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Storm naming and forecast communication: A case study of Storm Doris

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Abstract

On February 23, 2017, a significant low-pressure system named Storm Doris crossed the Republic of Ireland and the UK causing widespread disruption. As an early example of a storm named through the Met Office and Met Eireann “Name Our Storms” project, this provided an excellent opportunity to study how information about extreme weather in the UK spread through the media. In traditional media, the forecast of Storm Doris was widely reported upon on February 21–22. On the February 23, newspaper coverage of the event rapidly switched to reporting the impact of the storm. Around three times the number of words and twice the number of articles were published on the impacts of Storm Doris in comparison with its forecast. Storm Doris rapidly became a broader cultural topic with an imprint on political news because of two by-elections that occurred by coincidence on February 23. In the social media, the rapid growth in the number of tweets about Storm Doris closely mirrored the growth of newspaper articles about the impacts of the storm. The network structure of the tweets associated with Storm Doris revealed the importance of both the Met Office official Twitter account and newspaper and rail company accounts in disseminating information about the storm. Storm names, in addition to their benefit for forecast communication, also provide researchers with a useful and easily collected target to study the development and evolution of public understanding of extreme weather events.

KEY WORDS

communicating science, education, forecasting, severe weather, transport, warnings

1 | INTRODUCTION

Increasingly, communication of meteorological hazards has become both more sophisticated and more targeted as the range and diversity of communication channels has increased. Key to this change is a model of communication and decision-making that increasingly recognizes the role that the interaction of human social dynamics with forecast

information plays in driving the understanding of forecasts and forecast uncertainty (Morss *et al.*, 2017). Weather warnings that quantify both impacts and the likelihood of those impacts occurring (Neal *et al.*, 2014) are an increasingly prominent part of the forecast communication process, partly because they enable clarity of communication across the multiple different formats in which forecasts are delivered and consumed (Abraham *et al.*, 2015). Ultimately, it might

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be possible to use ensemble forecasts to tailor a decision to an individual end-user risk appetite (Economou *et al.*, 2016).

In the meantime, as both forecasting and communication techniques develop, ways in which messages about impactful weather events can be amplified and simplified are an important communication tool. A recent development in this direction in the UK and the Republic of Ireland is the “Name Our Storms” project (Met Office, 2018a). Beginning in September 2015 as a pilot project (Met Office, 2015a), the Met Office and Met Eireann have run a programme to provide official names to storms that are deemed to have a “substantial” impact on the UK or the Republic of Ireland. Storms are named when they have a potential for warnings in the top two categories (Amber and Red for the Met Office, Orange and Red for Met Eireann) over a sufficiently large spatial and temporal scale. The decision to assign a name to a storm focuses on wind impacts, but also covers rain and snow impacts. A successful part of the Name Our Storms project was the engagement of the public in providing suggested names through social media (Met Office, 2015b).

According to Smith (1990), storm naming can be first attributed to Clement Wragge, the Queensland government meteorologist between 1887 and 1907. As described by Landsea and Dorst (2018), this idea inspired first a work of fiction by George R. Stewart and was then adopted by US Air Force and Navy meteorologists during the Second World War for the internal communication and identification of tropical cyclones in the Pacific. Eventually, the practice of naming tropical storms with first exclusively female names and finally alternate male and female names by the US National Hurricane Center and Australian Bureau of Meteorology was adopted in the early 1950s. Currently, lists of names for all tropical cyclone regions are maintained by the WMO (2018).

In the extra-tropics, there is a similarly long history of naming both low- and high-pressure systems. Since 1954, low- and high-pressure systems over Europe have been named by the Free University of Berlin (2018). To avoid any confusion related to different naming schemes and conventions in different European countries and areas, a working group of European meteorological services has been set up to discuss how to develop a Europe-wide scheme (Cusack *et al.*, 2017). In North America, both the US National Weather Service and the Meteorological Service of Canada do not use storm names for winter storms, but one of the largest private sector providers does operate a similar naming system (Weather Channel, 2017).

Despite the wide adoption of storm naming, there is relatively little research that examines its impact on forecast communication. Recent empirical research by Rainear *et al.* (2017) suggests that perception of storm severity is not

changed for fictional cases with and without storm names, arguing that the impact of storm naming on forecast communication is minimal. However, little work studies the flow of information associated with a storm name in a real-world context before the analysis of Morss *et al.* (2017). They show clearly how hazard and risk perception can evolve during the course of a storm from forecast to impact. They also highlight how named storms can rapidly enter the public discourse and become the source of multifaceted discussion which centres not just on the forecast or impact of a particular event.

In other fields and as a subfield in itself, the study of information spread through social networks such as Twitter has grown rapidly in recent years (e.g. Romero *et al.*, 2011; Lazer and Radford, 2017). Several studies have used Twitter to analyse discussion and public response to extreme weather events such as Hurricane Sandy (Spence *et al.*, 2015) or tornado outbreaks (Middleton *et al.*, 2014).

The Met Office and Met Eireann Name Our Storms initiative provides an opportunity to study if and how these ideas apply in the context of mid-latitude storms crossing the UK and the Republic of Ireland. The present study describes and contrasts the spread of forecast information about Storm Doris through traditional media (newspapers) and social media (Twitter data). By studying the spread of information for a single case study, interesting aspects about this information transition are identified that can and should be studied for a wider class of storm events to understand fully the utility of storm naming.

2 | DATA AND METHODS

The focus of this study is on the transmission of information about Storm Doris through different media in the UK. Since it is impractical to analyse every media channel, the focus is on two types of media that exemplify the kinds of information transmission and discussion described by Morss *et al.* (2017).

2.1 | Newspaper articles

As an exemplar of traditional media, articles from national and local, daily and weekly newspapers are analysed. A similar analysis to determine changes in discussions of resilience and preparedness was conducted for other periods of extreme weather (e.g. Torres and Alsharif 2016). Full-text newspaper articles were obtained from LexisNexis, based on a keyword search for “Storm Doris”. All articles available from LexisNexis with the “Storm Doris” keyword during the period February 1–April 1 2017 were considered. Before analysis, duplicate or near-duplicate articles were removed (where the headline and majority of the text was duplicated).

Archived articles that consisted solely of correspondence with readers were also removed.

Following pre-filtering, the topics of national newspaper articles were modelled using the Latent Dirichlet Allocation (LDA) available from the gensim python package (Rehurek, 2018). The LDA is a probabilistic modelling technique frequently used to find the main topics in a collection of texts, where each item of a collection is modelled as a finite mixture over a set of topics, and each topic is modelled as an infinite mixture over a set of topic probabilities. After specifying several topics, the LDA is implemented using an online variational Bayes algorithm (Hoffman *et al.*, 2010). The resulting model represents each topic by a series of keywords along with a probability that an article would generate each word.

Standard pre-processing was applied before analysis, articles were converted to a “bag-of-words” representation and common stop words from the NLTK English corpus, along with “Storm” and “Doris”, were removed. The LDA with different numbers of topics from two to 12 was performed and coherence measured using the “*c_v*” metric (Röder *et al.*, 2015). For this particular collection of articles, the model had highest coherence when the number of topics was six, and so this model was used for article assignment. A one-word designation for each topic was assigned by examining its associated keywords (Table 2). Articles were then assigned to each of the six topics based on maximum probability, providing this probability > 0.5 .

2.2 | Twitter data

Twitter data were sourced *via* Brandwatch (2018) and collected by the Met Office based on a complex keyword query. A collection of tweets was limited to the UK based on geolocation or attributions from each account. The query filters tweets with keywords related to impacts (e.g. cancelled) occurring with keywords related to weather hazards (e.g. wind) in the UK. The query filters out tweets with weather-related words or phrases not usually found to be related to the impact of the weather (e.g. block of ice; winds me up; Rainford). In total a sample of 29,019 tweets was analysed collected over the period February 1–March 9, 2017. This was chosen since it encompasses the period over which forecasts and impacts of Storm Doris were most widely discussed and includes a discussion of Met Office warnings for an unnamed storm discussed later as a false named storm event. Often used to evaluate communication strategy on Twitter, sentiment analysis seeks to determine the overall emotional reaction of the user. For each tweet, a sentiment score (how positive or negative each tweet was) was calculated. An open-source program, Sentistrength (Thelwall *et al.*, 2012), was used to assign both a positive

(from 1 to 5) and a negative (from -1 to -5) score to all tweets. For short text, such as tweets, Sentistrength has been shown to perform with human-level accuracy (Thelwall *et al.*, 2012).

2.2.1 | Network analysis

To understand more about how information related to Storm Doris diffuses across Twitter, social network analysis was used (Wasserman and Faust, 1994). A social network is made of individuals who are connected by edges. From the collected tweets, successive social networks, corresponding to information passing on Twitter, were created, one for each week. Each network (a directed multigraph) contained a set of vertices (Twitter IDs) and directed edges between them created using a simple rule: for each mention of B by A in a tweet in that week, a directed edge from A to B was created, therefore allowing for multiple edges between two individuals. One tweet could be used to create several edges if it contained several mentions. If it did not contain any mentions, a tweet was ignored.

Analysis of the mentions networks was conducted at two levels:

- individual or node level, where each nodes’ “importance” is examined; and
- meso- or group level, where connected “communities” are examined.

At an individual level, centrality measures the relative importance of an individual (a node) and determines its involvement in a network. Four different centrality rankings were calculated:

- in-degree;
- out-degree;
- betweenness; and
- PageRank centrality.

The in-degree of v simply counts how many other users have mentioned a user v in that week, while the out-degree counts how many other users were mentioned by a user v that week.

The betweenness centrality measure aims to identify vertices that are often in between other vertices when a dynamic process (e.g. information diffusion) is happening on a network. For example, the vertices that connect two or more different communities in the network might be seen as central for information exchange, because without them information cannot propagate to other parts of the network. For a user v , betweenness score (Newman, 2010) is a fraction of all directed shortest paths (with the smallest length – the

number of nodes) between any other two nodes that passes through v . Another commonly used centrality measure is page rank (Page *et al.*, 1999), “one of the main ingredients of the search engine Google” (Brandes and Erlebach, 2005, p. 53). The main idea of this centrality measure is that the centrality of a node depends not only on the number but also on the centrality of nodes connected to it, forming a feedback on the network.

The connectivity is measured at group level. A network is connected if each node is connected to every other node through a path. A disconnected network will contain two or more connected components: maximally connected subnetworks. A directed network is “strongly connected” if there is a directed path from each node to every other node, and “weakly connected” if its underlying undirected network is connected. As all the networks were disconnected, the number of weakly connected components, denoted as `conn_comp` and the order (the number of nodes) of the largest weakly connected component (denoted `LCC`) were calculated.

2.3 | UK traffic data

To examine the impact of weather warnings on population behaviour, the 15 min flow of traffic on motorway routes in the centre of England during February was obtained from the Department for Transport WebTRIS system (Highways England, 2018). All sections of motorway routes between 52.5° and 53.5° N and west of 2° W were considered because this approximately corresponds to the region over which amber warnings for high winds were issued on February 23, 2017. Traffic flow on February 1–3, 6–10, 16, 17, 20, 21, 27 and 28 was averaged to provide a weekday baseline estimate. Sections of motorway with missing data for either February 23 or the baseline period were omitted. Comparison was also made with a similar, unnamed, storm that crossed the UK on February 12, 2014, and had both amber and red warnings for wind over a similar footprint. Baseline traffic flow for this storm was estimated for February 3–7, 17–21, 24–28, 2014.

2.4 | Weather data

To illustrate the passage of Storm Doris across the UK, data from the Met Office MIDAS weather station archive (Centre for Environmental Data Analysis, 2012) were used. The calibration of each instrument was assumed to be correct and so no further processing of the data to remove bias was used.

3 | STORM DORIS: METEOROLOGICAL BACKGROUND

Storm Doris was the fourth of five named winter storms during the 2016–2017 winter season and had the largest impact on the UK and the Republic of Ireland. On Monday, February 20, 2017, forecasts identified a developing area of low pressure expected to cause widespread wind gusts of 50–60 mph over the UK and the Republic of Ireland, and the Met Office issued a yellow wind warning for February 23. Subsequent forecast analysis of the same area of low pressure identified the potential for a short-lived core of very strong wind gusts of 70–80 mph. Since the strong wind gusts had the potential to damage structures, cause power supply interruptions and widespread travel disruption, an amber wind warning was issued on Tuesday, February 21 over a sufficiently large area for the storm to be named “Storm Doris” (Figure 1).

Overnight during the early hours of Thursday, February 23, the storm underwent rapid cyclogenesis, reaching a central low pressure of 974 hPa as it passed over the Irish Sea.

Thursday 23 February

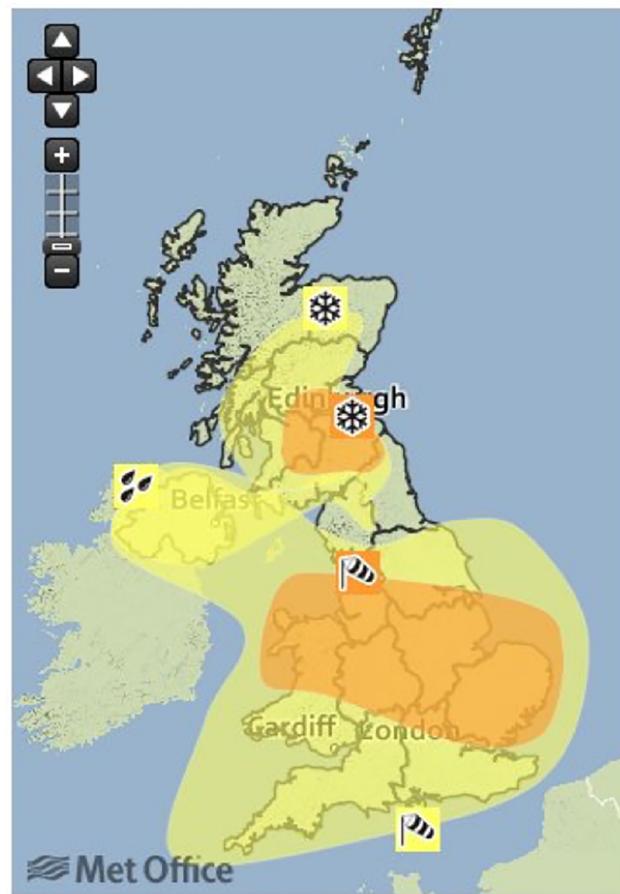


FIGURE 1 National Severe Weather Warning Service weather warnings valid for Strom Doris on February 23, 2017, issued on February 21

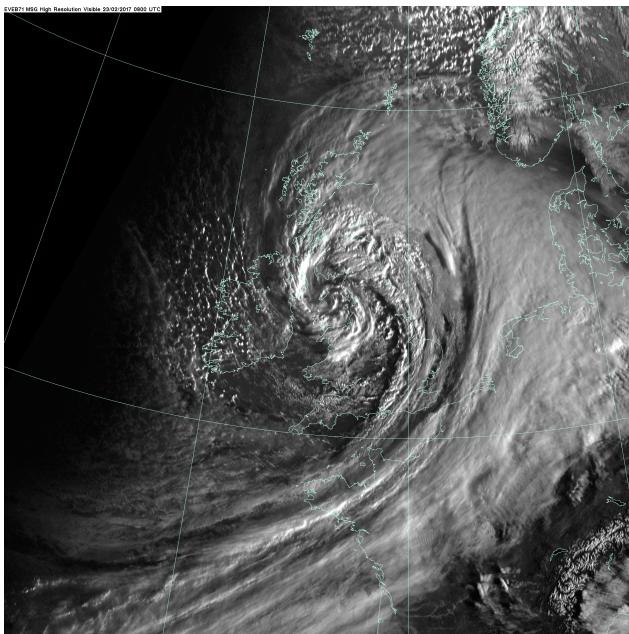


FIGURE 2 Satellite image of Storm Doris on February 23, 2017, 0800 UTC. The image is from the high-resolution visible channel on Meteosat Second Generation (MSG); the horizontal resolution is approximately 3 km over the UK

A visible satellite image showing Storm Doris as it crossed the Irish Sea is shown in Figure 2. The progression of Storm Doris across the UK and the Republic of Ireland can be seen in hourly observations of mean sea-level pressure and maximum hourly wind gusts during February 23 (Figure 3). The centre of Doris arrived on the western Irish coastline at around 2 a.m. with accompanying strong winds (gusts in excess of 30 m/s, or 67 mph). A number of locations over the UK experienced maximum wind gusts in excess of 80 mph, with a maximum wind gust of 94 mph observed at Capel Curig, North Wales (Met Office, 2018b).

By the morning rush hour, the centre of Storm Doris had arrived in Wales and moved across the UK by midday. The strongest wind gusts were on the southern and western flanks of the system, resulting in significant wind gusts across the UK throughout the day. Wind gusts > 25 m/s (56 mph) were experienced during the evening rush hour across Central England.

The peak wind impacts of Storm Doris were located throughout North Wales and Central England (Figure 4). Peak wind gusts for a large region east of Birmingham occurred in the early and mid-afternoon (2 p.m. onwards). The strongest wind gusts occurred along a swathe joining Anglesey and The Wash, but there were significant wind gusts across most of England, Wales and Ireland. Wind gust speeds were weaker in Scotland, but snowfall closed the M80 during morning rush hour. As an example of the snow

impacts, 6 cm of lying snow was recorded in Mugdock Park, near Glasgow.

Estimates of insurance losses associated with Storm Doris closely match the region of elevated wind gusts (PERILS, 2018), with significant losses throughout the densely populated regions of North West England and the West Midlands. PERILS also produced a final estimate of losses associated with the storm of €249 million across Europe, the majority of which occurred in the UK. For comparison, wind storm damage following Storm Desmond and Storm Eva and Frank during December 2015 and January 2016 were associated with estimated damages $< \text{€}200$ million in total. In contrast, flooding associated with these storms had a very large economic impact (£604 million for Desmond and £504 million for Eva-Frank).

4 | STORM DORIS IN TRADITIONAL MEDIA

Before developing an understanding of the information flow associated with Storm Doris in social media, the spread of information about Storm Doris through the print and online editions of newspapers is first examined. While it is extremely likely that most people were informed about Storm Doris through a variety of media sources, examining print and online newspaper data provides a consistent, searchable database to explore the evolution of the discussion of Doris. As a useful comparator, Table 1 provides an estimate of media reach for various relevant channels around the time of Storm Doris. National newspapers in the UK have a broad reach through both their print and online editions.

To understand how Storm Doris was discussed in national newspapers, articles are first separated into six broad topics through LDA, as described in the methodology section. Of the six topic groups, five were relevant to the discussion of the storm. Keywords associated with these topics are shown in Table 2. The first group of articles focused on the discussion of forecasts of the storm. The second group (three topics in the LDA) focused on the discussion of the impacts of the storm across the UK. Although there is strong overlap between these topics, they can be broadly divided into articles that discussed the impact on the transport system, articles that discussed the impacts on the population (including the three fatalities associated with the storm) and articles that focused on the longer term impacts and insurance costs. Finally, Storm Doris crossed the UK on the same day that two politically important parliamentary by-elections occurred in Copeland and Stoke-on-Trent Central. A large number of articles in national newspapers discussed the by-elections in the context of Storm Doris and its impact on voter turnout. The remaining articles do not focus on Storm

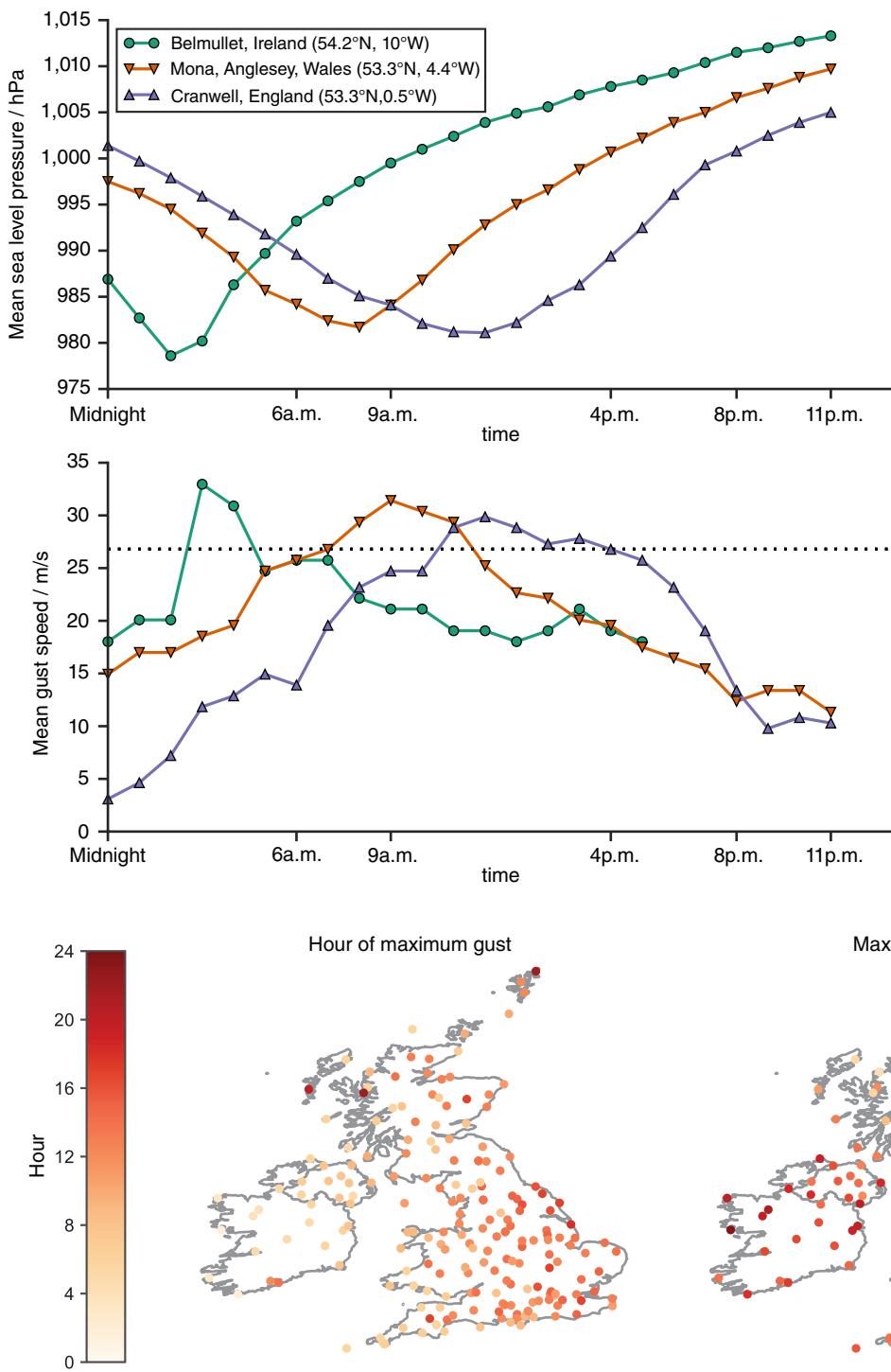


FIGURE 4 Time and magnitude of maximum hourly wind gusts during February 23 for all synoptic stations in the UK and Ireland with hourly wind records

Doris but have a minor or passing reference in the context of describing current events (e.g. headline: “What a turn on TV blackout derby a big miss: Celtic boss Rodgers hails capital clash but feels for armchair fans”, *Daily Record*, February 24: “Rodgers said: We looked at it over the course of the week. Storm Doris was on its way, so the present work was built around the early part of the week. Thursday was going

to be a down day anyway with the players inside doing some lower intensity stuff like head tennis and a bit of fun.”)

Figure 5 shows the number of words and articles published about Storm Doris, divided into the four category groups mentioned above. Figure 5d shows the interest in Storm Doris during February and March. Although most publishing volume is associated with the forecast and

TABLE 1 Estimated daily reach of various media channels to UK news consumers at the time of Storm Doris

Channel	Estimated daily reach (approx.)	Source
BBC Six O'Clock News	5.25 m	http://www.barb.co.uk/viewing-data/weekly-top-30/
BBC Ten O'Clock News	4.5 m	
ITV News (18:30)	3 m	
BBC News Channel	2.9 m	http://www.barb.co.uk/viewing-data/weekly-viewing-summary/
Sky News	1.9 m	
BBC website	1.2 m	http://www.pressgazette.co.uk/the-sun-overtakes-mirror-to-become-number-two-uk-national-newspaper-website-comscore-data/
Met Office website	1.1 m	Page Impressions (not unique users) https://www.metoffice.gov.uk/about-us/who/how/reach
Met Office apps (total)	1 m	
UK National print	14.4 m	http://www.pressgazette.co.uk/metro-circulation-overtakes-daily-mail-and-is-within-30000-of-the-sun-on-weekdays/
UK National online	48.2 m	http://www.pressgazette.co.uk/online-abcs-free-sun-more-than-doubles-website-traffic-as-partial-paywall-sees-telegraph-fall/
BBC radio (all)	34.1 m	http://www.rajar.co.uk/listening/quarterly_listening.php
Commercial radio (all)	34.5 m	

passage of Storm Doris, it is clear that there is some long-term interest in Storm Doris that lasts into the first week of March. The peak in publishing volume around March 7 is associated with a series of press articles that discuss comments on the use of weather warnings in forecasts by former BBC weather presenter Bill Giles. This shows the limits of the LDA as a classification algorithm, since the sense of

TABLE 2 Keywords associated with five of the six topics derived from the Latent Dirichlet Allocation (LDA) of national press articles

Topic label	Keywords (in order of prominence)
Forecast	Met Office, snow, wind, warning, weather, temperature, rain, Scotland, part, country, winter, condition, area, England, Wales, day, forecaster, Thursday, week, mph
Impact	
Transport system	Flight, pier, service, passenger, airport, plane, wind, train, road, pilot, tree, today, car, mph, time, line, incident, spokesman, day, airline
Population	Road, wind, yesterday, person, London, woman, man, country, scene, flight, car, today, time, train, tree, child, death, family, snow, Scotland
Longer term impact and insurance	Time, snow, road, person, area, day, gritter, child, woman, year, hit, today, way, part, traffic, insurer, roof, house, country, cliff
By-election	Labour, party, person, seat, Corbyn, by-election, Copeland, campaign, result, vote, UKIP, Tory, voter, day, leadership, Brexit, time, Conservative

these articles is not to provide a future forecast but to comment on current practice in forecast delivery. The peak in publishing volume at the start of the period is associated with forecasts of so-called “False Doris”. These stories report weather warnings issued by the Met Office associated with a storm that was not eventually given a name. An example headline from the February 1 edition of the *Daily Mail* is: “The Wrath of Doris: 80mph Winds Set To Batter UK”. This and other stories included quotations from Met Office spokespeople that make it clear that the storm had not yet been named (e.g. “It would be the first named storm of 2017 ...”). The articles published in early February highlight the complexity of the communication for storms that may or may not be subsequently given names. “False Doris” is discussed further in the following section.

Articles published during the days before and after Storm Doris show a clear pattern of transition from a peak of articles that focus on forecasts on February 21–22 to a discussion of storm impacts on February 23–25. Interest in Storm Doris in the broader culture peaks on February 24 when discussion of the Copeland and Stoke-on-Trent by-elections is most pronounced. A further interesting point of comparison is the overall publishing volume (expressed either as the number of articles or as the number of published words) of articles with a primary focus on forecasts of Storm Doris or its impacts. The peak number of words published on Storm Doris’s impacts is more than double the peak number of words published on forecasts of Storm Doris. Similarly, there are almost twice as many articles published about Storm Doris’s impact as on the forecast of Storm Doris.

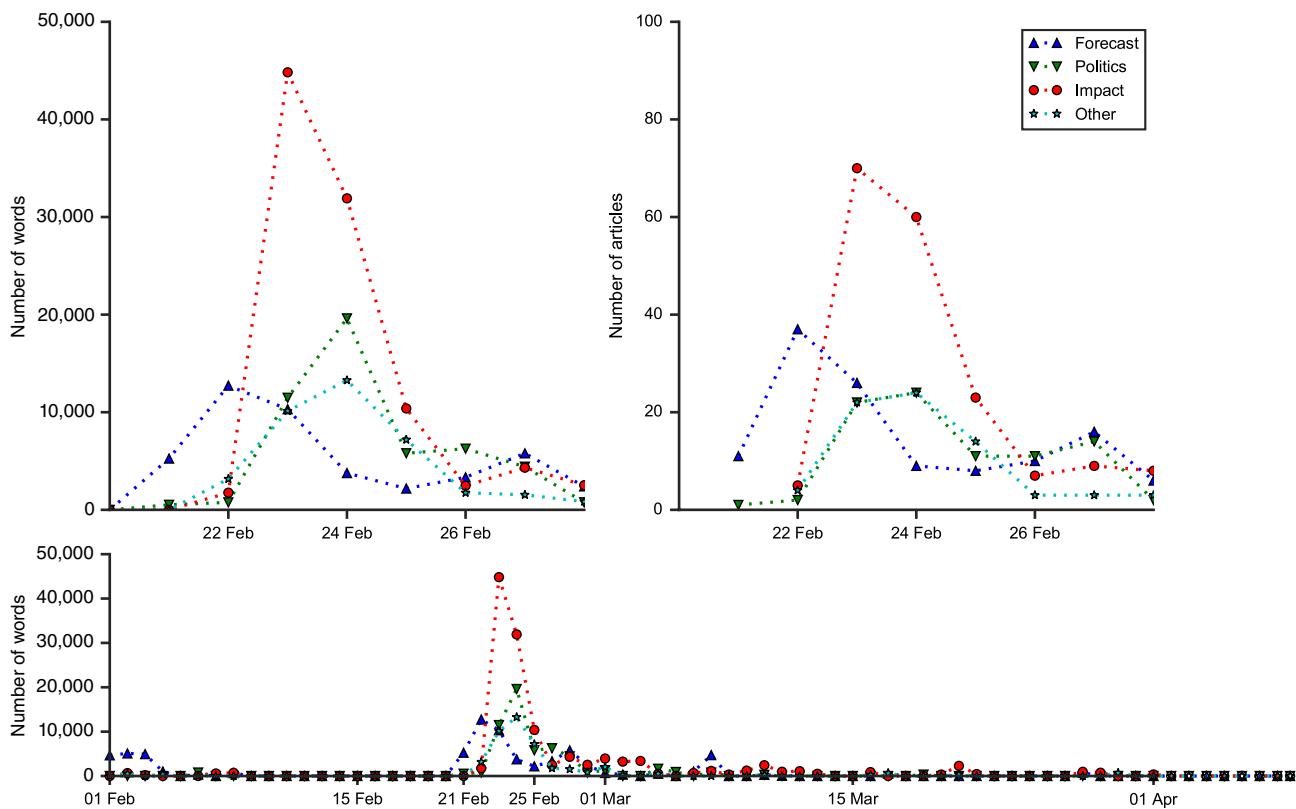


FIGURE 5 Time series of the quantity of national press coverage of Storm Doris: (a, b) number of words and number of articles published during the period February 21–28; and (c) number of words published in articles covering Storm Doris between February 1 and April 1, 2017, classified into four broad topics

Since UK daily newspapers are highly heterogeneous in outlook and readership (Boykoff, 2008), it is also useful to examine the coverage of Storm Doris as a function of the type of publication. UK national titles are classified into three different typical classes as well as by the country covered by each title as shown (Table 3). Figure 6 shows the average number of words about the forecast of Storm Doris in each of the different publication classes along with the ratio of words between forecast and impact. Tabloid and mid-market titles on average published a larger number of words about the forecast of Storm Doris. In contrast, the average ratio of words about Doris's impact to forecast is similar for all classes of publication in England. In Scotland, where Storm Doris's wind impacts were smaller, for some classes of publication relative publishing volume on the forecast is higher.

Although, as shown in Table 1, the UK media landscape has a large emphasis on national publications, regional daily and weekly newspapers can also play an important role in disseminating forecast information. Storm Doris also had a large media footprint in regional newspapers and on regional news websites. To examine this footprint, the number of regional publications that produced at least one article about Storm Doris on February 21–22 is plotted. This distribution is shown in Figure 7. Doris was featured in a range of

TABLE 3 Classification of UK newspapers

Category	Titles
English tabloids	<i>The Sun, Daily Mirror, Daily Star,</i> mirror.co.uk
English mid-market	<i>MailOnline, Daily Mail, The Express, Metro</i>
English broadsheets	<i>The Daily Telegraph, The Times, The Guardian, The Independent, i,</i> telegraph.co.uk
Scottish tabloids	<i>The Daily Record, Sunday Mail, Scottish Star,</i> dailyrecord.co.uk
Scottish mid-market	<i>Scottish Daily Mail, Scottish Express</i>
Scottish broadsheets	<i>The Scotsman</i>
Welsh	walesonline.co.uk, dailypost.co.uk

publications both with large regional circulation, such as the *Manchester Evening News*, with a daily circulation of 30,000–50,000 copies, and smaller regional titles that publish a few thousand copies. Regional news websites, such as liverpoolecho.co.uk and birminghammail.co.uk, which can have large numbers of unique users, also played a role in the communication of forecasts of Storm Doris.

FIGURE 6 (a) Average number of words *per title* for different classes of UK national publication; and (b) ratio of words *per title* for articles classified as forecast and articles classified as impact

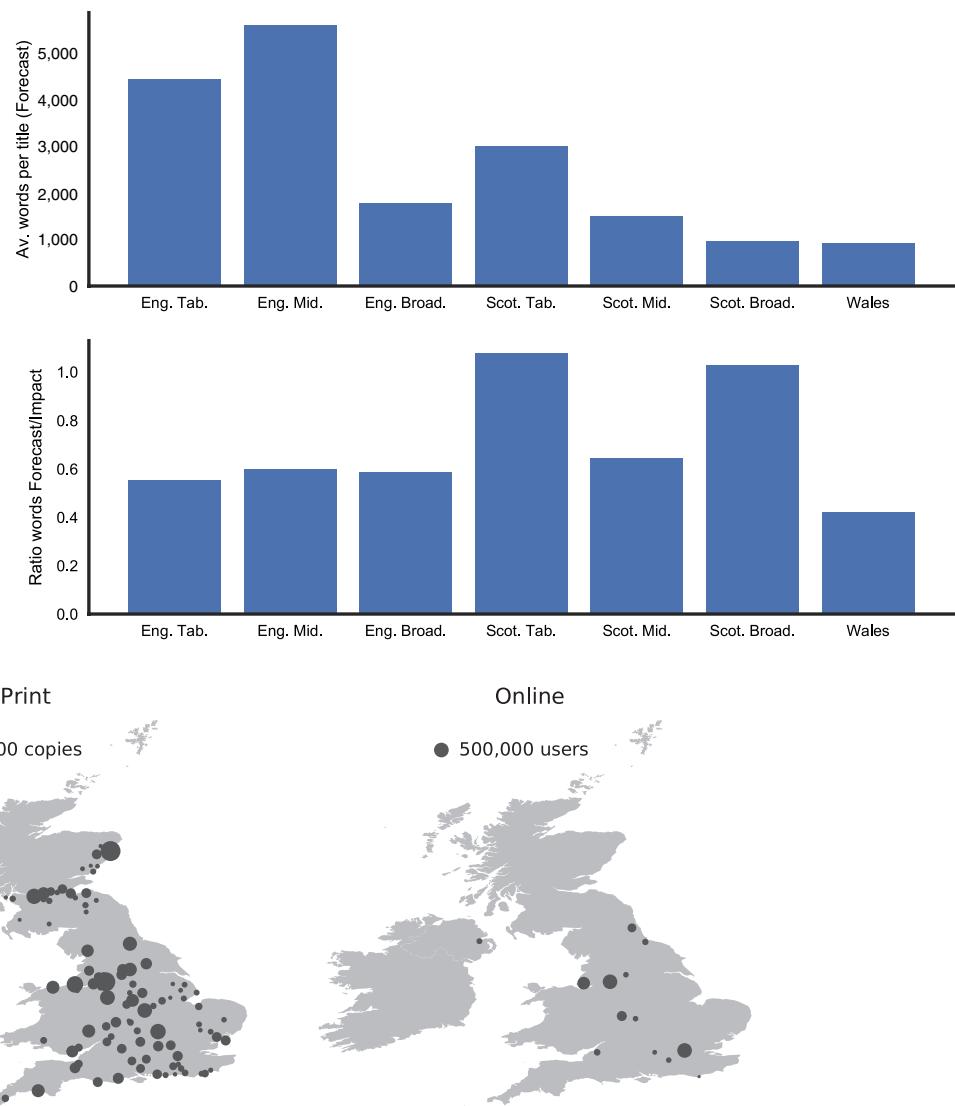


FIGURE 7 Location of regional newspapers (a) and news sites (b) that produced at least one article on Storm Doris during February 21–22, 2017. Dots are plotted at the location of the headquarters of each publication. Their size in (a) represents the circulation of each publication. Dots show the measured circulation for this period from ABC circulation data published by the *Press Gazette* (<http://www.pressgazette.co.uk/uk-regional-dailies-lose-print-sales-by-average-of-12-5-per-cent-wiganpost-and-the-national-are-biggest-fallers/>). If recent circulation data are unavailable, it is estimated based on 2010 circulation data and a 10% fall in circulation year on year during this period (in line with the national average). Dots in (b) show the average number of unique users (<http://www.pressgazette.co.uk/regional-abcs-online-london-evening-standard-overtakes-men-to-become-most-visited-regional-news-website/>)

In summary, as an indicator of the communication of Storm Doris through traditional media channels, analysis of newspaper articles shows that the following:

- The naming of Storm Doris resulted in a rapid growth in the quantity of information published about its forecast impact on February 21–22 in both the national and regional press.
- During the progress of the storm across the UK, there was a clear shift to a discussion of storm impacts. Publishing volume associated with the impacts of the storm is roughly double that associated with the forecast.

- Since Storm Doris is a useful cultural short-hand, some of the articles that mention Storm Doris are unrelated to either impacts or forecasts.

5 | STORM DORIS IN SOCIAL MEDIA

Analysis of the presence of Storm Doris in print and online media highlights how the storm's name was used to aid the dissemination of weather warnings. In contrast, analysis of social media data makes it possible to measure and

understand how the storm name and warnings about its impact are used and spread amongst the end users of weather warnings, as shown schematically in Morss *et al.* (2017, fig. 1).

Although detailed information on Twitter demographics is not routinely published, IPSOS Mori (2017) estimated that base level use in the UK is 19% of the population (or 12.5 million people). Twitter (along with other social networks) has a comparable reach with the other media discussed in Table 1. Twitter is used by 32% of 15–24 year olds, 21% of 25–34 year olds, 19% of 35–44 year olds, 14% of 45–54 year olds and 19% of those 55 years or older (IPSOS Mori, 2017). This means that although, in common with other communication methods, the reach of Twitter is limited, it is now a significant part of the communication system in the UK. Furthermore, the skewed age distribution of Twitter contrasts with the typical demographic split for

print media which is dominated by older readers (Media Briefing, 2017).

Tweet volume for both tweets that discuss extreme weather in general and for those that explicitly discuss Storm Doris show a prominent peak on February 23 (Figure 8). There are 385 tweets discussing Doris on February 22 in contrast to the more than 3,899 tweets on February 23. In contrast to the press publishing volume, there are very few tweets that discuss Storm Doris or extreme weather on February 21.

Comparison of the growth in tweet volume with the growth of published words in the forecast and impact categories shows that the tweet volume growth more closely mirrors the growth of published words in the impact category (triangles) than the forecast category (stars). The impact of naming Storm Doris on communication strategy is shown partly by the increasing ratio of tweets that mention Storm Doris and the total number of tweets that mention extreme weather

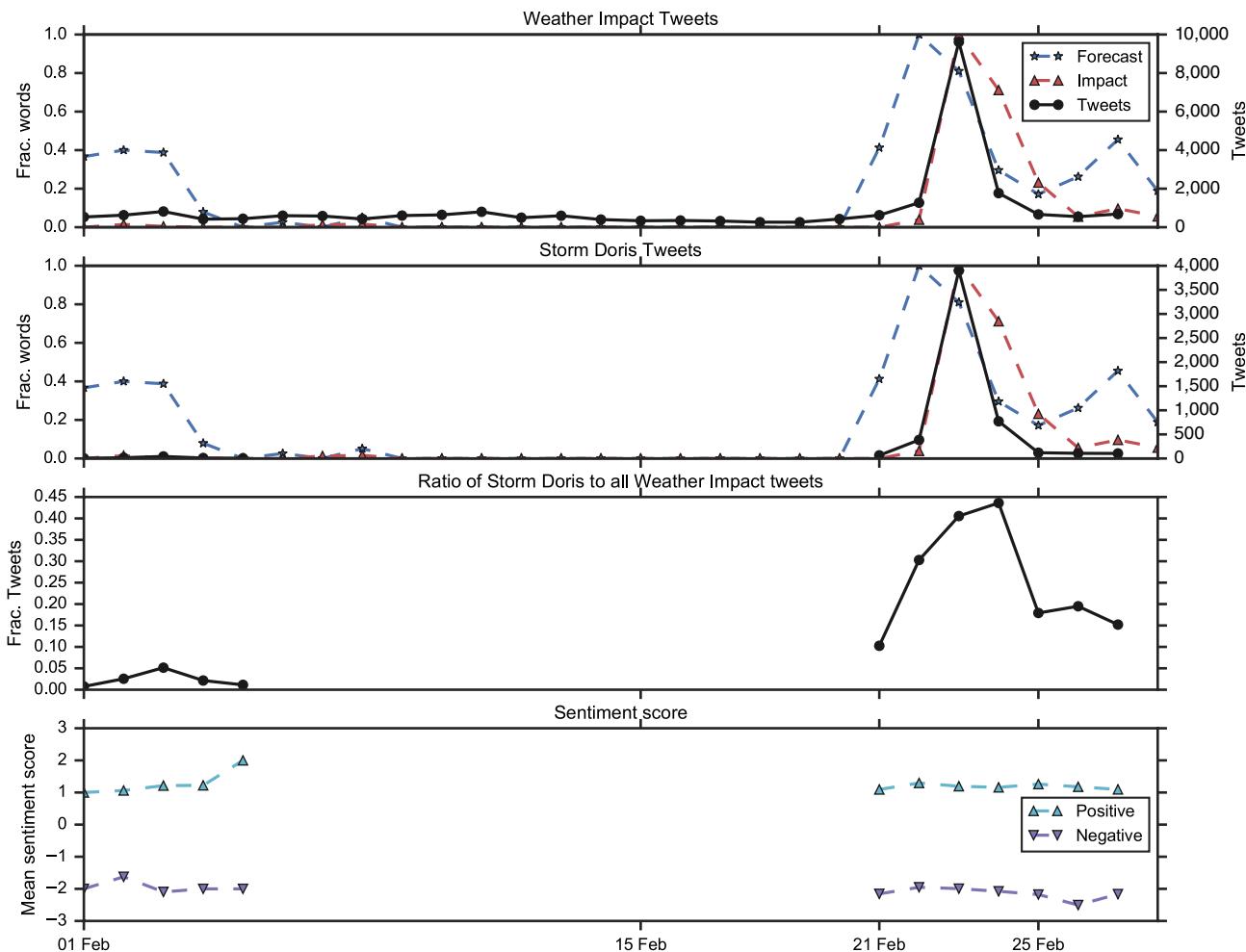


FIGURE 8 Volume and sentiment of tweets discussing Storm Doris compared with press articles: (a) number of tweets discussing weather impacts and the number of words published in the forecast and impact categories (shown previously in Figure 5). The number of words is displayed as the fraction of the maximum daily number of words published in each category. (b) The same press diagnostics and number of tweets published that explicitly mention Storm Doris. (c) The ratio of the number of tweets published that mention Storm Doris compared with the total number of tweets discussing extreme weather. (d) The mean positive and negative sentiment score for the tweets published that mention Storm Doris

TABLE 4 Network structure of tweets featuring “Doris” or “doris” during three weeks in February 2017

Week beginning	Nodes	Edges	Connected components	Largest connected component (LCC)
January 30, 2017	18	12	8	3
February 20, 2017	2,262	1,851	613	572
February 27, 2017	137	96	52	9

during the period that Storm Doris crosses the UK (Figure 8c). By February 23 and 24, more than 40% of the tweets discussing extreme weather explicitly mention Storm Doris. A small peak in tweet volume on February 3 is related to “False Doris”, as discussed in the previous section. Mean positive and negative sentiment scores for tweets related to Doris change little during February as the storm passes over the UK and its impacts become apparent (Figure 8d).

5.1 | Individual-level importance

The estimated size of the network of tweets mentioning Doris is shown in Table 4; all tweets that mentioned extreme weather and its impacts are shown in Table 5. The rapid growth of the number of users discussing extreme weather is shown by the difference in the number of nodes or users discussing extreme weather during the week beginning February 20 (6,058) compared with week beginning March 6 when weather conditions were relatively benign (838).

Around one-third of the tweets during the week beginning February 20 discuss Storm Doris explicitly.

Table 6 shows the top three Twitter accounts ranked by the measures of centrality above. The official Met Office Twitter account has a relatively high in-degree, which shows that several Twitter users are linking to forecast information when discussing Doris. However, this measure also indicates that information spreads from other important sources including in this measure a rail companies (VirginTrains), the rail network operator (nationalrailenq) and a national newspaper (MailOnline). The important role that the Met Office Twitter account plays as an information source is also highlighted by its relatively high rank in the betweenness measure. The high rank of OfficialDavid7 in the out measure is linked to a video of the crash landing of FlyBe flight BE1284 at Schipol Airport, Amsterdam, during Storm Doris recorded and tweeted by this user. The prominence of this story (which is also observed in the print media analysis) is an example of the increasingly prominent role that individual members of the public (so-called citizen journalists) play

TABLE 5 Network structure of all “impact” tweets during three weeks in February 2017

Week beginning	Nodes	Edges	Connected components	Largest connected component (LCC)
January 30, 2017	1,677	1,136	596	56
February 6, 2017	2,459	1,736	841	114
February 13, 2017	1,622	1,165	557	48
February 20, 2017	6,058	4,865	1,650	1,520
February 27, 2017	1,660	1,216	569	77
March 6, 2017	838	660	295	52

TABLE 6 Measures of network structure during the week beginning February 20, 2017

In	Out	Betweenness	Page rank
VirginTrains (0.0186)	ArrivaTW (0.0106)	VirginTrains (0.0003)	EDP24 (0.0092)
nationalrailenq (0.0133)	OfficialDavid7 (0.0093)	Virgin_TrainsEC (0.0002)	Virgin_Trains (0.0076)
MailOnline (0.0084)	EMTrains (0.0093)	metoffice (3.288e-05)	Nationalrailenq (0.0057)
metoffice (0.0084)	metoffice (0.0031)	metoffice (3.288e-05)	metoffice (0.0045)

Note: The top three Twitter accounts for each metric are shown (if the official Met Office account, @metoffice, is not included) or two Twitter accounts if @metoffice is in the top three. “In” indicates how many other users have mentioned a user v in that week. “Out” indicates how many other users had a user v mentioned that week. “Betweenness” is the fraction of all shortest paths that pass through the user. “Page rank” is a measure of the centrality of the user within the network. Many of the users listed are official accounts of commuter train providers (@VirginTrains, @nationalrailenq, @ArrivaTW, @EMTrains, @VirginTrains, @Virgin_TrainsEC), two are official newspaper accounts (@MailOnline, @EDP24), and one is an eyewitness to a significant Doris impact (a plane crash landing at Schipol airport: @OfficialDavid7).

in documenting and reporting on the impacts of extreme weather (Vultee and Vultee, 2011). Finally, the high rank of the EDP24 Twitter account (a large, regional newspaper covering East Anglia) in the PageRank diagnostics reinforces the idea that regional media organizations can be an important part of the dissemination process for extreme weather (Spialek *et al.*, 2016) and the channel complementarity theory (Dutta-Bergman, 2006) which found that those who post online are more likely to write a letter to a newspaper.

5.2 | Group-level importance

The increase in the size of the LCC, to around 25% of the whole network, during the week beginning February 20 (for both tweets that explicitly mention Storm Doris and those that discuss extreme weather; Tables 4 and 5) shows the growth in the number of Twitter users engaged in similar conversations during the week of Storm Doris. This indicates how quickly information can spread in the UK. In other weeks that percentage falls to a single digit (except for the first week for tweets mentioning false Doris, where it is around 16%), showing that conversations about extreme weather are much more fragmented. This likely reflects the more local nature of individual extreme weather events during weeks in which a dominant, national weather event such as Storm Doris is not present.

A graph of the largest weakly connected component during the week commencing February 20 is shown in Figure 9. It provides a helpful illustration for the information transmission during the week of Storm Doris. The Met Office account plays an important role connecting forecast information to other central “hubs” on the network, shown in the centre of the image and which largely include major transport infrastructure companies and some national and regional newspapers. Information then flows out from these central “hubs” to individual end users, often passing through a chain of two to four end users. As in the analysis in Section 5.1, “hubs” on the network are a mixture of transport companies, regional newspapers and individual private citizens.

6 | IMPACTS OF COMMUNICATION ON BEHAVIOUR

The previous two sections show Doris had large visibility across traditional and social media and that warnings about its impacts were widely shared and known about before the arrival of the storm on February 23 and during the time it crossed the UK. It is therefore interesting to consider if the extent to which these warnings resulted in changes to behaviour in the general public to avoid harm. While this very broad topic requires significant further analysis, some

preliminary results are included here as a motivation for further study.

The chosen measure of behaviour is the volume of traffic observed over the UK motorway network over a region ($52.5\text{--}53.5^\circ \text{N}$ and west of 2°W) consistent with the amber wind warnings issued for Doris on February 22 (Figure 1). Total traffic volume over this large region is observed at hourly intervals and compared with average traffic volume during other days in the working week during February 2017. Amber warnings ask members of the public to “think about changing your plans and taking action to protect yourself and your property”. As a comparison with an unnamed storm, results from a case with both amber and red warnings on February 12, 2014, and averaged over the same part of the motorway network are included for direct comparison.

Figure 10 compares the traffic flow in the warning area for all vehicles for Storm Doris and for the storm on February 12, 2014. It is clear that in both cases traffic flow was reduced significantly after midday for both storms and traffic volume during the evening rush hour peak was much reduced.

For Storm Doris, peak wind gusts for much of this region occurred during the mid-morning and early afternoon as Storm Doris’s southern and western flank crossed the centre of the UK. The reduction in traffic volume for Storm Doris begins to occur during and immediately after the morning rush hour, with much reduced volume by 10 a.m. In comparison, peak wind gusts for the unnamed storm occurred from early afternoon and into the evening. Traffic volume for the unnamed storm does not begin to decline until after the morning rush hour and returns to near normal volume before the evening rush hour (3 p.m.). From 5 p.m. on February 12, several sections of the M6 and M62 included in the study area were closed due to overturned vehicles, contributing to the overall reduction in traffic volume during the evening rush hour.

The comparison of these two storms is suggestive that by naming Storm Doris, the increased public awareness of the amber warnings might have resulted in earlier action to avoid harm. Further analysis would be needed to understand if and how storm naming contributed to this change in behaviour and if similar impacts are seen in other sectors.

7 | DISCUSSION AND CONCLUSIONS

In this study, a variety of different data sources were analysed in order to understand how information about a significant extreme weather event, Storm Doris, was transmitted from forecast organizations to end users. To the authors’ knowledge, this is the first study to examine the transmission of forecast information associated with a named extratropical storm in the UK.

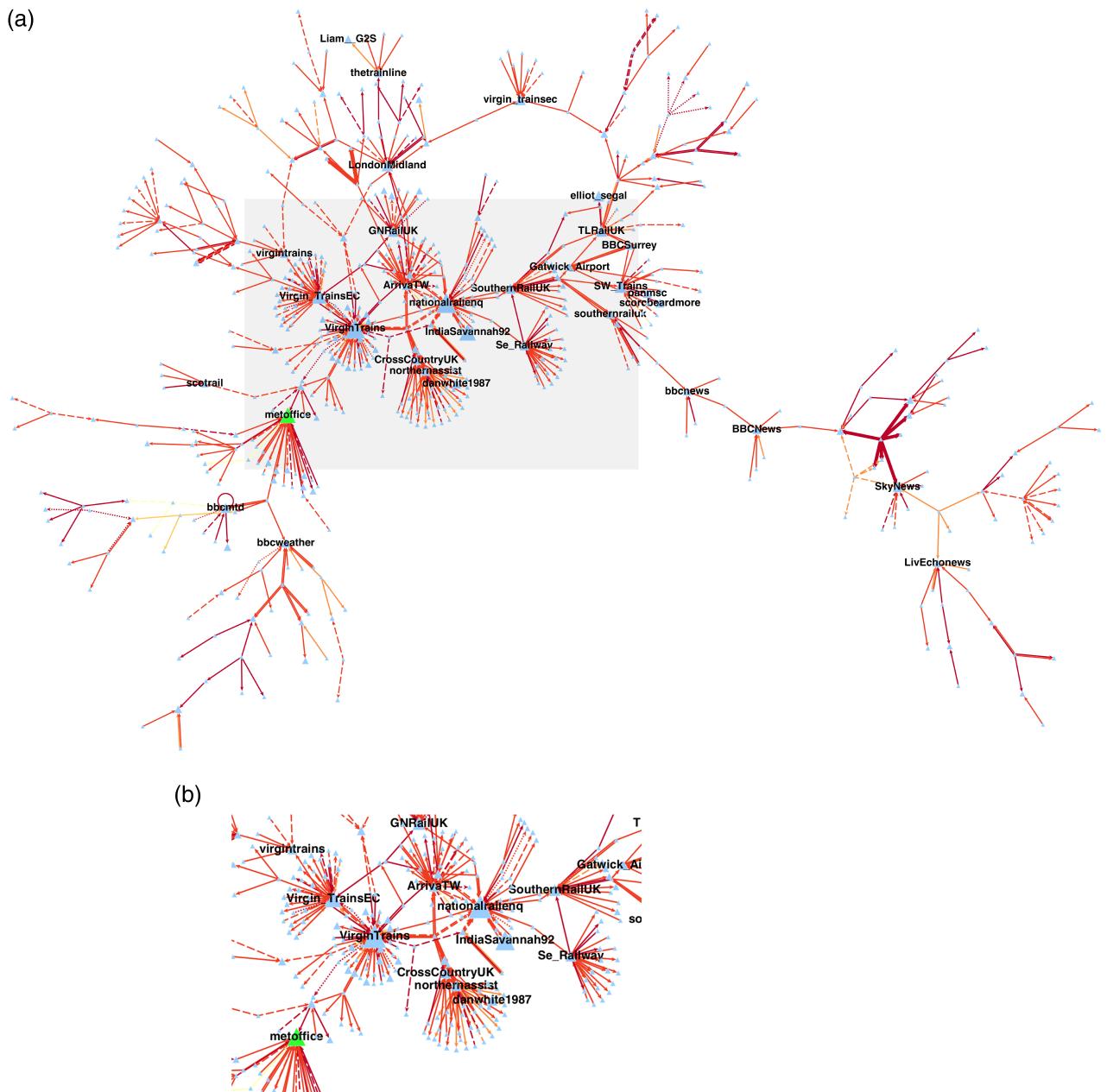


FIGURE 9 Largest weakly connected component of the mentions network during the week beginning February 20, 2017. The size of nodes is proportional to their PageRank centrality. (a) A zoom of the region focused on the Metoffice Twitter account, which is highlighted in grey and shown in (b). The size of nodes corresponds to their normalized PageRank centrality in the colour version online, the negative emotion of tweets is colour coded (-1 dark to -5 light) and the positive emotion is coded by line style (full line for $+1$, coarse-dashed for $+2$ and finely dotted for $+4$)

The analysis focused on two different sources of media data, national and regional newspaper articles and tweets, since both could be easily examined and searched to find mentions of Storm Doris. Analysis of newspaper data showed that articles that mentioned Storm Doris could be broadly divided into four categories:

- Forecasts of Storm Doris before its arrival.
- Discussion of the direct impacts of Storm Doris.

- Implications of Storm Doris for an important political event (the Copeland and Stoke-on-Trent by-elections).
- Unrelated news or gossip that incorporated Storm Doris as part of the story.

As Storm Doris passed over the UK, peaks in the number of articles and the number of words published in each category followed a predictable pattern with a shift of attention from the first to the third and fourth of these categories. The impacts of

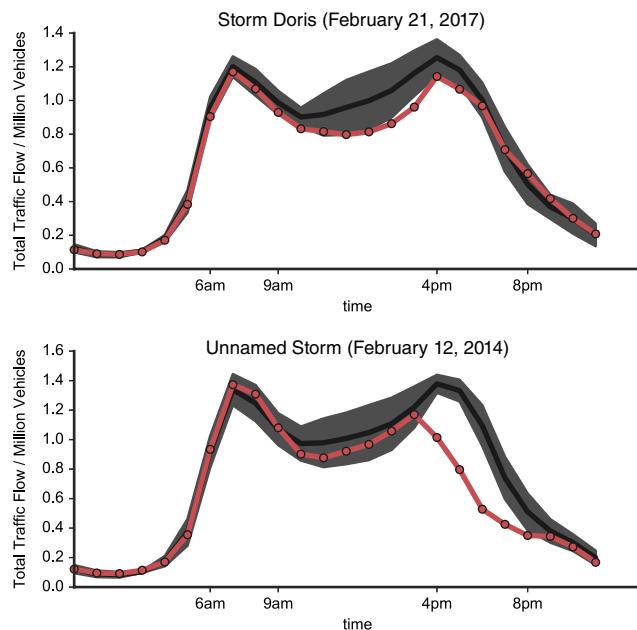


FIGURE 10 Traffic flow (millions of vehicles) for motorway sections in England between 52.5° N and 53.5° N and west of 2° W: (a) Storm Doris (February 23, 2017); and (b) an unnamed storm on February 12, 2014). The line with dot symbols shows the observed total volume for the day in which each storm crosses the UK. The line with no symbols shows the average for other weekdays in February 2014 or 2017. Grey shading shows the region ± 2 SD (standard deviations) from the average for the same days

Storm Doris were more widely reported than forecasts of the storm, but it is also the case that there was widespread reporting of the forecast of Storm Doris in both the national and regional press on February 21–22, 2017. While it is not possible to conduct a controlled experiment to measure the impacts of the storm name on forecast communication, the prominence of the storm name in articles unrelated to forecasts or impacts suggest storm naming is a very successful means of raising awareness of the storm. The small number of articles and tweets linked to “False Doris” in early February suggest that forecasters need to be cautious when discussing winter weather due to the media appetite for named storms.

Analysis of Twitter data during February 2017 shows that a significant fraction of the tweets discussing the impacts of the storm used the storm name, particularly during February 23 when Storm Doris had the largest impacts on the UK and the Republic of Ireland. Large weakly connected networks discussing the impacts of Storm Doris with and without using the storm name grew during the week in which the storm affected the UK. Analysis of these networks revealed the prominent role that network “hubs” other than official forecasts from the Met Office and peer-to-peer communication between users play in disseminating forecast impact information for extreme weather events for this event.

Both pieces of analysis suggest that the framework for understanding forecast communication proposed by Morss *et al.* (2017) is highly relevant to UK winter storms. Developing systems that can quickly determine and interrogate public sentiment about upcoming and ongoing weather events is likely to become an increasingly important part of the forecast process.

There are several limitations of the analysis presented in this study:

- The data sets used represent only a limited picture of the forecast communication problem. In particular, no analysis of either television or radio broadcasts or social networks other than Twitter is included. A broader picture of the forecast communication landscape could be developed by including a richer array of media sources.
- Similarly, it was not possible in this analysis to understand the impact of the different demographic groups who primarily consume different media types and how they might influence the communication of UK winter storms. A future longitudinal study that examines changing perception of weather amongst a controlled group of end users would be helpful in this context.
- The analysis techniques used (primarily LDA and network analysis) contain several assumptions and subjective choices of parameters that need to be made in order to make progress. Parameter choices are based on previous work (e.g. Manrique *et al.*, 2016) and the sensitivity of the results to the parameters has been explored where possible. Nonetheless, understanding the topic, sentiment and context of language is a complex and challenging problem, and further detailed analysis of the media sources available may provide additional insight.

Nonetheless, in addition to their benefit for forecast communication, storm names provide a helpful target for future analyses of the information environment for hazardous weather. Future studies may benefit from analysing a larger number of named and unnamed storms. As noted in the introduction, Storm Doris had a very large impact on the UK, and it may be the case that other, less consequential events have a different information footprint. Similarly, an interesting contrasting case in 2018 for the UK was the prominence of the name “Beast from the East” to describe the causes of a period of prolonged cold weather during late February and early March.

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