooded; 2. 5 million records were safely rescued! In Rushden (Northants, a leisure centre was inundated.

A funnel cloud was almost certainly observed from Hockley Heath, near Solihull, during an afternoon of several thunderstorm downpours.

June 3rd: Although thunder was less widespread, bands of heavy, thundery showers moved north-east across the Wales and the west and north of England. Hail caused severe local damage to growing hops and walnut trees at Dormington, near Hereford. A funnel cloud was observed from Todmorden (West Yorkshire),

June 4th: Intense hail up to 10-20mm diameter fell in the Nottingham area during a late afternoon storm.

June 5th: On another very unsettled day, three funnel clouds were observed: at places as far apart as Radcliffe (Manchester) and Soberton (Hants), where the funnel appeared to "touch down" to true tornado status.

June 6th: TORRO observer David Bowker observed a funnel cloud at Hawes, North Yorkshire. Another TORRO observer, Andrew Gough, experienced marble sized hail during a thunderstorm at Bloxwich,

West Midlands.

June 7th: Once again, there was considerable thundery activity with a complex low covering the British Isles.

In Norfolk, a funnel cloud was sighted from Norwich, while marble sized hail fell at Necton, near Swaffham.

June 11th: After two drier days, falling pressure initiated some large cumulus clouds and a few showers across southern England late in the day. A funnel cloud was seen at Gosport (Hants)

June 12th: Slow moving, heavy, thundery showers affected eastern. England. Two houses were struck by lightning at Fingringhoe (Essex), one being quite seriously damaged. Hail damaged plants at Bromham (Beds).

June 20th: Newcastle-upon-Tyne, a probable tornado occurred in the western suburb of Slatyford.

June 21st:A probable tornado was observed at Chester-le-Street, Co Durham.

June 22 nd ,

A tornado/funnel cloud was seen from Caithness in the far north of Scotland.

June 26th: During thunderstorms which were quite extensive in the west of Britain, lightning struck a house near Cardigan and a caravan on a site near Llandysul (both in Ceredigion).

June 28th: Another tornado/funnel cloud was observed in Caithness, northern Scotland, this time at Wick.

Further details of the above incidents, and of additional ones which are likely to come to our attention, will be discussed in the TORRO Thunderstorm, Tornado, and Hailstorm reports (including the synoptic backgrounds etc).

WORLD WEATHER REVIEW: August 1998

United States: *Temperature*: warm almost everywhere; +3degC in and near N.E. Montana. Cold in N.W. Hawaii; S.E. Colorado to N.W, Oklahoma; C. Texas (all -ldegC at least locally). *Rainfall*: wet from N. Utah through E. Montana and most of Dakotas to S. Wisconsin, Illinois, W.Pennsylvania and W. New York; from Illinois to Alabama, N.W. Georgia and E. Mississippi; E. Florida; S. Texas to S.W. Arkansas; E. North Carolina, S. Virginia, N.W. Hawaii. Over 200% in C. Iowa, N.W. Hawaii; in and near W. North Dakota; locally N. Wyoming, S. Montana, S. Texas. Dry elsewhere; under 50% from Pacific coast to N.W'. Montana, 8. Utah and N. Arizona; C. Maine, C. Hawaii, extreme W. Texas; much of N. Texas to N. Missouri.

Canada and Arctic. *Temperature*. warm almost everywhere; +3degC locally in S.W. Saskatchewan, S. Alberta, N. Manitoba and Northwest Territories. Cold in C. and S. Alaska (-ldegC widespread); marginally in E. Greenland. *Rainfall*: wet from N.E. Greenland through N. Baffin Island to E. Manitoba and S.E. Saskatchewan; S. Iceland, Alaska, Newfoundland. Over 200% in N.E. Greenland, W. Alaska; locally S.E. Saskatchewan. Dry elsewhere; under 50% in Spitsbergen, S. Baffin Island, S.E. Quebec, N.W. Greenland, N.W. Manitoba, N. Saskatchewan, N. and E. Alberta, E. and S. British Columbia; parts of Canadian Arctic islands.

South and Central America. *Temperature.*: Warm in most of South America 15-40 S.; Mexico to Honduras; +3degC in C. Brazil. Cold from S. Bolivia through most of Paraguay to much of Buenos Aires province

(Argentina); -2degC in S. Bolivia, N.W. Paraguay and extreme N. Argentina. *Rainfall:* wet in most of South America 15-40 S.; N.E., N.C. and S.E. Mexico, S. Honduras. Over 200% across a very large area from S.C. Brazil and extreme E. Bolivia to N.W. Argentina and most of Paraguay; locally all three parts of Mexico. Dry in E.C. Brazil, W. Bolivia, N. Chile, C. and N.E. Argentina, N.W., extreme N.E. and most of S. Mexico, S. Guatemala, N. Honduras; most of Uruguay. Under 50% at least locally in all these areas, especially Argentina and N. Chile.

Europe: *Temperature*: warm S. of 50 N. and in Urals; +3degC in N.E. Portugal; locally W. Spain. Cold elsewhere; -2degC in S. Sweden; locally S.E. Finland. British Isles near normal or marginally warm. *Rainfall*: wet in European Russia (except N.E. of Black Sea), C. Ukraine, Belarus, S. Moldova, Baltic States, Finland, Norway (except N. and parts of S.), Sweden (except parts of S.), W. Ireland, C. Scotland, S.W. Hungary, C. Switzerland, C. Spain, N. Poland, N.E. Germany, Denmark; most of Former Jugoslavia. Over 200% locally in S. Russia, C. Ukraine, N.E. Belarus, C.Norway, N. Sweden, C. Switzerland, C. Spain. Dry elsewhere; under 50% in Murmansk area (N.W. Russia), N.E. of Black Sea, E. Bulgaria, extreme S. and much of N. Italy, N.W. and S.W. Spain; most of Greece, France, Portugal, S. England; locally S.E. Ukraine, E.Romania, S.W. Poland, Czech Republic, Slovakia, N. Austria, S. Germany, E. Ireland. Provisional sunspot number 92.

Africa. *Temperature*: warm almost everywhere N. of 10 N. and S. of 15 S.; +2degC locally in N.E. Algeria, Morocco, Mauritania, Libya and Egypt; possibly more widely in last three. Cold in and around Lesotho; locally on coast from N.Morocco to N.E.Algeria; -1degC locally in both areas. *Rainfall*: wet on and near coast from N. Morocco to N. Tunisia; S. Namibia, W. Botswana, extreme S. South Africa; much of Mozambique; over 200% at least locally in all these areas; widely in S. Namibia and W. Botswana. Dry generally elsewhere S. of 15 S. and from Canary Islands to Egypt; under 50% very widely in both areas.

Asia. *Temperature:* warm, in Turkey, Turkmenistan, Uzbekistan, Kazakstan, W. Tajikistan, Ob basin, S. Korea, S. Japan, Taiwan, Pakistan, Bangladesh, Sri Lanka; Thailand to Indonesia and Philippines; most of Kyrgyzstan, China, Mongolia, India, Nepal; +4degC in N. Kazakstan. Cold in E. Tajikistan, S.E. Mongolia, N. Korea, N. Japan; much of N. and E. China; locally in S. Kyrgyzstan and N. India; 1degC locally in N. China, S.E. Mongolia, N.E. Korea. *Rainfall*: wet in E. Turkey, extreme S.W. and S.E. Kazakstan, E. Tajikistan, S. Kyrgyzstan, Korea, S. and N.E. India, E. Nepal, Bangladesh, extreme S. Vietnam, Malaysia; most of Uzbekistan, Mongolia,China, Japan, Indonesia. Over 200% widely in Korea, Japan; locally in the other areas except possibly E. Turkey, E. Tajikistan, S. Kyrgyzstan, E. Nepal, Bangladesh, S. Vietnam. Thailand variable, but no large anomalies. Dry in W. Tajikistan, N. Kyrgyzstan, S.W. Mongolia, S.E. and parts of N. China, S. and extreme N. Japan, Pakistan, C. and N.W. India, Sri Lanka, W. Nepal; most of Turkey, Turkmenistan, Kazakstan, Vietnam, Philippines. Under 50% widely in Turkey, Kazakstan, Philippines, Pakistan, N.W. India; locally in the other areas except perhaps Turkmenistan, S.W. Mongolia and W. Nepal.

Australia. *Temperature*:, warm everywhere; +3degC locally in N.C. Northern Territory. *Rainfall*: wet from C. Queensland to extreme E. Victoria (most of this area over 200%); locally in W. Western Australia and from Alice Springs area to near Spencer Gulf. Dry elsewhere (no data for Tasmania); under 50% from C. Victoria to extreme S.E. Northern Territory; N. Queensland to N. Western Australia; parts of S.W.

M.W. ROWE

TORRO THUNDERSTORM REPORT: JULY 1999

by BOB PRICHARD

Thundery activity was less frequent than usual for July, but was quite widespread and severe on the 3rd and 5th and, to a lesser extent, the 6th and 31 st. There were few

other days in the month when it occurred at all. Thunder was heard on four or five days over parts of the Midlands and southeastern England, but not at all over parts of the southwest (especially Cornwall) and over much of Ireland and northern Britain.

A cold front drifting eastwards into warm air over Wales and England was responsible for the month's first outbreak of thunderstorms on the night of the 2nd/3rd. Initially, there were isolated thundery outbreaks ahead of it during the evening over southern England, then a more widespread development over Wales from mid-evening; this transferred eastwards during the night. Within this outbreak, a particularly severe series of storms started over Hampshire around midnight and moved northeast, with further development, across the south and east Midlands and East Anglia; it brought much of this area its most impressive night-time thunderstorm for several years, with virtually continuous lightning for a couple of hours. The observer at Higher Denham (Buckinghamshire) counted 150 flashes in 156 seconds, using a stopwatch, whilst at Cropwell Bishop (Nottinghamshire) it was reported that overhead lightning was so continuous that the street lighting switched itself off. At Great Kingshill (Buckinghamshire), thirty cloud-to-ground flashes were observed within a mile of the observer. Not surprisingly, there were numerous reports of lightning damage ; a few of the most noteworthy incidents are recorded here. A house was set on fire, and four people were treated for smoke inhalation, at Thame (Oxfordshire); there was a serious fire at a farmhouse near Stone (Staffordshire); 30% of the ground floor of a house at Luton was damaged when a fire began after a television and video recorder blew up; the loft of a house at Baldock (Hertfordshire) was badly damaged by fire; part of a listed seventeenth century garden wall at Stanstead Abbotts (Hertfordshire) was destroyed after lightning struck a nearby lime tree; at Kington (Herefordshire), a 120 foot Wellingtonia Redwood tree exploded when lightning struck it; the electricity supply was interrupted in Norfolk and Suffolk, and the water supply disrupted at Hornsea (East Yorkshire). The observer at Calthorpe (Norfolk) found himself on his hands and knees after lightning struck the anemometer on his house whilst he was standing at the window; he carried on observing the rest of the storm! There was also flooding in places - the fire service received 75 calls in two hours to pump out flooded buildings in Reading, and thousands of pounds worth of damage was caused at Bishop's Stortford (Essex) - whilst other features of these storms included hail, gusty winds and marked pressure fluctuations. Despite the severity of the outbreak, there seems to have been very little media coverage of it. The storms had moved out into the North Sea off Yorkshire by mid-morning on the 3rd, but there were isolated thundery showers around the (east) England/Scotland border just behind the cold front in the early afternoon. The northern limit of the overnight storms was around south Lancashire to North Yorkshire, with the extreme southwest and southeast and much of the south coast barely affected.

Shallow low pressure drifted east across the country from the 4th to the 6th, accompanied by thundery showers which peaked on the 5th. The 4th saw a few weak storms, mainly from north Wales across to Norfolk. On the 5th, storms first broke out in scattered locations in England in the late morning, and then became extensive through the afternoon over much of England and Wales, away from most western and southern coasts, and just into southern Scotland. There tended to be a slow northward movement of the storms, but this was erratic, and continual redevelopment meant persistent activity through much of the afternoon in places, especially over the Midlands; the slow movement also meant that there were pockets of the country that missed all the storms, for example central London. Hail, squally winds, tornadoes, flooding and lightning damage all featured prominently on this day, with the tornado at Selly Oak and the flooding at Pendeford, in the West Midlands, particularly well covered in the media, whilst at one stage Cannock was described by police as being "virtually an island". There was serious flooding around Manchester; 51 millimetres of rain fell in one hour at Kearsley, and a man had to be rescued from a car stranded in floodwater at Breightmet. A landslide forced closure of the A657 road near Harrogate. Around 150 calls were made to the emergency services to deal with flooding in the Lincoln area. 73 millimetres fell at Great Maplestead (Essex), with a report of 114 millimetres at a nearby farm; there was severe flooding in the upper Colne valley, with Sible Hedinghain particularly badly affected. In Hampshire, 66 millimetres was recorded at Andover, and many buildings suffered severe flooding. Amongst the most serious incidents due to lightning was the death of a horse at Anslow (Staffordshire). Many houses were hit by lightning across the country, and power supplies were disrupted in, for example, Cleveland, Lincolnshire, Derbyshire and Berkshire. Another giant Wellingtonia tree was split in two, this time at Ramsbury (Wiltshire), whilst a pine tree fell through the roof of an annexe to a house at Wotton-under-Edge (Gloucestershire). Thunderstorm activity died away by sunset.

With the depression retreating to the east, storms were fewer, and took longer to develop on the 6th; eventually, though, the day's higher temperatures (as a result of more sunshine) led to some sharp thunderstorms over Lincolnshire, East Anglia and Kent in the late afternoon and evening. There was some localised flooding and isolated reports of lightning damage. A further 27 millimetres fell at Sible Hedingham.

The next reports are for the 10th - an interesting outbreak as an ostensibly weak cold front drifted southeast around the England/Scotland border within an area of high pressure. Thunderstorms and intense rainfall affected parts of Lanark, Dumfries and Galloway (with 82 millimetres in two and a half hours at Corsock), Cumbria and north Lancashire, where it was reported that part of the coastal road at Barton-le-Sands was washed away. On the 13th, isolated thunder appeared to the northeast of London in the evening as a weak cold front took away a mass of hot air. On the 19th, a thundery outbreak moved northnortheast across southeasternmost England from East Sussex to Norfolk in the early hours (lightning set a roof cavity on fire in a residential home at Birchington (Kent), and there was also thunder near Yeovil in the evening, with a further report from northeast Scotland on the 20th.

The month's final outbreak occurred on the very hot closing day. A cumulus cloud appeared, and then rapidly grew into a towering cumulonimbus, over south London in mid- afternoon, with a fierce storm over the Clapham/Brixton area; this storm then tended to drift east into northwest Kent and weaken, whilst others developed in the early evening over parts of the east and south Midlands. Despite the localised severity of these storms, lightning incidents were minimal - whilst extensive press coverage of this Saturday's hot weather completely ignored the storms, despite much of London being affected for a time.

BRITISH WEATHER SUMMARY: JULY 1999

This was a warm, dry and sunny month over most of the British Isles. In the south, almost all of the rain came from thunderstorms (which were severe and fairly widespread in the first week), so that those areas that missed these were exceptionally dry; under five millimetres fell in several districts, especially in Surrey. Frontal rain was more significant in northern areas, and rainfall totals were nearer normal here. Mean monthly temperatures ranged from just above normal in northwest Scotland to around two degrees above normal in parts of southern Britain. A feature of the month was the short bursts of hot weather, which tended to be centred on the weekends with cooler interludes in the middle of the weeks.

After a fairly cloudy start with some rain, temperatures rose rapidly in a warm southerly airflow on the 2nd, before a cold front crossed from the west to trigger the most impressive night-time thunderstorms for several years over a large area of England; there was much lightning damage. It was fairly warm, but showery, until the 6th, with further heavy thunderstorms over many southern and central districts on the afternoon of the 5th. Several places received over 50 millimetres of rain in an hour or so, causing serious flooding; there were tornadoes as well, notably in the Selly Oak area of Birmingham. Rising pressure then brought a week of fairly sunny and increasingly hot weather. Temperatures peaked at just under 30 degrees at Lee-on-Solent on the 11th.

Much cooler weather spread from the west on the 13th, and the next few days were unsettled, with intervals of wet and windy weather in the north and west, but mostly very little rain in the south; here, in a warm sector, the temperature rose close to 30 Celsius in the London area on the 18th. It then turned cooler again everywhere, with a notably chilly, dull day in a northwesterly airflow in the north and east on the 22nd. Temperatures were back up to 30 degrees in parts of the southeast over the weekend 24th/25th, before cooler weather spread from the northwest; there was local ground frost in northern and central regions early on the 26th and 27th. The closing days of the month were fine over most of the country, and mostly sunny with rising temperatures - although some eastern districts were quite cloudy and chilly in a northeasterly airflow for a while. The month closed with its hottest day on the 31st, when Northolt recorded 31 degrees; however, thunderstorms broke out in parts of the southeast.

TEMPERATURE AND RAINFALL TABLES : JULY 1999

Station	*Authority*	*Mean*				*Grass*					
		Max	*Min*	*Max*	*Min*	*Min*	*Rain*	*%*	*Wettest*	*RD*	*T*
BELGIUM: Uccle	Inst. Roy. Met.	24.2	14.9	29.4(18)	11.3(1)	7.2(1)	34.5	47	19.3(4)	9	-
... Middelkerke	Inst. Roy. Met.	22.0	14.6	27.7(30)	10.7(1)	7.6(16)	19.7	34	8.3(4)	10	0
... Rochefort	Inst. Roy. Met.	24.9	12.2	30.6(18)	7.4(24)	-	49.0	59	38.0(4)	14	-
... Liege	Inst. Roy. Met.	25.3	16.0	31.6(18)	11.8(27)	-	84.7	109	67.5(4)	6	-
... Spa	Inst. Roy. Met.	22.1	12.9	28.6(18)	8.3(24)	4.6(27)	43.4	-	17.9(4)	11	-
DENMARK: Frederikssund	Ebbe Skjodt	23.5	13.9	29.7(12)	9.8(27)	5.0(27)	31.9	49	7.9(19)	11	2
HOLLAND: Ten Post	H. A. Veldman	23.2	13.7	30.0(19)	10.1(1)	5.2(28)	48.2	58	30.6(5)	9	4
ITALY: Genova	R. Pedemonte	28.5	21.0	31.5(5)	18.8(11)	18.6(13)	87.4	-	29.8(11)	8	7
LUXEMBOURG:Luxembourg	Inst.Roy.Met.	24.6	14.5	29.5(18)	9.6(1)	9.1(1)	49.4	-	21.1(6)	6	6
MALTA : Luqa	Civil Aviation	31.3	21.4	34.8(13)	19.6(1)	14.7(1)	0	0	0	0	0
SPAIN: Peralejos d.Truchas	M. Lorente	28.7	9.4	32.4(1)	5.9(28)	-	39.8	-	13.8(26)	8	7
EIRE : Straide, *Co. Mayo*	Martin Sweeney	20.1	12.1	26.5(8)	4.0(26)	0.0(26)	67.8	90	12.4(16)	17	0
Mt Russell, *Limerick*	David Meskill	19.8	12.0	24.5 (31)	7.8(26)	4.5 (28)	43.5	-	7.9(5)	18	0
SHETLAND: Fair Isle	David Wheeler	13.4	10.0	15.1(8)	8.1(3)	4.3(19)	41.6	81	16.9(22)	17	0
SCOTLAND: Cambo, *Kinros*	Malcolm J. Smith	19.2	9.7	26.0(12)	4.0(26)	2.0 (26)	57.4	-	12.8 (18)	14	0
WALES: Gower, *Glam*	John S. Powell	21.2	12.9	26.4(30)	8.1(23)	5.5(23)	12.6	17	9.5(19)	6	0
Crymych, *Pembroke*	Stuart Sweet	20.4	12..1	25.7(30)	6.6 (23)	1.4(23)	34.5	32	17.1 (19)	9	0
Velindre, *Powys*	John Goodger	22.4	11.8	27.5(31)	4.7(23)	0.6(23)	28.2	59	11.1 (19)	4	2
Llansadwrn, *Anglesey*	Donald Perkins	20.7	12.7	27.5(31)	8.6(23)	5.9(23)	26.1	36	9.5 (19)	9	1
Red Wharf Bay, *Anglesey*	Keith Ledson	19.8	12.9	25.6(31)	9.7(28)	6.1(23)	17.3	28	8.9 (19)	7	1
ENGLAND:											
Haselbury Plucknett, *Somer*	J. S. Kellaway	24.6	10.6	30.4(30)	6.1(23)	2.2(23)	6.4	16	3.2(19)	7	0
Gurney Slade, *Somerset*	W. J. Newman	23.1	11.6	28.6(30)	7.1(23)	6.8(23)	31.0	39	20.0(5)	8	1
Yatton, *Somerset*	A. H. Weeks	23.7	12.9	29.5(30)	6.2(23)	3.3(23)	9.3	17	4.7(19)	6	2
Reading University , *Berks*	Ken Spiers	23.7	13.0	30.2(31)	8.1(23)	1.0(23)	52.9	132	42.5(2)	9	3
Sandhurst, *Berkshire*	John M. Heighes	24.7	12.0	31.6(31)	6.1(23)	4.4(23)	15.2	24	7.2(31)	8	3
Maidenhead, *Berkshire*	Roger Brugge	24.7	13.6	30.9(31)	7.8(23)	6.4(23)	22.9	49	15.3(2)	5	3
Brighton, *Sussex*	Leslie S. Laskey	22.8	13.8	27.5(11)	10.2(23)	9.2(23)	11.1	21	10.5(19)	2	1
Hastings, *Sussex*	D. I. Powell	22.7	14.6	28.5(30)	11.5(15)	7.0(15)	21.6	41	11.2(19)	5	2
Dover, *Kent*	Norman Brooks	22.4	14.7	28.7(31)	11.3(15)	6.5(15)	22.9	-	15.1 (18)	3	2
East Malling, *Kent*	Research Station	24.3	14.2	30.5(31)	9.7(15)	4.9(15)	14.8	29	10.8(5)	5	-
Epsom Downs, *Surrey*	John A. Bird	25.0	12.6	31.3(31)	6.0(23)	3.7(23)	5.7	13	2.5(19)	6	5
Motspur Park, *Surrey*	Edward Hanna	-	-	31.0(31)	8.3(23)	-	3.7	-	-	-	-
Coulsdon, *Surrey*	Ian Currie	24.0	13.2	30.7(31)	9.4(23)	6.1(23)	4.4	-	2.2(19)	4	4
Hayes, *London*	A. J. E. Barty	25.3	14.8	30.4(24)	9.8(23)	6.9(23)	3.6	8	1.8(19)	4	4
Royston, *Hertfordshire*	Richard Barker	24.1	13.3	29.6(31)	8.0(27)	4.9(27)	50.3	103	24.9(6)	9	4
Loughton, *Essex*	Bob Prichard	24.1	13.5	28.9(31)	9.9(15)	6.0(15)	25.0	-	11.8(2)	6	3
Colchester, *Essex*	Terry Mayes	24.5	13.6	30.3(31)	10.8(15)	-	9.1	27	4.0(19)	6	3
Buxton, *Norfolk*	Charles Briscoe	22.8	12.5	28.4(24)	5.4(27)	1.8(27)	40.3	75	20.4(2)	9	3
Oxford University , *Oxon*	Radcliffe Observ	24.2	13.3	30.4(31)	9.4(23)	4.5(23)	7.2	12	2.9(20)	6	-
Tipton, *West Midlands*	Terry Holmes	23.6	13.3	29.6(31)	9.2(27)	-	28.3	-	16.7(5)	7	2
Cosby, *Leicestershire*	David Mutton	23.5	13.2	31.1(31)	8.9(23)	5.5(23)	9.9	20	3.0(19)	6	1
Louth, *Lincolnshire*	Ian Trowsdale	22.7	12.8	28.8(24)	7.9(13)	6.2(26)	17.3	38	5.4(1)	5	2
Lowdham, *Nottinghamshire*	John E. Osborne	23.6.	12.5	30.3(31)	8.9(27)	6.5(27)	21.4	47	14.7(2)	8	1
Derby, *Derbyshire*	David Stanier	23.6	13.2	30.1(31)	8.9(23)	6.7(23)	35.0	61	23.4(2)	9	2
Middleton, *Derbyshire*	David Evans	20.2	12.0	26.2(31)	8.5(27)	6.0(27)	45.9	86	21.3(2)	8	2
Keele University, *Staffs*	M.B. Edge	22.0	12.5	28.1(31)	8.8(27)	3.3(27)	28.8	44	8.3(2)	8	3
High Bradfield, *S. Yorks*	Peter Smithson	19.6	11.3	26.4(31)	7.4(27)	4.3(10)	-	-	-	-	-
Carlton-in-Cleveland, *N.Yks*	M. B. Cinderey	21.3	12.0	27.4(31)	4.7(27)	0.9(27)	11.6	25	2.9(19)	8	6
Durham University, *Durham*	Helen Goldie	20.8	11.5	26.0(8)	4.1(27)	2.9(27)	12.1	66	4.4(19)	8	-
Sunderland University, *T/W*	Dennis Wheeler	20.0	13.5	24.8(24)	9.3(27)	-	7.6	12	5.0(19)	5	0
Ambleside, *Cumbria*	John Burton	20.2	11.6	26.7(31)	6.1(27)	-	86.9	68	25.7(19)	13	0
Keswick, *Cumbria*	Ken Bond	20.4	11.1	26.3(30)	6.1(27)	-	61.6	63	11.3(17)	12	0
Coniston (Haws Bank), *Cum*	John Oxborrow	20.6	12.6	26.9(9)	8.9(26)	-	109.5	-	32.3(19)	12	0
U.S. Bergenfield, *New Jersey*	Rudy Nickmann	33.4	20.0	38.9(5)	12.8(11)	-	9.4	-	6.1(1)	4	3
U.S. Norfolk, *Virginia*	James Fentress	32.0	22.3	37.7(6)	17.8(16)	-	234.1	180	50.0(14)	10	6
U.S. Venus, *Texas*	Will A. Shaw	35.5	24.5	39.5(29)	19.5(18)	-	40.9	-	39.4(10)	2	5
JAMAICA: Kingston	Met. Service	33.4	25.8	35.3(9)	24.5(28)	-	10.5	28	4.0(10)	4	4
" Montego Bay	Met. Service	32.9	24.4	34.2(3)	22.3(13)	-	46.3	87	19.4(6)	12	10

The International TORRO Tornado Intensity Scale

T0	LIGHT TORNADO 17-24 m/sec., 39-54 mph	Loose light litter raised from ground-level in spirals.,' Tents, marquees seriously disturbed; most exposed tiles, states on roofs dislodged. Twigs snapped; trail visable through crops.
TI	MILD TORNADO 25-32 m/sec., 55-72 triph	Deckchairs, small plants, heavy litter made airborne' minor damage to sheds. More serious dislodging of tiles,.slates, chimney pots. Wooden fences flattened. Slight damage to hedges and trees.
T2	MODERATE TORNADO 33-41 m/sec., 73-92 mph	Heavy mobile homeOdisplaced, light caravans blown over, garden sheds destroyed, garage roofs torn away, much damage to tiled roofs and chimney stacks. General damage to trees, some big branches twisted or snapped off. small trees uprooted.
T3	STRONG TORNADO 42-51 m/sec., 93-114 mph	Mobile homes overturned/badly damaged; light caravans destroyed; garages, outbuildings destroyed; house roof timbers considerably exposed. Some of the bigger trees snapped or uprooted.
T4	SEVERE TORNADO 52-61 m/sec., 115-136 mph	Mobile homes destroyed; some sheds airborne for considerable distances; entire roofs removed front some houses or prehbricated buildings, roof timbers of stronger brick or stone houses completely exposed; possible collapse of gable ends, Numerous trees uprooted or snapped.
T5	INTENSE TORNADO 62-72 m/sec., 13,7-160 mph	Motor cars levitated; more serious building damage than for T4, yet housewalls usually remaining; the weakest, old buildings may collapse completely.
T6	MODERATELY-DEVASTATING TORNADO ; 73-83 m/sec., 161-186 mph	Heavy motor vehicles levitated; strong houses lose entire roofs and perhaps also a wall; more of the less-strong buildings collapse.
T7	STRONGLY-DPVASTATING TORNADO 84-95 m/sec., 187-212 mph	Frame house completely demolished; some walls of stone or brick houses beaten down or collapse; steel-framed warehouse-type buildings may buckle slightly. Locomotives thrown over. Noticeable de-barking of any standing ttees by flying debris.
T8	SEVERELY-DEVASTATING TORNADO 11 96-107 m/sec., ~13-240 mph	Frame houses and their contents dispersed over big distances; most other stone or brick houses irreparably damaged; steel-framed buildings buckled; motor cars hurled great distances.
T9	INTENSELY-DEVASTATING TORNADO : 108-120 m/sec., 241-269 mph	Many steel-framed buildings badly damaged locomotives or trains hurled some distances. Complete debarking of any standing tree-trunks.
TIO	SUPER TORNADO 121-134 m/sec. or more, 270-299 mph or more	Entire frame houses and similar buildings lifted bodily rom foundations and carried some distances. Steel-reinforced concrete buildings may he severely damaged.

For further infoniiation refer to *J. Meteorology*, vol.1, no.8,242-251 and vol.8, no.79, 151-153.

JOURNAL OF METEOROLOGY Vol. 24, no. 243, November 1999

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