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The role of cyclone clustering during the stormy winter of 2013/2014

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Introduction

Extratropical cyclones are the primary natural hazard affecting western Europe. They are associated with strong winds and rainfall (Lamb, 1991) which can result in significant societal impacts. For example, windstorms *Anatol*, *Lothar* and *Martin* in 1999 resulted in approximately €16 billion of total insured losses (Swiss Re, 2016). Cyclones contribute to more than 70% of the precipitation that falls over northwest and central Europe in winter (Hawcroft *et al.*, 2012).

Extratropical cyclones in the North Atlantic tend to travel in a northeasterly direction, forming off the east coast of North America and dissipating over the northeastern Atlantic Ocean or Nordic Sea. Clustering of extratropical cyclones is often defined as the passage of multiple high intensity cyclones through one geographical region within a relatively short period of time (Pinto *et al.*, 2014). It has been statistically shown that extratropical cyclones cluster in the exit region of the storm track and in the vicinity of northwestern Europe (Mailier *et al.*, 2006). The physical mechanisms behind the observed clustering that affected western Europe for several high-impact months across various winter seasons was initially explored by Pinto *et al.* (2014) and expanded on by Priestley *et al.* (2017). The latter study looked at all clustered events for 36 winter seasons from 1979/1980 to 2014/2015 and found that a typical clustering event affecting the British Isles was associated with a very strong and straight jet stream in the North Atlantic, with the jet being flanked to the north and south by Rossby wave breaking (RWB; more details on RWB in Box 1).

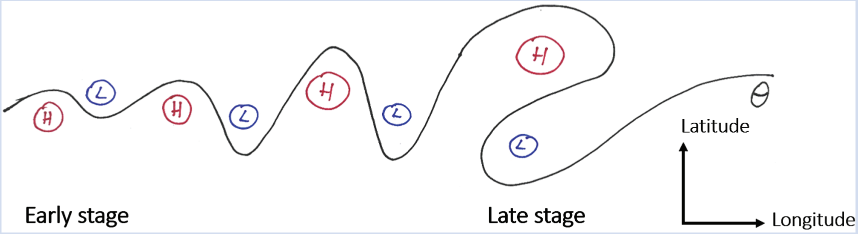
It is hypothesised that the physical mechanisms leading to clustering include steering by the large-scale flow, which orientates storms in the same direction and provides the conditions necessary for rapid intensification (Mailier *et al.*, 2006; Hanley and Caballero, 2012). An additional mechanism is secondary cyclogenesis, in which new cyclones form on the cold fronts of more mature cyclones (Parker, 1998); this allows for the occurrence of many storms in a short period of time. The combination of these mechanisms results in clustering (Pinto *et al.*, 2014), that is the large-scale flow allows for all cyclones that form in a region to follow the same direction; in addition, the occurrence of secondary cyclogenesis ensures that the time gap between the passage of these cyclones is reduced.

December, January and February of 2013/2014 (DJF1314) was one of the most extreme DJF periods in the British Isles and the stormiest in 143 years (Matthews *et al.*, 2014). The season was known for its persistent wet weather. The average precipitation accumulation across England and Wales was 456mm for the DJF1314 season according to the England–Wales precipitation (EWP) series (Alexander and Jones, 2001), which corresponds to 175% of the seasonal average and is the wettest such period since the record began in 1766 (Kendon and McCarthy, 2015). Several intense storms affected the British Isles during this period (such as *Bernd*, *Dirk*, *Erich* and *Tini*; all named winter storms herein were named by Freie Universität Berlin: *http://www.met.fu-berlin.de/adopt-a-vortex/historie/*), which brought high winds and intense rainfall to large parts of the country. The storminess persisted from early December through to late January and early–mid February (Kendon and McCarthy, 2015). This continuously unsettled and severe weather made coastal areas particularly vulnerable (Figure 1(c)), with the main rail line from Exeter to Plymouth collapsing at Dawlish (Figure 1(a)) and the flooding of the Somerset levels being a persistent feature of this season (Figure 1(b)).

Since highly clustered seasons such as DJF1314, 1990/1991 and 1999/2000 are clearly able to cause large-scale environmental and socio-economic impacts, it is important to understand the atmospheric drivers causing them. The aim of this study is to investigate a short period in the DJF1314 season to determine if one anomalously stormy period follows the dynamical framework

Box 1: Rossby wave breaking

In the upper atmosphere, high and low pressure systems propagate around the globe as waves with varying amplitudes. These waves are known as Rossby waves. When Rossby waves become unstable they can overturn and Rossby wave-breaking (RWB) occurs. When this occurs, all of the energy and momentum possessed by the wave is transferred into the upper-level jet (Barnes and Hartmann, 2012). We can identify RWB using the potential temperature (θ) field at the tropopause. When this field is sufficiently overturned, the method of Masato *et al.* (2013) can identify occurring RWB (see Scheme 1).



Scheme 1. Evolution of Rossby waves on the tropopause. RWB occurs when these waves overturn. High temperatures: H; low temperatures: L

Figure 1. Images of storm impacts from DJF1314. (a) Breached sea defences and collapsed train line at Dawlish, Devon on 6 February 2014. (Source: Network Rail.) (b) The flooded Somerset Levels on 2 February 2014. (Source: Tim Pestridge.) (c) Large waves at Porthcawl, Wales on 5 February 2014. (Source: Karl Baker.)

identified in previous clustering studies (e.g. Priestley *et al.*, 2017). The precipitation associated with these storms and how clustering acts to contribute to high values of accumulated precipitation is also investigated.

Data and methods

Cyclones are tracked and identified in the European Centre for Medium-Range Weather Forecasts Interim Re-Analysis dataset (ERA-Interim; Dee *et al.*, 2011) using an objective tracking algorithm first developed by Murray and Simmonds (1991). Full details can be found in Priestley *et al.* (2017).

The method of Pinto *et al.* (2014) and Priestley *et al.* (2017) was followed to calculate clustering. The method defines a circular area with a radius of 700km centred at 55°N, 5°W (i.e. focussed around the British Isles) and identifies cyclones when they pass through this area. A day is classed as clustered for the British Isles if four or more intense cyclones pass through the area in the surrounding 7-day period, centred on the day of interest. An intense cyclone is defined as one whose minimum pressure within the 700km radius exceeds the local 95th percentile of sea level pressure climatology; this is 984hPa at 55°N, 5°W during DJF (see Pinto *et al.* (2014) and Priestley *et al.* (2017) for more details).

ERA-Interim data are also used to determine the location of RWB in the North Atlantic. Following the method of Masato *et al.* (2013) RWB is identified as a meridional overturning in the potential temperature (θ) field on the tropopause (2 PVU surface; 1 PVU = 1×10^{-6} km^{2}kg^{-1}s^{-1}). If the normal equator–pole gradient of high θ to low θ values is not present, then RWB is identified at that latitude/longitude point (see Scheme1 in Box 1). ERA-Interim 250hPa winds are also used for the jet analysis.

The precipitation output from ERA-Interim is used to examine accumulations from individual storms. Precipitation observations are not assimilated into ERA-Interim, and so precipitation is used from the short-term forecast in the assimilation cycle (Dee *et al.*, 2011). An additional precipitation climatology is obtained from the daily and seasonal observations taken from the Hadley Centre UK regional precipitation series (HadUKP) England–Wales precipitation (EWP) dataset and sub-regions within (Alexander and Jones, 2001). The EWP data uses area averaged rain gauge data, with daily data dating back to the start of 1931.

Analysis of 2013/2014

Precipitation associated with Cyclone Tini

Figure 2 shows cyclone *Tini*[1] as it passes over the British Isles in a Meteosat SEVIRI visible satellite image on 12 February 2014 at 1200 UTC. A comma-shaped cloud pattern is identifiable from this image, and overlaid is the 1500–2100 UTC precipitation accumulation field from ERA-Interim. A broad area of >2mm accumulation encompasses most of the cloud band and the British Isles, with the exception of far northern Scotland. The 2mm contour extends beyond the northeast boundary of the cloud and into the North Sea. This mismatch between the accumulation and the cloud area is a result of the different time frames of the two fields and the precipitation being accumulated 3–9h after the image was taken. The red contour marks the area of at least 4mm precipitation accumulation, which also covers a large portion of the cloud band and most of the British Isles.

The close association of the precipitation accumulations with the cloud structure of cyclone *Tini* shown in Figure 2 demonstrates how large amounts of precipitation over a wide area are directly associated with extratropical cyclones. With the passage of many cyclones in a short period, precipitation accumulation will increase. Despite the accumulations from this 6h-period being relatively small, the accumulations could increase rapidly through two mechanisms. Firstly, if many cyclones were to pass over the British Isles in quick succession each would bring further precipitation, contributing to high accumulations; secondly, if any of these cyclones were to stall and move slowly across the British Isles, this would increase the duration for which they could precipitate over land (Hand *et al.*, 2004).

Identification and analysis of clustering and associated cyclone family

Including *Tini*, 57 storms passed through the 700km radius surrounding the British Isles in the 90-day DJF1314 period, with 37

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[1] Storm *Tini* was named *Darwin* in Ireland.

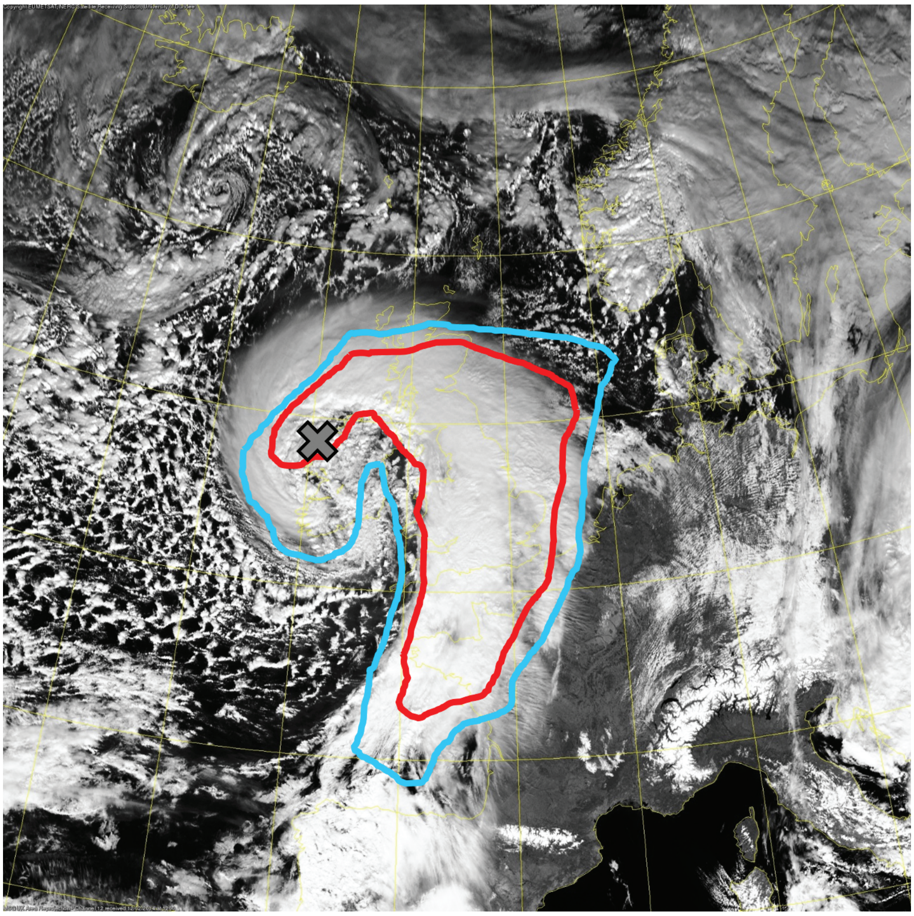

Figure 2. Meteosat SEVIRI visible satellite image of cyclone Tini at 1200 UTC on 12 February 2014, centred over the British Isles. Also shown are 2mm (blue) and 4mm (red) contours of precipitation accumulation from 1500 to 2100 UTC from ERA-Interim. The grey cross indicates the cyclone centre at 1200 UTC. (Source: NEODAAS/University of Dundee.)

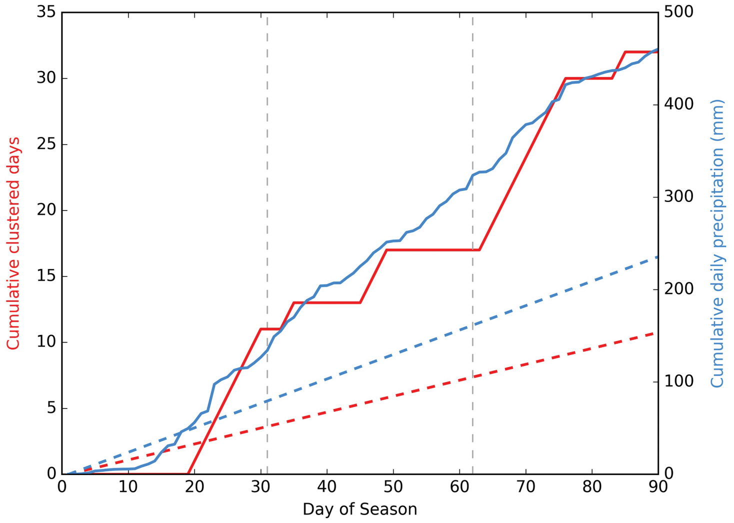

Figure 3. Cumulative clustered days during DJF1314 (red), with the climatological cumulative clustered days for DJF 1979/1980–2014/2015 being represented by the dashed red line. The cumulative daily precipitation (mm) in DJF1314 for the EWP region from HadUKP is in blue. The EWP HadUKP DJF climatology from 1766/1767 to 2015/2016 is the dashed blue line. 31 December 2013 and 31 January 2014 are indicated by the vertical dashed grey lines.

of these exceeding the local minimum sea-level pressure threshold. This corresponds approximately to one intense cyclone every 2.5 days, which is more than twice the climatological average of one intense cyclone every 5.5 days. Many of these arrived as part of a cluster, with Figure 3 showing a time series of the accumulated number of clustered days throughout DJF1314. During DJF1314 there were 32 clustered days, which is the highest of any DJF period from 1979/1980 to 2014/2015 (the next highest is DJF0607, with 30 days). There are only five DJF periods in the 1979/1980–2014/2015 period with greater than 20 clustered days.

Two periods of intense clustered activity can be identified in Figure 3 (20–30 December 2013 and 2–14 February 2014). Consequently, DJF1314 has almost three times the climatological value of 11 clustered days. Each of the two longer clustered periods in DJF1314 are equal in length to the climatological average, further highlighting just how unusual this season was. From the EWP data in Figure 3, it can be seen how the national average precipitation accumulation of 460mm, like the clustering, is considerably greater than the climatological value of 235mm. The time series of DJF1314 precipitation accumulation closely mirrors the number of clustered days (as suggested from Figure 3), demonstrating the expected link between the clustering of intense cyclones and the floods that impacted the British Isles in this season. Clustered days are associated with an average of 6.25mm of precipitation, whereas non-clustered days receive an average of 3.78mm (the variances are 30.4 and 14.6mm respectively). Using a Welch's t-test the difference in precipitation accumulation between clustered and non-clustered days is statistically significant at the 95% level in both the regional and sub-regional HadUKP datasets (not shown). The recurrent presence of high-pressure systems over Scandinavia and eastern Europe also contributed to the high precipitation accumulation: as cyclones were unable to move eastwards, they had a tendency to stall over the British Isles (see charts in Figure 4 and for the remainder of the DJF1314 season).

From the two intense periods of clustering mentioned above, we will focus on the latter occurring between 2 and 14 February 2014. This period was characterised by many intense cyclones such as *Nadja* (30 January 2014); *Okka* (2 February 2014); *Petra* (3 February 2014); *Qumaria* (4 February 2014); *Ruth* (6 February 2014); *Stephanie* (8 February 2014); *Tini* (10 February 2014); and *Ulla* (12 February 2014; the dates are the days on which the storms were named).

The selected time period and cyclones named above were specifically chosen as they form one cyclone family. A cyclone family is identified when secondary cyclogenesis occurs on the trailing cold front of a main cyclone, with the main cyclone acting as the parent cyclone to the secondary cyclone. This process may then repeat as the secondary cyclone replaces the main cyclone and then acts as the parent cyclone.

The development and propagation of these cyclones can be seen in Figure 4. Here we show 6-hourly synoptic analysis charts from the Met Office for 6–13 February 2014

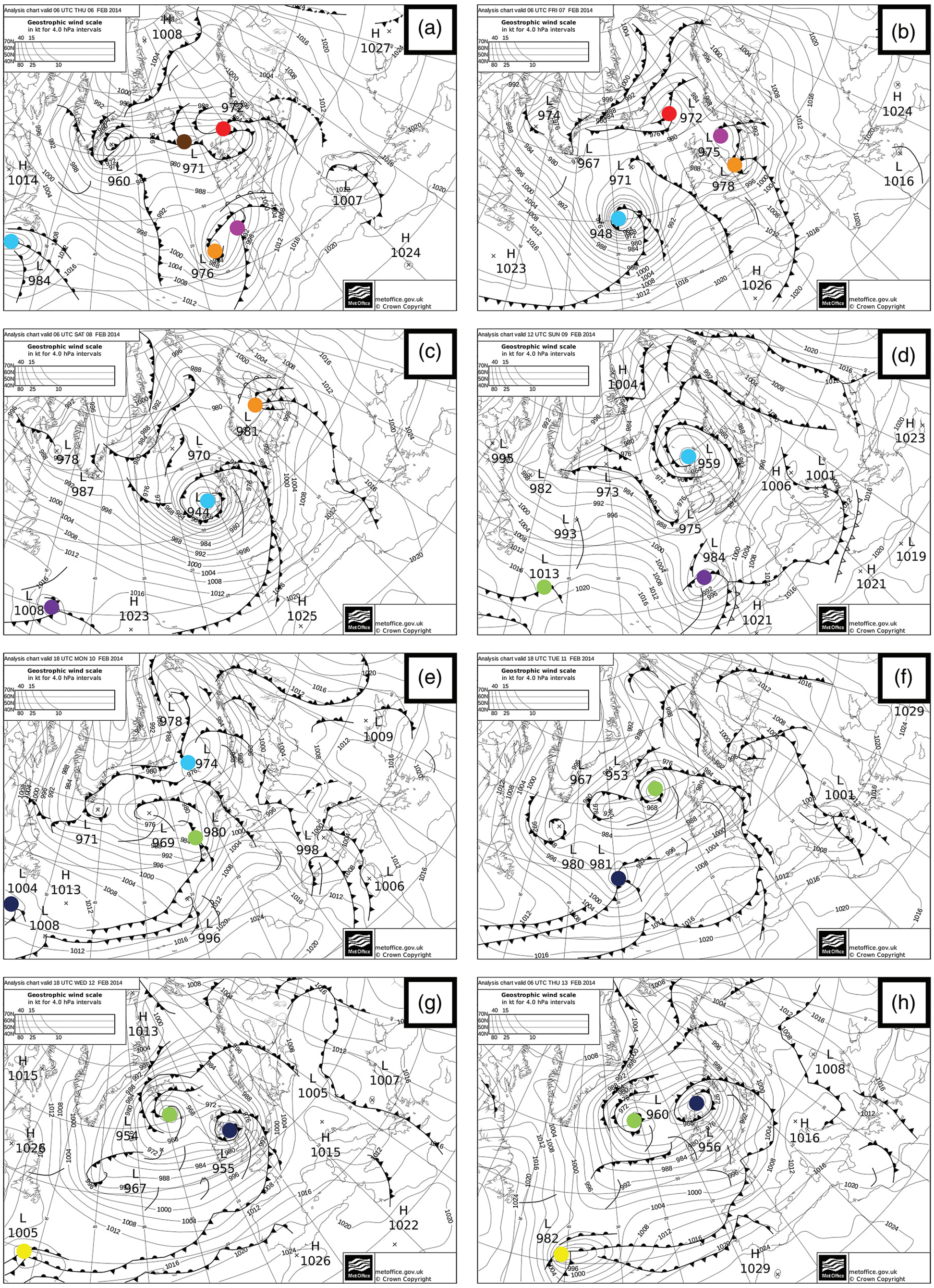

Figure 4. Daily Met Office surface weather charts from 6 February 2014 (a) to 13 February 2014 (h). Related cyclones that impact the British Isles have been coloured: Petra (Red), Qumaria (Orange), Ruth (Cyan), Stephanie (Purple), Tini (Dark Blue), Ulla (Yellow) and three unnamed storms (Brown, Pink, Green). Colours are consistent for cyclones across multiple days. Charts are as follows: (a) 0600, 6 Feb 2014, (b) 0600, 7 Feb 2014, (c) 0600, 8 Feb 2014, (d) 1200, 9 Feb 2014, (e) 180010 10 Feb 2014, (f) 1800 11 Feb 2014, (g) 1800, 12 Feb 2014, (h) 0600, 13 Feb 2014.

in order to identify which cyclones form on the trailing cold front of a parent cyclone and hence are part of one cyclone family; however, only one chart from each day is shown. All of the cyclones that contribute to the observed clustering are labelled with coloured circles, with the same colour on subsequent days corresponding to the same cyclonic system. Hereafter the cyclones will be referred to by their assigned names, with the exception of the green, brown and pink cyclones, which are unnamed. The period in early February 2014 was cyclonically very active over the North Atlantic, with multiple fronts, troughs and cyclones, as can be seen from the crowded and complex nature of all the charts in Figure 4. However, not all the cyclones identified pass over the British Isles, with *Stephanie* passing slightly to the south, and the green storm curving away from the British Isles before it reaches the west coast of Ireland.

From Figure 4 a timeline of storms for this particular cyclone family is as follows: *Petra – Qumaria – Ruth – Stephanie –* Green *– Tini – Ulla.*

Large-scale dynamics of observed DJF1314 clustering

Using the Murray and Simmonds (1991) identification and tracking algorithm, we can visually display each cyclone's path across its entire lifecycle. Only the storms that pass within 700km of 55°N, 5°W are shown; hence the omission of *Stephanie*, which from Figure 4 can be seen to track much further to the south of the British Isles. There are also two other tracks in Figure 5 which have not yet been mentioned: the brown track (Figure 4(a)) and the pink track (Figure 4(a) and (b)). Neither of these systems is part of the observed cyclone family in the North Atlantic and was assigned a name in this winter period; however, as they passed through our area of interest they did contribute to the observed clustering and so have been included in Figure 5.

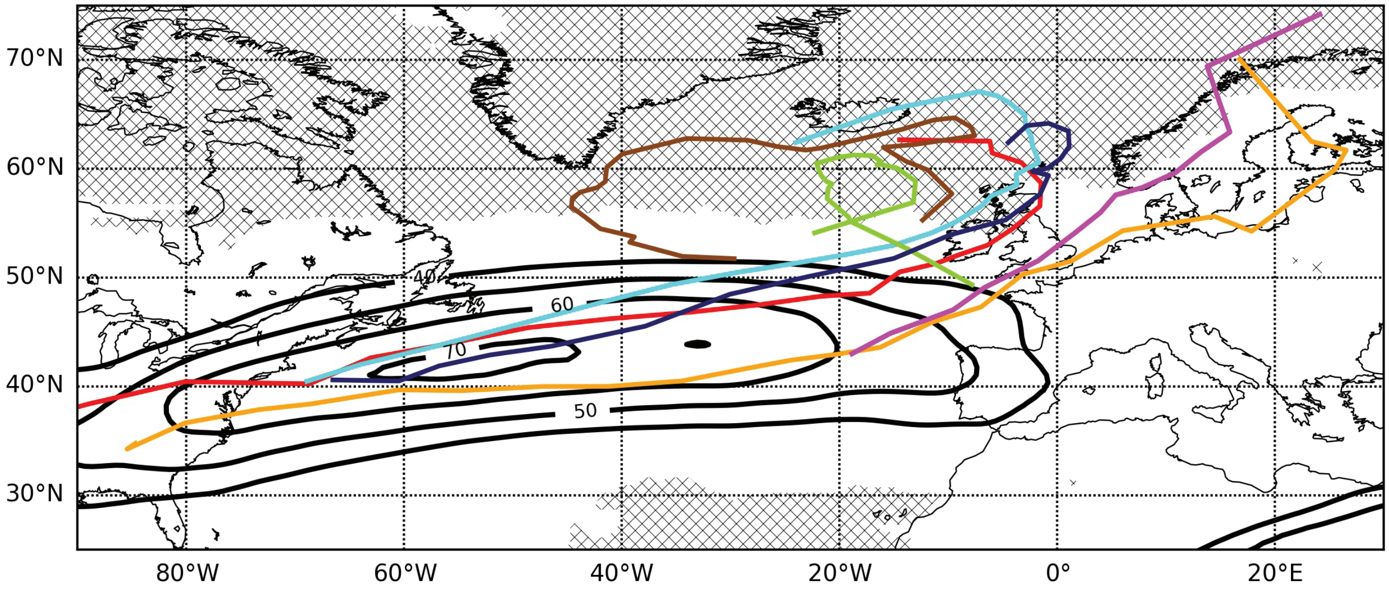

Figure 5. Dynamical composite in the North Atlantic for 6–13 February 2014. Thick black contours depict 250hPa wind (ms^{-1}). Coloured lines are the cyclone tracks identified as influencing the British Isles in this period. The track colours are consistent with cyclones in Figure 4: Petra (Red), Qumaria (Orange), Ruth (Cyan), Tini (Dark Blue), and three unnamed storms (Brown, Pink, Green). Crossed regions are where RWB is occurring on at least 30% of days.

In addition, we can examine the associated upper-level dynamics by compositing fields for this time period. A strong and straight upper-level jet stream was present during the entirety of the period from 6 to 13 February 2014, as can be seen from the values of 250hPa wind in the composite of Figure 5. The jet core across the majority of the North Atlantic is located between 40°N and 50°N, with peak speeds of over 70ms^{-1}, which is well above the DJF average of 30–40ms^{-1}. It is also more zonal than would be seen normally (not shown). Regions to the north and south of the jet are characterised by anomalously large areas of RWB. The dynamical pattern of a strong, straight upper-level jet between areas of RWB on either side has been associated with extratropical cyclone clustering in the studies of Pinto *et al.* (2014) and Priestley *et al.* (2017), and this is further apparent for this intensely clustered period of early February 2014 (the climatological states of both the RWB and jet can be seen in Figure 2d of Priestley *et al.* (2017)).

The presence of RWB on either side of the jet acts to converge momentum into the region of the jet core (Barnes and Hartmann, 2012), resulting in an acceleration of the wind speeds and an extension of the jet towards western Europe and the British Isles. The presence of these features for the entire 8-day period of 6–13 February 2014 allows for the jet to remain in the same place and the cyclones that form to propagate in the same direction and follow a similar track (Figure 5), resulting in clustering over the British Isles. The above-mentioned mechanisms of a strong and straight jet flanked by RWB on both sides can also be found for other clustered periods during the season (not shown).

Discussion and conclusions

The DJF1314 season was one of the most extreme winter seasons on record. It was a season dominated by the clustering of extratropical cyclones, with an average of one intense cyclone every 2.5 days. This study has focussed on one particularly clustered period in this stormy season: 6–13 February 2014. This period had several intense cyclones affecting the British Isles, including cyclones *Ruth* and *Tini*.

All the storms that passed over the British Isles in this 8-day period were part of one cyclone family and were connected through secondary cyclogenesis. Multiple secondary cyclogenesis events were accompanied by persistent dynamical features in the North Atlantic. A very strong and extended jet stream observed at 250hPa was kept in place due to the presence of RWB on its northern and southern flanks. This persistent jet allowed for multiple cyclones to track in the same direction and cluster over the British Isles, resulting in major impacts for the British Isles and other parts of western Europe.

Some recent studies have investigated possible remote influences that may have resulted in such a cyclonically active winter season in the North Atlantic. For example, Slingo *et al.* (2014) and Huntingford *et al.* (2014) hypothesise that the high sea surface temperature in the tropical West Pacific and/or the reduced Arctic sea ice may be linked to the stormy activity. However, no clear causal link has yet been identified. An interesting future direction for work in this area would be to examine any potential link between these teleconnections and RWB in the North Atlantic, and how these remote influences may have contributed to the observed storminess in DJF1314.

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References

Alexander LV, Jones PD. 2001. Updated precipitation series for the U.K. and discussion of recent extremes. *Atmos. Sci. Lett.* **1**: 142–150.

Barnes EA, Hartmann DL. 2012. Detection of Rossby wave breaking and its response to shifts of the midlatitude jet with climate change. *J. Geophys. Res.: Atmos.* **117**(D9): 2156–2202.

Dee DS, Uppala SM, Simmons AJ *et al.* 2011. The ERA-Interim reanalysis: configuration and performance of the data assimilation system. *Q. J. R. Meteorol. Soc.* **137**(656): 553–597.

Hand WH, Fox NI, Collier CG. 2004. A study of twentieth-century extreme rainfall events in the United Kingdom with implications for forecasting. *Meteorol. Appl.* **11**: 15–31.

Hanley J, Caballero R. 2012. The role of large-scale atmospheric flow and Rossby wave breaking in the evolution of extreme windstorms over Europe. *Geophys. Res. Lett.* **39**: L21708. doi:10.1029/2012GL053408.

Hawcroft MK, Shaffrey LC, Hodges KI *et al.* 2012. How much Northern Hemisphere precipitation is associated with extratropical cyclones? *Geophys. Res. Lett.* **39**: L24809. doi:10.1029/2012GL053866.

Huntingford C, Marsh T, Scaife AA *et al.* 2014. Potential influences on the United Kingdom's floods of winter 2013/2014. *Nat. Clim. Change* **4**(9): 769–777.

Kendon M, McCarthy M. 2015. The UK's wet and stormy winter of 2013/2014. *Weather* **70**(2): 40–47.

Lamb HH. 1991. *Historic Storms of the North Sea, British Isles, and Northwest Europe*. Cambridge University Press: Cambridge, UK.

Mailier PJ, Stephenson DB, Ferro CAT *et al.* 2006. Serial clustering of extratropical cyclones. *Mon. Weather Rev.* **134**(8): 2224–2240.

Masato G, Hoskins BJ, Woollings T. 2013. Wave-breaking characteristics of northern hemisphere winter blocking: a two-dimensional approach. *J. Clim.* **26**(13): 4535–4549.

Matthews T, Murphy C, Wilby RL *et al.* 2014. Stormiest winter on record for Ireland and UK. *Nat. Clim. Change* **4**(9): 738–740.

Murray RJ, Simmonds I. 1991. A numerical scheme for tracking cyclone centres from digital data. Part 2: application to January and July general circulation models. *Aust. Meteorol. Mag.* **39**(3): 167–180.

Parker DJ. 1998. Secondary frontal waves in the North Atlantic region: a dynamical perspective of current ideas. *Q. J. R. Meteorol. Soc.* **124**: 829–856.

Pinto JG, Gómara I, Masato G *et al.* 2014. Large-scale dynamics associated with clustering of extratropical cyclones affecting western Europe. *J. Geophys. Res.: Atmos.* **119**(24): 13704–13719.

Priestley MDK, Pinto JG, Dacre HF *et al.* 2017. Rossby wave-breaking, the upper-level jet and serial clustering of extratropical cyclones in western Europe. *Geophys. Res. Lett.* **44**: 514–521.

Slingo J, Belcher S, Scaife A *et al.* 2014. The recent storms and floods in the UK. http://www.metoffice.gov.uk/binaries/content/assets/mohippo/pdf/1/2/recent_storms_briefing_final_slr_20140211.pdf (accessed 15 December 2016).

Swiss Re. 2016. *Winter Storm Clusters in Europe*. Swiss Re Publishing: Zurich, Switzerland.

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Does high-resolution modelling improve the spatial analysis of föhn flow over the Larsen C Ice Shelf?

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Introduction

The Antarctic Peninsula (AP) mountain range stretches over approximately 1500km, from Drake Passage in the north to Ellsworth Land in the south (Figure 1(a)). Its average elevation is 1500m, and approximately 80% of the area is permanently covered by ice sheets, glaciers or adjacent ice shelves. During the twentieth century this was the fastest warming region on earth; however, in the last 16 years, this warming has paused (Turner *et al.,* 2016).

The AP Mountains provide a barrier between the warm, maritime climate to the west and the cold, continental climate to the east. Locations on the west coast are, on average, around 10 °C warmer in annual mean temperature than those at the equivalent latitude and elevation on the east coast (Cook and Vaughan, 2010). Despite the cold eastern climate, several ice shelves have disintegrated – in particular Larsen A in 1995, shortly followed by Larsen B in 2002.

The Larsen Ice Shelf is comprised of four ice shelves (Larsen A to D); Larsen C Ice Shelf is the focus of this study and is the largest remaining ice shelf of the group (Figure 1(b)). Prior to 2013, it was largely believed that this ice shelf was stable for the foreseeable future. However, a rift has opened on the southeastern edge of the ice shelf and approximately 10% of its ice volume may be lost in the near future (Jansen *et al.,* 2015). The calving of ice shelves is a natural process, but due to the location of the rift, the ice shelf may become unstable once the calving event has occurred.

One proposed theory for the destabilisation of ice shelves is the 'föhn hypothesis'. This has been studied over Larsen B by Cape *et al.* (2015) and the Larsen C Ice Shelf by Elvidge *et al.* (2015; 2016) amongst others. It theorises that föhn winds have increased in frequency due to a contraction and strengthening of the circumpolar vortex. The circumpolar vortex is a persistent low pressure system in the upper atmosphere – centred over the interior of the Antarctic continent – that generates the predominant westerly flow of air around the Antarctic. When westerly winds interact with the AP, warm and dry föhn winds can develop. They can induce and enhance surface melt on the ice shelf.

Due to the large spatial area and remote location, observations of föhn winds using Automatic Weather Stations (AWS) are relatively sparse compared with, for example, European observational networks. We have used archived regional model output at 5km horizontal resolution to analyse föhn winds in conjunction with observations. However, the complex local interactions with the boundary layer can be misrepresented in the relatively coarse model output, leading to inaccuracies in quantifying the impact of föhn events. For global climate models, 5km horizontal resolution is very fine. However, for regional modelling of the AP region, finer resolution is required to accurately