A climatology of heavy rain–producing convective systems in the UK

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1. Introduction

Flash flooding represents a significant natural hazard due to its rapid onset which gives little time for warning dissemination and response. Compounding the issue is the long-recognised difficulty in accurately forecasting the small-scale convective systems which typically cause these floods. While many regional NWP models now operate at sufficiently fine horizontal resolution to permit the explicit representation of deep convection, significant difficulties remain in predicting the exact timing and location of storms. For such high-impact, low-predictability events, climatologies can be a valuable component of the forecaster's toolbox, providing an expectation of when and where hazardous weather might occur under different large-scale conditions. Here, we present a five-year climatology of heavy rain–producing convective events in the UK, with a focus on quasi-stationary systems.

2. Data and Methodology

- Previous studies have generally identified heavy convective rain events based on gauge measurements of extreme daily precipitation totals [1][2]
- Extreme convective precipitation is less common in the UK so to achieve a reasonable sample size we consider long-duration convective rain events; i.e. those with the *potential* to produce extreme rainfall totals given sufficiently high rain rates
- Archived rain rate data from the UK 1-km radar composite [3] (see Fig. 1 for coverage) for 2008–2012 was used to identify events based on three main criteria:
  1. Accumulations of at least 15 mm over an area of 100 km^2 or more
  2. Large gradients in rain rate within the causative rainfall objects (used to isolate precipitation associated with deep convection)
  3. A quasi-continuous rainfall duration of at least three hours

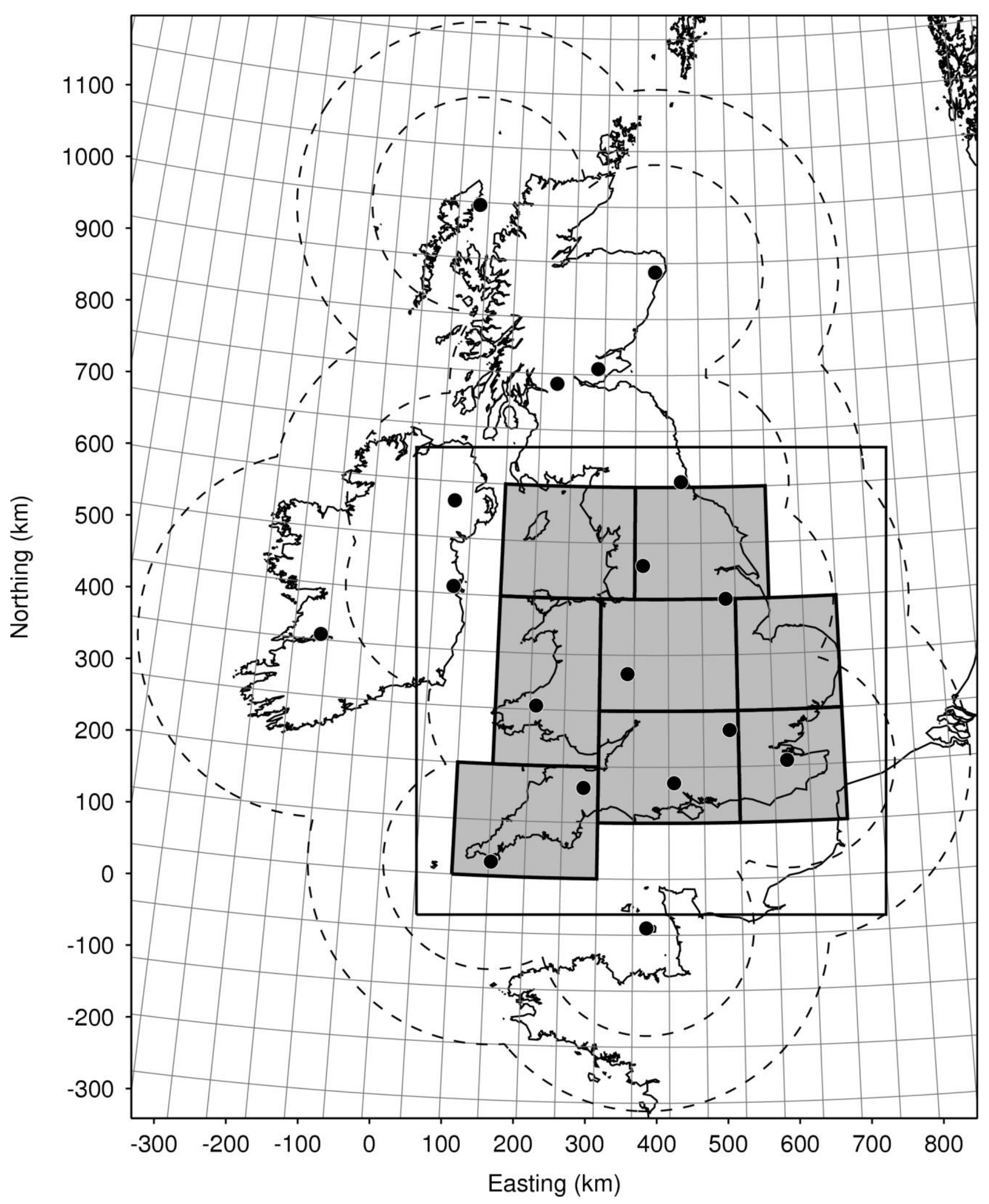

Figure 1. Map showing the coverage of the UK 1-km radar composite (outer dashed line) with black dots indicating the locations of the individual radars. The inner dashed line marks a distance of 150 km from the radars (excluding Shannon in SW Ireland) beyond which data was masked out during the identification procedure. Grey lines mark ERA-Interim grid boxes. The black square shows the area used for our convection climatology with grey-shaded boxes defining the eight 'regions' (see Section 5).

3. Classification of Identified Events

- A total of 519 events were identified; 103 of these were rejected, either as false identifications (30) or due to data quality issues (73)
- The remaining 416 events were placed into one of six categories based on the dominant cause of the long rainfall duration as determined from radar animations of their evolution:

Category	No. Events	Description
1	88	Back-building / quasi-stationary convective systems (roughly fixed initiation point)
2	109	Non-stationary training of linearly organised convection (no fixed initiation point)
3	46	Near-stationary convection with repeated / slow cell development
4	14	Training / slow system motion associated with rotation of the flow around a low centre
5	100	Training of cells without any clear linear organisation
6	59	Large and/or slow-moving convective clusters without a clear cellular structure

- In subsequent analysis, we focus on Type 1 events which will be referred to as *quasi-stationary convective systems* (QSCSs)

4. QSCSs: Event Characteristics

- QSCSs occur across the UK, but most commonly around coastlines and regions of significant orography (Fig. 2a)
- The diurnal and seasonal cycle of events (Fig. 2b) closely resembles that of UK convection in general (not shown)
- Most events (76 %) occur during the summer (JJA) with the rest distributed either side of these months (none in Nov–Mar; Fig. 2b)
- Two-thirds occurred within 24 h of another event (Fig. 2c) – this suggests some relation to the large-scale conditions

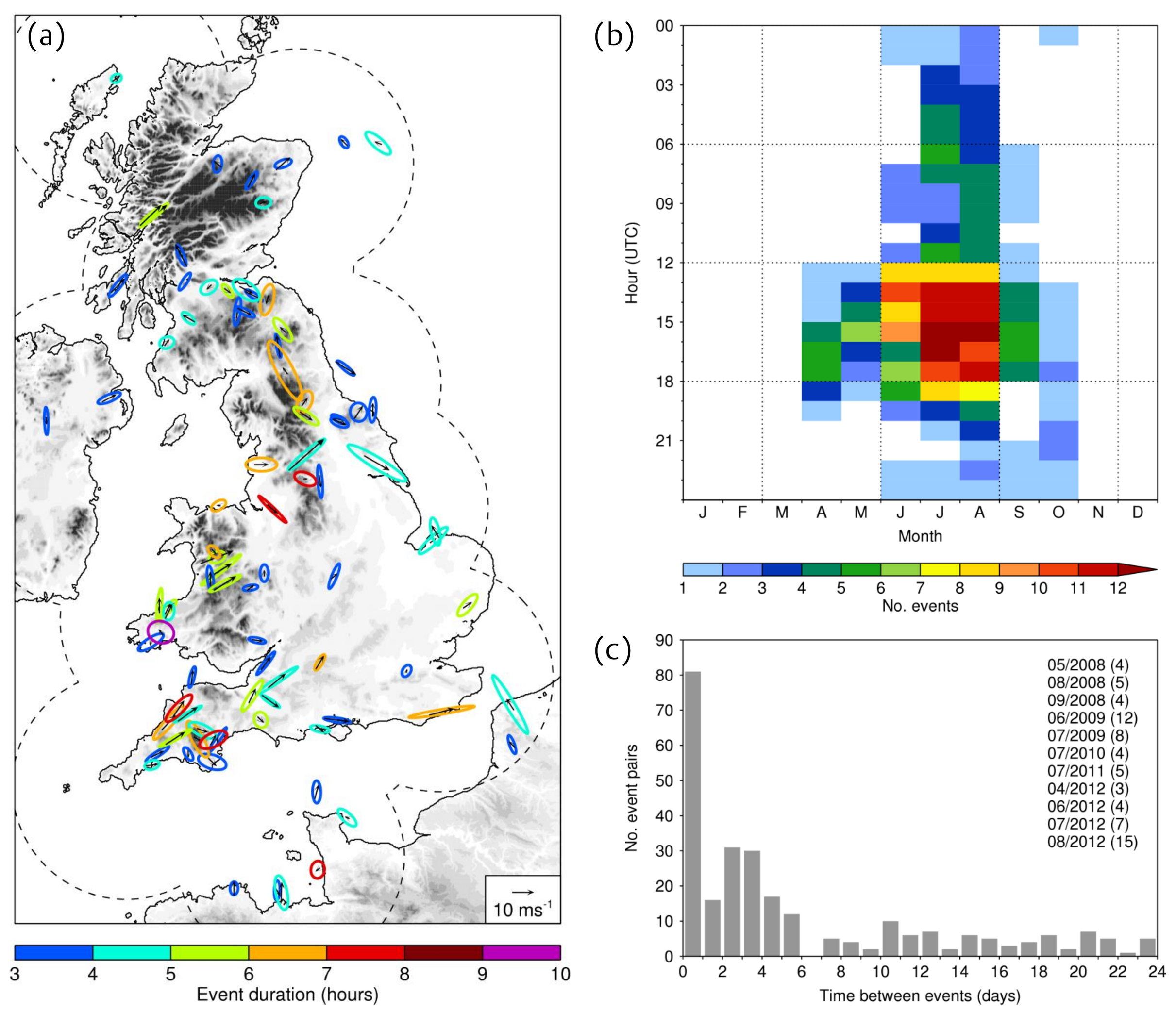

Figure 2. (a) Map showing the location of all identified QSCSs. Ellipses approximate the accumulation area, their colours indicate the event duration, and vectors show the time-averaged cell velocity (computed through correlation of successive radar images for a small region centred on the event). Orography is contoured in grey-scale with an interval of 100 m. (b) Bivariate histogram showing the diurnal and seasonal variation of QSCSs. (c) Histogram of time between events for the 11 months with three or more events. Dates for these are shown on the right with the number of events in parentheses.

5. QSCSs: Environment Characteristics

- Previous studies have linked certain synoptic-scale patterns to flash flooding in particular geographical regions [4][5]
- We have used 6-hourly analyses from the ERA-Interim (ERA-I) dataset to examine the environmental conditions during QSCSs
- Synoptic maps reveal great diversity in the large-scale conditions under which these systems form (Fig. 3); however, patterns are apparent for events in particular regions (not shown)
- Wind profiles suggest a tendency for approximately unidirectional flow with weak speed shear (Fig. 4)

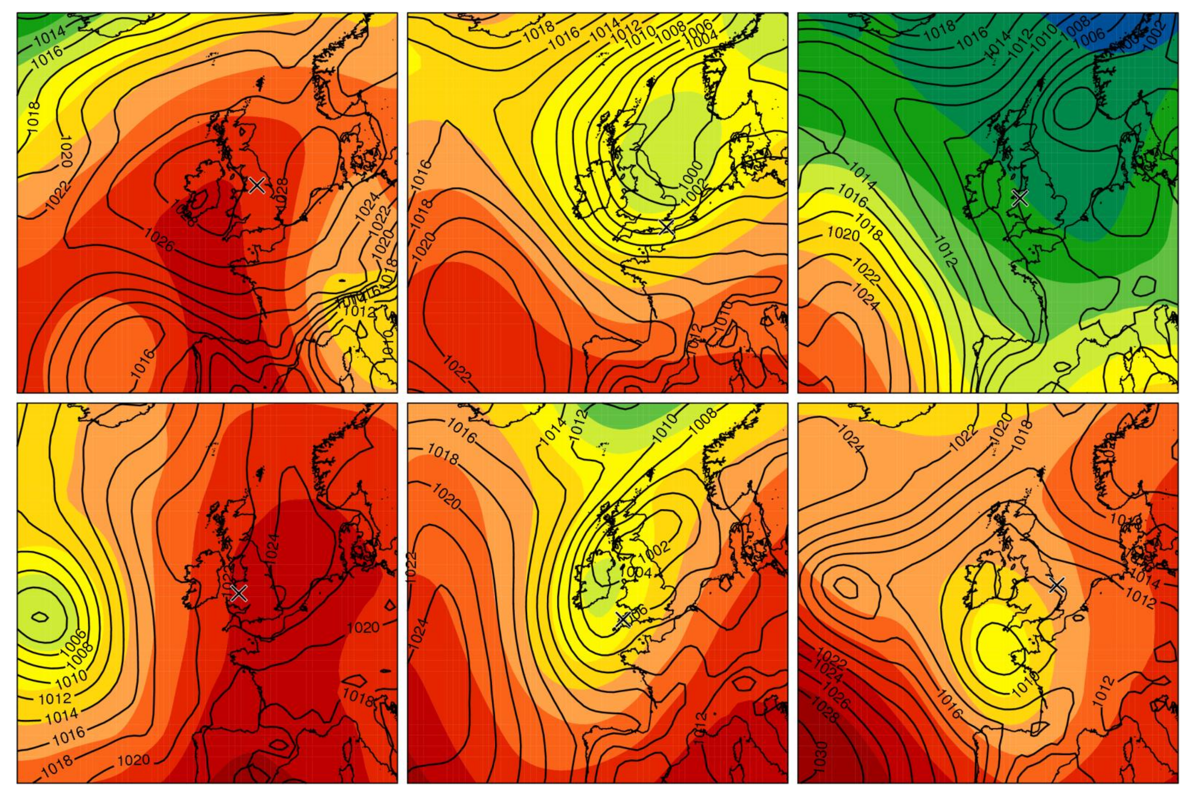

Figure 3. ERA-Interim analyses of 500-hPa geopotential height (colours, 6-dam interval) and mean sea-level pressure (contours, 2-hPa interval) for six of the identified QSCS events (location marked with a cross in each panel). In each case the analysis time closest to the event central time has been used.

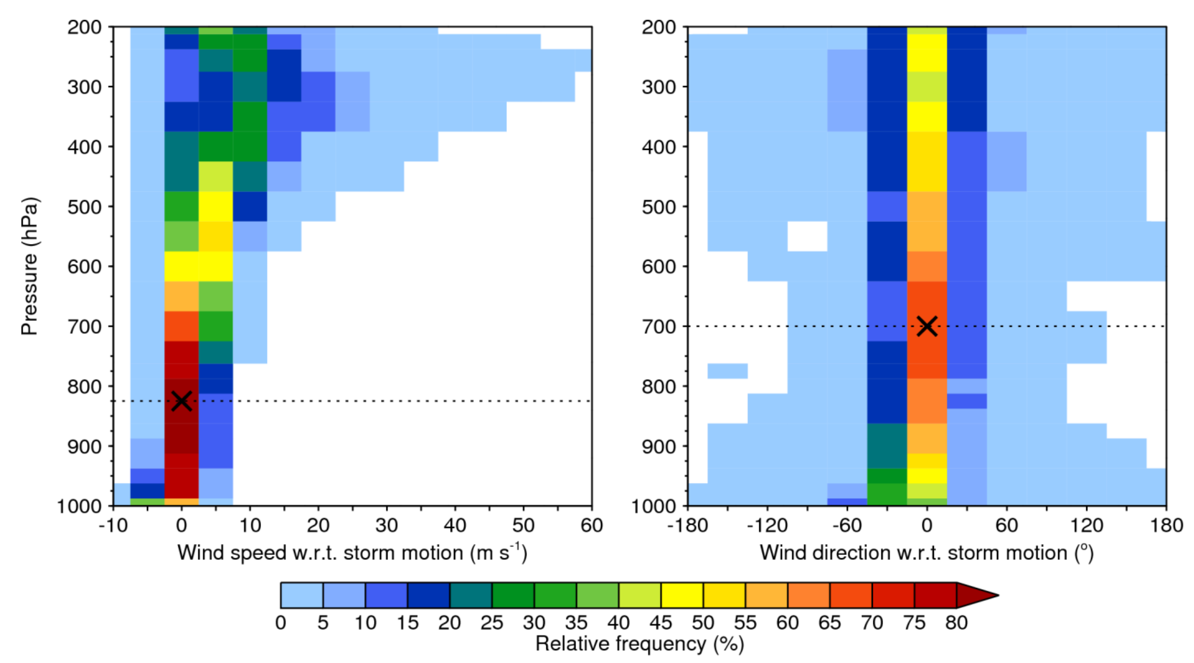

Figure 4. Bivariate histograms showing relative frequency of wind speeds (left) and directions (right) computed with respect to convective cell motion as a function of pressure for all of the identified QSCSs. In each case, profiles were extracted for the time closest to the event central time and for an array of 3 x 2 grid points around the accumulation centroid. Crosses mark the maximum relative frequency with the dotted line indicating the pressure level at which the wind most closely matches the storm motion.

- To provide information useful to forecasters, we must determine whether the environmental conditions during QSCSs are significantly different from those during other convective episodes
- Convective days were identified for each of the 8 regions in Fig. 1 (covering most of England and Wales) for June–September 2008–2012, based on the presence of convective precipitation covering an area of at least 500 km^2 at some time between 11 and 18 UTC
- This gave 2513 convective 'events'; for each, data from the 12 UTC ERA-I analysis was extracted for the region grid points allowing for a statistical comparison with the QSCS environments (Fig. 5)
- Based on Fig. 4, we use the 850–700-hPa mean wind to quantify the 'steering level' flow

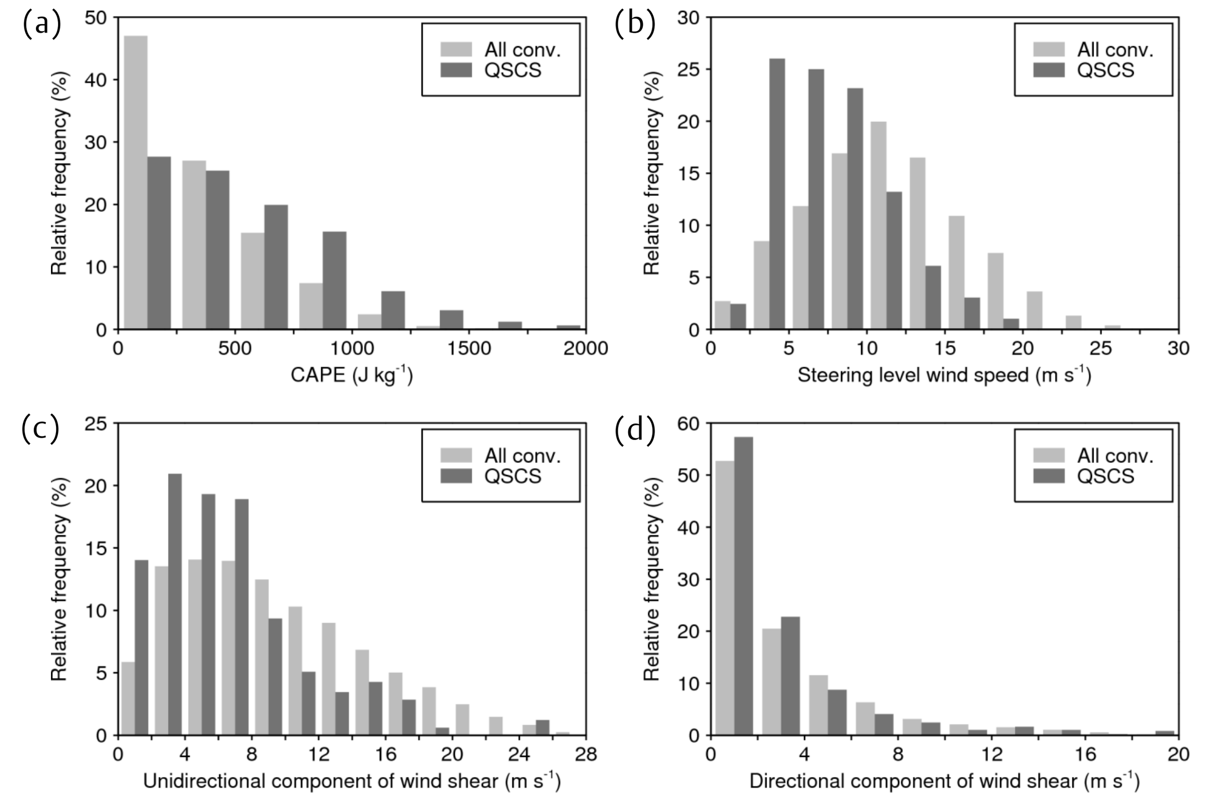

Figure 5. Histograms of (a) CAPE, (b) steering level (850–700-hPa mean) wind speed, (c) magnitude of the unidirectional component of wind shear between lower (1000–700-hPa) and upper (700–300-hPa) layers, and (d) magnitude of the directional component of wind shear between lower and upper layers. Light and dark grey bars show, respectively, all convective events and QSCSs.

- The distributions of CAPE and steering level wind speed are shifted towards higher and lower values respectively for QSCSs (Fig. 5a, b); winds at all levels are weaker on average (not shown)
- Directional and unidirectional shear are weaker (Fig. 5c, d), but this largely reflects the tendency for weaker flow in general

6. Conclusions

- **During 2008–2012, 17 QSCSs occurred each year on average, most during the summer, but with large interannual variability**
- **Topography likely plays an important role in the repeated initiation of convective cells in many UK QSCSs**
- **It does not appear that particular synoptic-scale patterns favour the occurrence of QSCSs generally; however, there is a clear relationship for events in some locations (e.g. the SW Peninsula)**
- **On average, QSCS environments are characterised by greater instability and weaker winds (and shear) than those of summertime convection in general; however, individual cases may feature low CAPE, strong flow, and/or significant shear**
- **The variety of suitable conditions for QSCSs may relate to the different mechanisms by which repeated cell triggering can occur (e.g. forced orographic lifting, topographically related convergence lines, back-building along convective outflow)**
- **Future work should investigate the sensitivity of these different types of QSCSs to small changes in ambient conditions, in particular CAPE, wind direction, and shear**

References

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