Institution: University of Reading

Unit of Assessment: 7 Earth Systems & Environmental Sciences

Title of case study: Storm prediction improved by sting jet discovery

1. Summary of the impact

Starting in 2001, researchers from the Unit undertook a retrospective analysis of data from the Great Storm of October 1987 which led to them identifying and understanding a region of extremely strong winds within some storms. They termed these winds a "sting jet". In collaboration with the Met Office, the researchers developed ways to identify sting jets in current and imminent weather and, later, methods to forecast these extremely damaging events up to a several days in advance. These techniques are now used in the UK National Severe Weather Warning Service (NSWWS) and in European storm forecasts. Since the development of this new early warning capability, events have been too few to compile proper statistics; however, there is general agreement amongst the emergency services, local government officials and insurers that the improved warnings of extreme winds have saved lives, minimised disruption and generated considerable cost savings.

2. Underpinning research

In the early hours of 16 October 1987, a now infamous storm struck southeast England and northern France, resulting in the deaths of 22 people in these two regions. Extreme winds of up to 115 miles per hour, which had not been forecast, also caused widespread structural damage to buildings, and brought down an estimated 15 million trees.[1] Rail and road transport were disrupted and power supplies to some areas were interrupted for more than two weeks. The storm was the second most expensive weather event in the UK on record, costing the insurance industry £1.4bn.[2]

Motivated by a similar, "near-miss" storm on 30 October 2000 (in which the strongest winds did not cause damage because they were over the North Sea)[3] Unit scientists examined surface observations (wind, temperature, humidity and pressure), satellite imagery and radar rainfall data, for the 1987 storm, to ascertain the cause of the very strong wind gusts that developed that night. This work was carried out by Prof K. Browning between 2001 and 2003, with a PDRA (M. Field) under his supervision. Browning retired from UoR in 2003 and is now a visiting Emeritus Professor with the Unit. Subsequently, the work was carried on by Unit members Dr S.Gray and Prof P. Clark (the latter being Unit member for 1998-2010 as part of the embedded Met Office Joint Centre for Mesoscale Meteorology, JCMM now called MetOffice@Reading, who rejoined the Unit as a UoR Professor in 2012). Also involved in the work have been Unit members Dr J. Methven, MetOffice@Reading research assistant Dr. C. Wang, PDRA Dr. O. Martínez-Alvarado, PhD student Dr. L. Baker (who became a PDRA in with the Unit in 2011), and PhD student J. Catto (until 2010): all these PDRAs and students were supervised by Gray and Clark.

Browning found that the most damaging gusts the 16 October 1987 storm had occurred in a small region (roughly 50 km across) present for only a relatively short time (a few hours) compared with the lifetime of the storm as a whole (1-2 days). He interpreted observations as showing that these most damaging winds emanated from a jet of air emerging from the tip of a hook-shaped cloud that encircled the low-pressure centre of the storm system, a region different from the commonly-understood areas where strong winds were expected (Browning, 2004[6]; Browning and Field, 2004[7]). Browning named the phenomenon a "sting jet", because meteorologists from Bergen had previously noted that such hook-shaped clouds had the appearance of a scorpion's tail. Browning also identified the evolution of the cloud pattern in satellite imagery as a useful tool for identifying the presence of a sting jet once it had developed.

Clark et al. (2005)[8] used high-resolution numerical weather prediction models to study the 3-dimensional structure of sting-jet storms. They confirmed that the most damaging surface winds result from a jet of air descending from a part of the hook-shaped cloud several kilometres above the ground, which is unstable to an atmospheric instability known as Conditional Symmetric Instability (CSI). Based on an understanding of when and where damaging surface winds might develop, other researchers in the unit (Gray with Martínez-Alvarado and Baker) went on to confirm the presence of sting-jets in a number of storms, as did international collaborators using different models (Martínez-Alvarado et al., 2010).[9] Broader collaborative projects involving the Unit have observed such events in yet greater detail, including the NERC-funded DIAMET project (DIAbatic influence on Mesoscale structures in ExTratropical storms).

High-resolution modelling studies by the Unit's researchers enabled them to determine the minimum resolution needed in weather forecast models to capture the phenomenon. Models of sufficient resolution are now run operationally by forecast centres such as the Met Office for short-range forecasts. They also showed that strong sting jets only occur in storms which develop CSI in the hook-shaped cloud, and hence they developed a diagnostic to detect sting jets in the low-resolution datasets typical of longer-range forecast models incapable of directly resolving the sting jet (Gray et al., 2011).[10] The diagnostic enabled the Unit's researchers to assess the likely frequency of sting jets in past storms using re-analysis data (Martínez-Alvarado, 2012)[11] and opened up the possibility of earlier warnings. The work was funded by a series of NERC grants.[4]

The ability to predict the sting jets is very important because of the potential loss of life and property damage that the extremely high wind speeds can cause. Understanding the mechanisms that give rise to sting jets has allowed their diagnosis from low-resolution general circulation models or statistical models, such as those in use within the insurance/reinsurance industry[2] and forecasts and warnings of such events, several days in advance, were made possible.

1. Met Office Factfile: http://www.metoffice.gov.uk/news/in-depth/1987-great-storm/fact-file
2. Risk Management Solutions (2007), The Great storm of 1987: 20-year retrospective, *RMS Special Report* www.rms.com/publications/Great_Storm_of_1987.pdf
3. K. A. Browning et al. (2001), Wind-profiler measurements in the storm of 30 October 2000. *Weather*, 56: 367–373. doi:10.1002/j.1477-8696.2001.tb06509.x
4. Work forming parts of NERC grants NER/A/S/2001/00437 (£165k), NE/E004415/1 (£249k), and NE/I005196/1 (£1.009M)
5. Royal Society Sting Jet exhibit http://royalsociety.org/summer-science/2003/european-cyclones/

3. References to the research:

Citations to each paper, as found by a WoS search (October 2013) are given in brackets for the following relevant journal papers. The three papers on which the research quality can best be judged are marked by an asterisk. The work was funded by a series of grants from NERC[4] with contributions by Met. Office staff seconded to the Unit it as part of the MetOffice@Reading group. The quality and potential applications of the research was stressed by a Royal Society Summer Science Exhibition as early as 2003.[5]

6. *K.A. Browning (2004). The sting at the end of the tail: Damaging winds associated with extratropical cyclones. *Q.J.R. Meteorol. Soc.* 130: 375–399. doi: 10.1256/qj.02.143 (29 cites)
7. *K.A. Browning, M. Field (2004) Evidence from Meteosat imagery of the interaction of sting jets with the boundary layer. *Met. Apps.* 11: 277–289, doi:10.1017/S1350482704001379 (13 cites)
8. *P.A.Clark, K.Browning and C. Wang (2005) The sting at the end of the tail: model diagnostics of fine-scale three-dimensional structure of the cloud head. *Q.J.R. Met. Soc.* 131: 2263 (17 cites)
9. O. Martínez-Alvarado, F. Weidle, and S.L. Gray (2010) Sting jets in simulations of a real cyclone by two mesoscale models. *Mon. Wea. Rev.*, 138 (11) 4054-4075. (6 cites)
10. S.L. Gray, O. Martínez-Alvarado, L.H., Baker and P.A. Clark (2011) Conditional symmetric instability in sting-jet storms. *Q.J.R. Meteorol. Soc*., 137(659), 1482-1500. (4 cites)
11. O. Martínez-Alvarado, S.L. Gray, P.A. Clark and L.H. Baker (2011) Objective detection of sting jets in low-resolution datasets. *Met. Apps*. doi:10.1002/met.297 (1 cite)

4. Details of the impact

Pathway to Impact.

The National Severe Weather Warning System (NSWWS) is a free warning service, originally established by the Met Office in response to the enquiry set up by the Secretary of State into the forecasting and impact of the 1987 Great Storm. Warnings of forecasts of severe weather enable Civil Contingencies Category 1 and 2 responders to plan and implement action needed to reduce the impact of the severe weather. Warnings are also issued to the public at large via the broadcast media, and other authorities when appropriate. The warnings also make the tasks of the emergency services easier by providing reliable updates of the current situation and prognosis. The system was radically overhauled in 2011 and the Unit's research into sting jets provided the Met Office with the means to incorporate more accurate predictions of the likely impact of a sting jet into their severe weather warnings. The ultimate beneficiaries are the inhabitants and businesses of the UK. In addition, timely warnings reduce losses and damage to infrastructure and property so local and national government and insurance companies also benefit.[12]

The Met Office was involved closely in the research and its application from the outset. The realisation that the most destructive winds are associated with a characteristic cloud formation produced an immediate benefit in terms of diagnosing current weather patterns: by 2005, the Met Office had started to use satellite images to issue warnings to locations likely to be in the path of a sting jet but with warnings only one to two hours in advance of the storm (as reported in media articles of the time[13]). Joint work by the Unit and the Met Office established what was needed to predict the occurrence and severity of sting jets further in advance. As a result, the Met Office introduced the capability of issuing warnings of sting jet via the NSWWS in April 2011.[14] The first explicit forecast taking account of a sting jet was issued for the storm of 8 December 2011, and the term 'sting jet' was used for the first time in a televised public weather forecast on 3 January 2012[14] with full explanation of the term appearing on the Met Office web site,[15] in Met Office leaflets[16] and in press reports.[17]

Impact on Met Office and European severe weather warnings

The importance of the Unit's research in issuing severe weather warnings is made clear on the Met Office website:[23] *"one feature of the 1987 storm was the presence of 'sting jets'. …. At the time of the storm, however, no-one knew they existed or how they worked. Today they are well understood and represented in forecasting models so we can warn about them in advance".* In addition, the head of Numerical Weather Prediction at the Met Office at the time has said "*The work of Browning and others at Reading was very helpful to the Met Office in making reliable forecasts and warnings of hazardous weather, in that it led to us gaining the capability to identify damaging sting jets, predicting their evolution and issuing timely warnings. The collaboration between Reading and the Met Office was very effective in bringing this about*".[24] France, Germany, Switzerland, Scandinavia and the Baltic countries have also started to issue warnings of sting jets.[25,26] Since summer 2012 work is underway in the US to similarly upgrade their capability based directly on this research.[27]

Applications in windstorms Friedhelm and Ulli

The benefits of sting jet prediction are demonstrated by warnings the Met Office issued on 8 December 2011 and 3 January 2012 for storms "Friedhelm"[18] and "Ulli"[19], respectively. In both cases, the Met Office forecast that particularly ferocious winds would affect parts of Scotland and issued the strongest possible severe weather warning on the basis that these had been identified to be sting-jet storms.[28] Agencies acted on the advice: schools were closed, police warned people not to travel unless absolutely necessary, and emergency services were put on alert. The Kingston, Erskine, Tay and Forth bridges were closed, and many bus, rail and ferry services were cancelled.[18,19,20,21] Furthermore, the Met Office forecasts of these two storms were incorporated into warnings issued by various European and Scandinavian Meteorological Institutes, and triggering the cancellation of North Sea ferry services and the closure of several bridges.

The preventative action minimised the impact of these storms, which brought gusts of wind up to 164 mph and widespread disruption including uprooted trees, damage to power lines (e.g. 150000 homes without electricity in the 8th December storm) and overturned vehicles (including a school bus that was not in use because schools had been closed because of the alert). Importantly, nobody was killed. How the outcome would have differed had the warnings not been issued cannot be known and reliable statistics, that allow comparison with events that took place without the warnings, will require analysis of many such cases. Scotland's Deputy First Minister Nicola Sturgeon said: "*The conditions are exactly as predicted when the Met Office issued its red warning*",[19] Central Scotland Police Emergency Planning reported "*spot on forecasting over the last 2 days*" and Grampian Police said: "*thanks as always for the updates, they are vitally important to us and are a great source of detail for warning and informing our communities*".[20] Angus Bruce, Bridge Manager at Amey, added: "*I would complement the Met Office for the accuracy of their information, this helps to give us confidence in the information we receive and allows us to plan things such as the re-opening of the Erskine Bridge with confidence and accuracy*".[21] That sting jet science was at the heart of these warnings and the benefits achieved using those warnings discussed in a Met Office review of the Freidhelm and Ulli events (Fox et al. (2012).[23]

It is not yet possible to quantify the benefits that arise from the improvement to warnings brought about specifically by sting jet science. However, the savings resulting from the Met Office's severe wind warnings in general give an indication of the scale of the potential savings for the most damaging (sting jet) events. The total savings were evaluated in a 2007 report by the Met Office, working with the Cabinet Office.[22] At that time, sting jet warnings were still in their infancy (specifically, satellite images were used to warn of locations likely to be in the path of a sting jet but only one to two hours in advance); nevertheless, severe wind warnings were estimated to save 23 lives and £34m per annum in the UK construction industry, £41m efficiency savings in the emergency services and £95.5 million saved in the UK through improved aircraft routing and a further £3.6 million reduction in flight delays. The prediction of sting jets is also finding applications in severe weather warning around Europe and in France, Germany, Switzerland, Scandinavia and the Baltic countries in particular.

The Unit's research led to the understanding that sting jets are a feature of many, but not all, rapidly developing storms. It has been estimated that if the Great Storm of 1987 had recurred in 2007, it would have caused between £4 billion and £7 billion in insured loss Europe-wide,[2] over 70% of this generated in the UK. Discussions have been held between the Unit and a number of insurance, re-insurance and CAT (Catastrophe) modelling companies (Willis-Re, RMS, AIR-Worldwide and Axa) to appraise them of the need to include the impact of sting jets in their statistical cyclone databases. Most insurers rely on "vender" models from sub-contractors but for reasons of commercial confidence, they do not know if these incorporate sting jets (and associated losses) or not. By making them aware of the science and its implications, the Unit has already had an influence on both the insurers and the CAT modellers demonstrated, for example, by KT partnerships funded by Axa.[29]

Background Information

12. e.g., P. Heneka, B. Ruck (2008) A damage model for the assessment of storm damage to buildings, Engineering Structures, 30, (12) 3603-3609
13. The Telegraph 13/1/2005. 'Sting Jet' blamed for Winds. http://www.telegraph.co.uk/education/3349225/Sting-jet-blamed-for-winds.html
14. T. Hewson (2012) Forecasting Extreme Weather, Presentation at "Understanding the Weather of 2011" Royal Met Soc Meeting, Birmingham, 4 Feb 2012. Available from the Unit or from http://www.rmets.org/sites/default/files/pdf/presentation/20120204-hewson.pdf
15. Met Office website (posted Oct. 2012): The 1987 Great Storm - What is a Sting Jet? http://www.metoffice.gov.uk/news/in-depth/1987-great-storm/sting-jet
16. Met Office (2012): "The sting jet: Forecasting the damaging winds in European Cyclones" http://www.metoffice.gov.uk/media/pdf/2/p/Sting_Jet_Flyer.PDF
17. Guardian 16/10/2012 http://www.guardian.co.uk/uk/2012/oct/16/sting-jets-hurricane-michael-fish
18. Willis Re Analytics, Event Response, December 9th 2011 Windstorm Friedhelm http://bit.ly/1glurKP A collection of media reports: http://en.wikipedia.org/wiki/Cyclone_Friedhelm
19. A collection of media reports is available at http://en.wikipedia.org/wiki/Cyclone_Ulli
20. D.Cotgrove (2012) Risky business of weather forecasting, The Barometer, issue 20, Met Office, http://www.metoffice.gov.uk/media/pdf/k/0/Barometer_Issue_20.pdf
21. Met. Office Website (2012) Atlantic storm case study - December 2011. http://bit.ly/1alxVVg
22. "The Public Weather Service's contribution to the UK economy", Met Office, 2007, produced PA Consulting Group. http://www.metoffice.gov.uk/media/pdf/h/o/PWSCG_benefits_report.pdf

5. Sources to corroborate the impact

23. Met Office website (posted Oct 2012) "The great storm – 25 years on" http://www.metoffice.gov.uk/news/releases/archive/2012/great-storm
24. Testimonial letter from the then head of Numerical Weather Prediction (now renamed Weather Science) at the Met Office. Available upon request.
25. e.g., S. Haanpää et al. (2007) Impacts of winter storm Gudrun of 7-9th January 2005 & measures taken in Baltic Sea Region, ASTRA report. http://www.astra-project.org/06_winterstorm_study.html (search for "sting jet")
26. e.g., ESTOFEX storm warning (search on "sting jet"): http://bit.ly/1dFTxjW
27. NASA DEVELOP Project Summary http://www.ces.slu.edu/Projects/DEVELOP/2012_Develop.php (search for "sting jet")
28. A. Fox, et al (2012) Lessons learnt at the Met Office from the Great Storm of 1987-a comparison with recent strong wind events, *Weather*, 67 (10) 268-273, doi: 10.1002/wea.1981 Paper written by 3 Met Office staff on improvements gained from sting jet science.
29. Axa research fund's Book of Knowledge: Environmental Risks (Nov. 2012) http://bit.ly/1dFTPap (see p 35 for sting jets)