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A damaging microburst and tornado near York on 3 August 2011

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Introduction

Damaging winds associated with severe thunderstorms are a common phenomenon. Examples have been documented in many countries around the world, most especially the United States (e.g. Wakimoto and Bringi, 1988). Damaging winds from deep convection can be categorised into two basic types according to their origin: those associated with strong, sub-storm scale vortices, including tornadoes, and so-called 'straight-line' winds associated with the descent of cold air from a storm in the form of a 'downburst' or 'microburst' (for a review see Wakimoto, 2001). To date, however, there are few published accounts of downbursts from thunderstorms in the United Kingdom (exceptions are the papers by Naylor (1995) and Waters and Collier (1995)). In the present article we document the results of a site investigation of damage caused by a severe thunderstorm near York (North Yorkshire) on the afternoon of 3 August 2011. We found that there were several distinct swathes of damage, the

†The contribution of this author was written in the course of his employment at the Met Office, UK, and is published with the permission of the Controller of HMSO and the Queen's Printer for Scotland.

principal one with a divergent pattern, which we attribute to a 'microburst' (a small-scale downburst (Fujita, 1981)), and a second, separate narrow damage track which was probably associated with a weak tornado. We provide a brief résumé of observational data and imagery of this storm and suggest an interpretation of the observed storm morphology. The environment in which the storm developed did not appear especially conducive to severe thunderstorms and, indeed, other storms on this day did not produce damaging winds or tornadoes. Some possible reasons for the development of severe winds in this particular storm are proposed.

Reported damage and site investigation

There were widespread news reports of severe weather from eastern England on 3 August 2011, including reports of lightning damage to property in East Anglia and flash flooding at Goole (East Yorkshire). Of particular note were local news reports of localised flooding, hail and wind damage at the village of Dunnington, 7km to the east of York. The village was preparing for the 'Britain in Bloom' competition at the time of the storm and urgent remedial work had to be undertaken by the villagers for the imminent judging. The York Press (Anon., 2011) showed pictures of a large tree brought down on to a summerhouse, flood water up to about a metre deep and accumulations of small hail. The village was visited by a member of the Tornado and Storm Research Organisation (TORRO) soon after the event; initial investigations were inconclusive as to the exact cause of the damage, although it was clear that the winds were associated with a severe thunderstorm. In subsequent days it became apparent from local press reports that damage had occurred over a much more extensive area to the east and southeast of York, and that this warranted further investigation. In particular a local farmer, Mr. Julian Hopwood, reported extensive hail damage to his crops and the raising of a heavy wooden stable over a fence into an adjacent field. The following account of damage at Grimston Grange and Clock Farms is based on information obtained from telephone and personal interviews with Mr. Hopwood and three site investigations by two of the authors, Tim Prosser and Louise Hill (see Figure 1 for the locations of various places mentioned in the account). We shall refer to this damaging storm as 'the storm' or the 'Dunnington-York storm'.

Mr Hopwood gave a graphic account of the storm, describing a menacing black cloud which 'came up against the wind' and enveloped the farm in a violent storm, accompanied by thunder and lightning, and horizontally-blown hailstones, approximately 1.0–1.5cm in diameter, which damaged crops and scarred paintwork on fences and doors. Although little damage was done to farm buildings, the cost of the impact on crops was estimated to have been in excess of £30 000. A large and heavy wooden horse shelter, albeit not secured to the ground, was lifted over a 1.0–1.5m fence (without damage to the fence) and deposited in a field 20m away. Friends of Mr Hopwood later reported seeing a 'tall black cloud', extending from cloud to ground and travelling over the fields, which they identified as a 'tornado'. No injury to livestock or persons was reported. On the southern border of Grimston Grange Farm, and at neighbouring farms, Mr Hopwood reported extensive damage to trees. This area borders on Elvington Airfield, on to which garden furniture had been transported a distance of several hundred metres from a house near the boundary fence. The Automatic Weather Station (AWS) at the airfield recorded an isolated gust of 43kn (~22ms^{-1}, ~50mph) at around 1430 UTC (Steve Roper, Airfield Manager, pers. comm.), which is consistent with the time given by other eyewitnesses.

Figure 1. Locations mentioned in the text. The inset shows the location of the main figure. The box in the main figure shows the location of Figure 2. Main roads are in grey.

The farm and surrounding area was visited on three occasions. Investigations consisted of recording, photographing and mapping the damage with the help of a Global Positioning System (GPS) instrument, Geographical Information System (GIS) software and the Google Earth software platform. The surrounding area was surveyed by road and by following up reports of local damage on foot where possible. Some fallen trees had been cleared away but much debris remained, and scars in hedgerows and field boundaries were clearly visible. It was not possible to survey accurately the damage to field crops here or at surrounding farms; however, hail damage to crops was extensive in a west-east swathe in the York area (J. Hopwood, pers. comm.).

The results of the site investigations are summarised in Figure 2. The linear features apparent within the overall damage pattern are due to the location of field boundaries, hedgerows and roads. There are clearly two or more distinct areas of damage. The major swathe to the south is shown in more detail in Figure 3, whilst Figure 4 is a photograph of tree damage from this swathe. In some areas large, mature trees had been uprooted or broken off at the main trunk, or had suffered severe damage to major limbs.

A second swathe was much narrower and orientated southwest to northeast, extending northeastwards from Grimston Grange Farm (from where the stable was tossed over the fence) and then towards Dunnington. Tree damage near the A1079 appeared to be due to a rotational component of the wind with debris mainly thrown to the west, or left of the track, implying a cyclonic windfield. Another concentrated area of damage is evident at Dunnington itself. A large, mature tree had been toppled in the village and sightscreens at the local cricket club had been overturned and damaged. Since extensive reparation work had been carried out here soon after the event it was not possible to infer the precise nature of the wind-field in the village but it was essentially unidirectional towards the eastnortheast. Further intermittent damage, with no

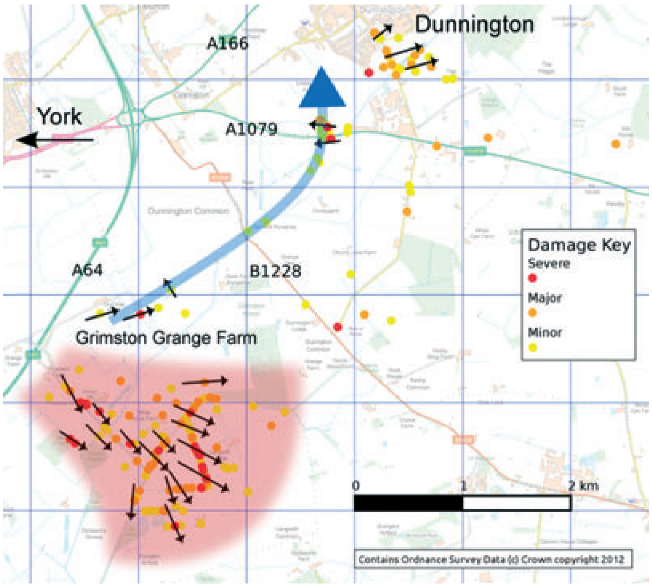
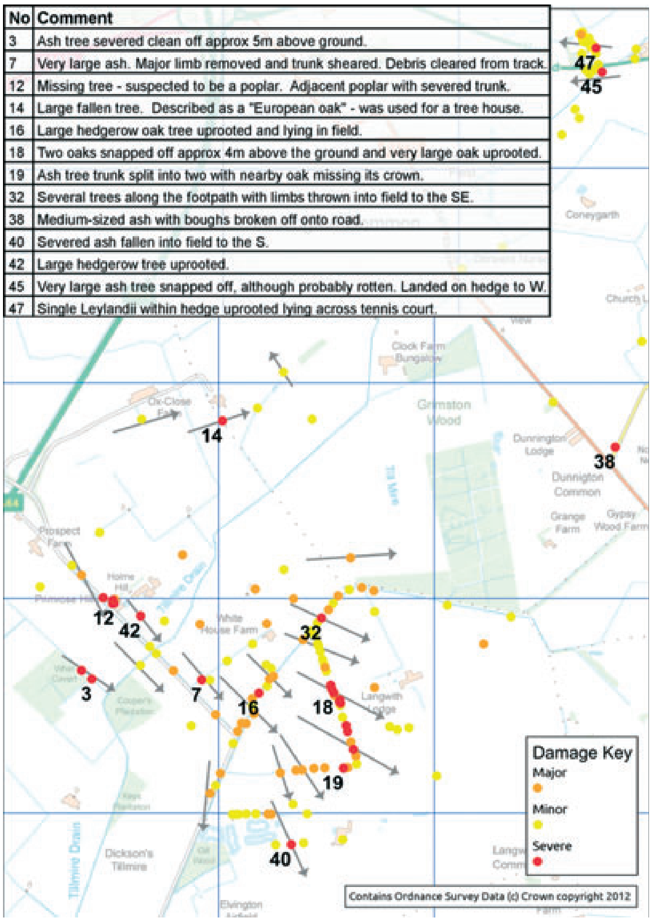


Figure 2. Results of the damage surveys. The area of damage attributed to a microburst is highlighted in red. The inferred track of a tornado is indicated by the blue arrow. The direction of debris-throw at selected locations is indicated by the black arrows. (Tim Prosser and Louise Hill.)



No	Comment
3	Ash tree severed clean off approx 5m above ground.
7	Very large ash. Major limb removed and trunk sheared. Debris cleared from track.
12	Missing tree - suspected to be a poplar. Adjacent poplar with severed trunk.
14	Large fallen tree. Described as a "European oak" - was used for a tree house.
16	Large hedgerow oak tree uprooted and lying in field.
18	Two oaks snapped off approx 4m above the ground and very large oak uprooted.
19	Ash tree trunk split into two with nearby oak missing its crown.
32	Several trees along the footpath with limbs thrown into field to the SE.
38	Medium-sized ash with boughs broken off onto road.
40	Severed ash fallen into field to the S.
42	Large hedgerow tree uprooted.
45	Very large ash tree snapped off, although probably rotten. Landed on hedge to W.
47	Single Leylandii within hedge uprooted lying across tennis court.

Figure 3. Results of the damage surveys with comments on damage type at selected locations. (Tim Prosser and Louise Hill.)

clear pattern, was found to the east of Dunnington.

Interpretation of the site investigation results

Having described the results of the site investigation, we now provide an interpretation of the observed patterns of damage. The southern, fan-shaped swathe we interpret as the result of a microburst. Interestingly, Figure 3 suggests there was a core of more severe damage along the central axis of the swathe which may correspond to the microburst core. Although substantial and highly-localised de-limbing of trees occurred within this swathe (see Figure 4) and might suggest tornadic winds, we believe this damage is more likely to be due to violent turbulent motions at the leading edge of the microburst. The nature of the damage to the trees suggests wind speeds possibly well in excess of 30ms^{-1} (~67mph).

The origin of the second damage swathe is less easy to interpret with confidence. However, the length and narrowness of the damage track, the lifting of the horse shelter over the fence and the throw direction of intermittent tree damage near the A1079 suggests to us the presence of a weak tornado, with an intensity rating of F0–F1 on the Fujita scale or T0–T2 on the TORRO-scale (Meaden, 1983). This is also consistent with the eyewitness report of a 'tall black cloud' in contact with the ground. The damage at Dunnington itself probably occurred either in association with a surge of strong winds on the southeast flank of this circulation, as it dissipated, or in association with a separate, small swathe of downdraught winds.

The coexistence of downburst and tornadic damage swathes has been reported previously in the literature (e.g. Fujita, 1981); indeed horizontal and vertical vortical circulations may form as part of the downdraught circulation as it strikes the ground (e.g. Orf and Anderson, 1999), or along the leading edge of the gust front (Lee and Finley, 2002).

The nature of the thunderstorm

Here we seek to summarise the observed life-cycle of the thunderstorm itself, make a preliminary interpretation of its behaviour and formulate hypotheses which will be examined in detail in a later research paper.

The shower that became the Dunnington-York storm originated on the northern Peak District hills at about 1100 UTC; it quickly turned thundery, producing the first lightning before 1200 UTC. The observed track of the storm, as seen in Met Office network radar imagery, is shown in Figure 5. The movement of showers on this day was from the southwest, consistent with the (rather weak) southwesterly synoptic flow observed throughout much of the convective boundary layer, illustrated by the 1200 UTC radiosonde observation from Nottingham (Figure 6). Interestingly the Dunnington-York storm showed persistent motion to the right of the mean convective-layer wind, even in the early phases of its life cycle. In supercell storms (i.e. storms which exhibit persistent, deep rotation, (e.g. Weisman and Klemp, 1984)), rightward deviant motion is associated with continuous development on the right flank of the storm. Some of the early deviant motion in this case may have been associated with the tendency for daughter cells to form periodically on the

Figure 4. Photograph of severe damage to trees in the downburst swathe. The two trees to the left of centre of the photograph have been snapped off at the main trunk and a third, to the right, has been uprooted. (Tim Prosser and Louise Hill.)

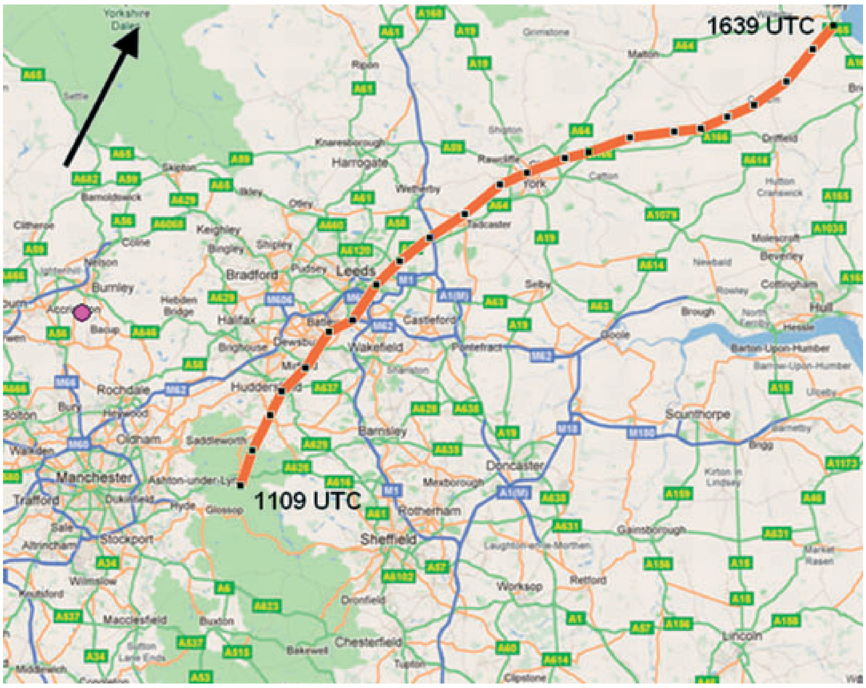


Figure 5. The track of the Dunnington-York storm as inferred from network radar imagery. Black arrow shows the observed direction of movement of other, non-severe, cells on this day. (Matthew Clark, Met Office; map image, Google Earth.)

right flank of the storm, as was evident from sequences of radar data, rather than having been due to continuous development. Another possibility is that the shower was tracking along or interacting with a convergence line extending downwind of the Peak District orography. However, there were no reports of severe weather along the track of the shower prior to 1400 UTC. In the vicinity of York the storm developed even more marked rightward motion (Figure 5). Inspection of the radar imagery revealed no new daughter cell development after ~1400 UTC; it is therefore likely that the storm was exhibiting continuous rightward development, consistent with supercell behaviour, by the time it reached York. At approximately 1400 UTC explosive intensification occurred. By this time, the storm was producing intense precipitation, including small hail, strong gusts (as logged by an AWS located on the University of York campus to the southeast of the city centre) and frequent lightning. The storm core subsequently tracked just to the north of Grimston Grange Farm and towards and over Dunnington. The rightward motion reached a maximum at, or shortly after, this time with a motion vector towards the east or eastnortheast.

During the morning of the 3rd strong sea breezes had developed along the east coast of England, and these subsequently penetrated inland. In places, the sea-breeze fronts were apparent as reflectivity 'fine lines' (i.e. lines of very weak echoes) in radar imagery. By 1400 UTC a section of this Sea-Breeze Front (SBF) lay just to the east of York The evidence suggests that between 1400 and 1430 UTC the storm was located along, or just to the east (ie the seaward side), of the SBF. It was during this period that the damaging microburst and tornado occurred. Network radar and visible satellite images for 1500 UTC are shown in Figure 7. The satellite image shows the storm had a fairly well defined V-shaped appearance (most apparent in animation), with the radar indicating an intense core (reflectivity > 55dBZ) colocated with the apex of the 'V' on the southern flank of the cell. Examination of raw radar imagery (not shown) at various elevations suggests the presence of a weak overhang in the reflectivity echo on the right (southeast) flank, though no Bounded Weak Echo Region (BWER) or hook echo is apparent. The lack of a BWER (a well-defined region of low radar reflectivity in supercell storms implying a highly organised separation of a rotating updraught and downdraught), together with the deviant rightward motion, the storm morphology and occurrence of severe weather, indicates that the storm probably acquired the characteristics of a high-precipitation supercell (e.g. Beatty *et al.*, 2008) as it interacted with the SBF. Unfortunately, the network radars within range of the storm had not been Doppler-enabled at the time of this event and, as a result, direct observations of a rotating updraught ('mesocyclone'), which would have provided more conclusive diagnosis of supercell behaviour, were not available.

Discussion

We have presented evidence that the Dunnington-York storm produced a microburst and a tornado. Preliminary analysis of radar, satellite and model data suggests that the storm was at its most severe on, or soon after, interacting with and crossing the SBF. The structure of the storm around this time resembles that of a supercell storm with an intense updraught, as indicated by the V-shaped anvil outflow and evidence of an overhang on the forward flank. The absence of a detectable hook echo or BWER, and the intense precipitation observed, suggests it can be classified as a 'High-Precipitation' (HP) supercell.

Past studies provide evidence that interaction with boundaries is one of the key factors involved when thunderstorms produce severe weather, including tornadoes (e.g. Markowski *et al.*, 1998). Most studies are of cases in the United States, but there are recent examples of storm-boundary interaction in the UK including the Birmingham tornado HP supercell of 28 July 2005 (Smart, 2008; Groenemeijer *et al.*, 2011). The Bracknell hailstorm of 7 May 2000 was also thought to have

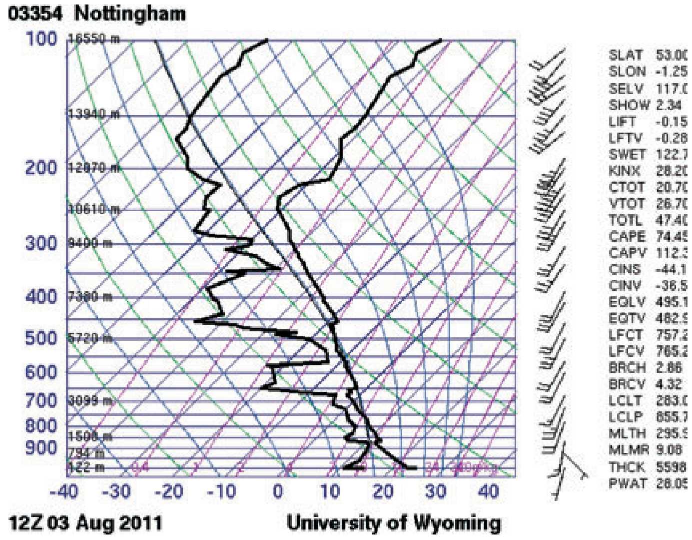


Figure 6. Radiosonde ascent for Watnall (Nottingham) at 1200 UTC on 3 August 2011. (Courtesy University of Wyoming.)

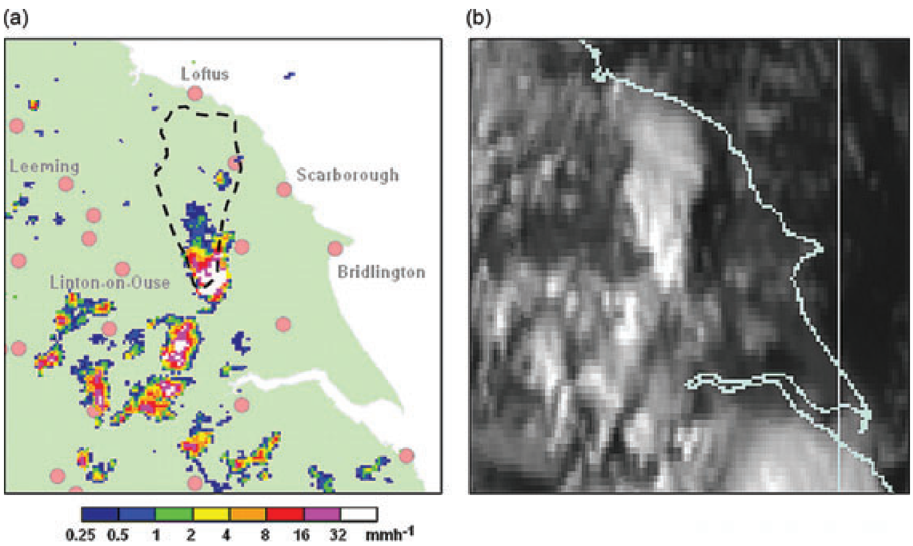


Figure 7. (a) Network radar image at 1500 UTC on 3 August 2011 (Copyright Met Office). The edge of the anvil cloud from the satellite image has been overlaid as a dashed line. (b) METEOSAT visible satellite image at 1500 UTC on 3 August 2011. (Copyright Met Office and EUMETSAT.)

produced its most severe weather on storm-boundary interaction (Pedgley, 2003). In the current case, the larger-scale environmental conditions did not appear especially conducive to severe thunderstorms; in particular, the vertical wind shear was rather weak (Bulk shear ~13ms^{-1} in the 0–6km layer). Although we have not discussed other storms in eastern England on this day, cell-entraining on the seaward side of the SBF appears to have been responsible for the quasi-stationary storm behaviour which caused the flooding at Goole and the thunderstorms which produced damaging lightning in East Anglia. Therefore, it could be suggested that sea-breeze interaction was a necessary condition for severe storms on this day.

Although this type of thunderstorm and its attendant severe weather is uncommon in the UK, the occurrence of the sea breeze and the SBF are regular, almost daily, events during the warm season. Forecasters need to be alert for the potential of showers to intensify and produce severe weather when interacting with SBFs, even where the larger-scale conditions may appear marginal for severe weather. The new generation of kilometre-scale numerical weather prediction models should be capable of modelling the key features of storm-boundary interaction. For the present case we have conducted a number of simulations with the Weather Research and Forecasting (WRF) model initialised with operational runs of the Global Forecast System (GFS) model. So far these have produced mixed results. The Dunnington-York storm is not itself present in the simulations; however, the SBF is well-represented and at least one model run produces a storm which crosses the SBF and acquires supercell-like characteristics. A downburst with surface winds up to ~30ms^{-1} and small tornado-like circulations along the gust front is produced in one simulation. However, as has been found for other numerical simulations of storms, the results are highly sensitive to the choice of microphysics parameterisation in the model. Further discussion of the modelling results is beyond the scope of the present paper, but we have identified a number of questions requiring clarification:

- Why did the Dunnington-York storm exhibit a degree of deviant rightward motion apparently soon after its inception over the Peak District?
- How and why are the model results sensitive to model configuration and resolution?
- Can models with grid spacing of the order of 1km truly simulate the key details of this complex storm boundary interaction with sufficient fidelity and reliability to provide useful information for forecasting and nowcasting?
- What are the mechanisms by which severe weather is produced on storm-boundary interaction?

Such questions will need to be answered by conducting careful experiments with operational and idealised numerical model simulations. Another area for future research will be to assess whether the higher capability radars that are currently being rolled out by the Met Office – with their ability to discriminate between hydrometeor types, measure winds at high resolution and their potential ability to detect areas of moisture convergence – bring significant improvements in the real-time detection and short-term forecasting of small-scale, dangerous weather phenomena.

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Chris Johnson (TORRO) conducted a preliminary site investigation in the Dunnington area. We are greatly indebted to Julian Hopwood and family at Grimston Grange Farm, who gave valuable time for interviews and assisted the site investigation. We thank Emeritus Professor Keith Browning who provided invaluable advice and interpretation of data during this phase of our research.

We thank numerous other people who provided further data, information and assistance, and a reviewer is thanked for constructive comments that helped us to improve the clarity of the manuscript.

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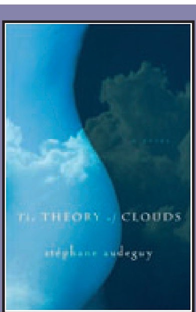
Book reviews



The Theory of Clouds

Stéphane Audeguy (ed.)

Harcourt Publishers, reprint edition, 2008

Paperback £9.99

272 pp

ISBN 978-0156034814

Stéphane Audeguy's first novel about man's relationship with clouds is an absorbing work of loosely-historical fiction: 'loose' because even though it contains key events from the last 200 years of progress in cloud science (Luke Howard pops up from time to time) the author has taken the liberty of creating an inner world for each of his cloud characters.

With a leap of artistic licence he has the painter Constable (thinly veiled as a character called Carmichael) driven to insanity by his all-encompassing desire to capture the heart of the ever-changing clouds in his paintings, and the Swedish meteorologist Hugo Hildebrand Hilderbransson (not so thinly veiled as William Svensson Williamsson) becomes a fame-hungry womaniser who takes sole credit for the invention of the International Cloud Atlas, betraying his quieter collaborator Ralph Abercromby (even less thinly veiled as Richard Abercrombie).

It is Abercrombie's story that I found the most enjoyable. Spurned by Williamsson/Hilderbransson he sets out on a round-the-world trip to produce a first-hand anthology of clouds at every latitude. In reality the expedition produced a book called 'Seas and skies in many latitudes or Wanderings in Search of Weather' (1888, Nabu Press), whereas in the novel Audeguy has him travel into the heart of darkness and emerge to discover the joys of life beyond his precious clouds, leading him to create the 'Abercrombie Protocol', a mysterious notebook around which much of the novel revolves.

The contrasting themes of death and sex run steadily throughout the novel, though they are both presented in an almost entirely emotionless way. Which is why whenever there is a moment of pure feeling it comes across all the more powerfully. Narrating these beautifully-embellished snippets of cloud history is the elderly Kumo, survivor of the Hiroshima atomic mushroom cloud, who relates each tale to his new librarian Virginie and has his own heart-rending cloud story to tell, which only the reader gets to discover.

To present such a specialist subject as the history of cloud science is in itself a grand task but to then add fiction, erotic fiction at that, is ambitious to say the least. But it works. It is well researched in its passages of fact, and the eloquence and maturity with which Audeguy writes makes the fiction believable, even in its imagination.

Emma Turner

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