Geomorphology 216 (2014) 193–207

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Geomorphological records of extreme floods and their relationship to decadal-scale climate change

S.A. Foulds *, H.M. Griffiths, M.G. Macklin, P.A. Brewer

Centre for Catchment and Coastal Research, Department of Geography and Earth Sciences, Aberystwyth University, Ceredigion SY23 3DB, United Kingdom
River Basin Dynamics and Hydrology Research Group, Department of Geography and Earth Sciences, Aberystwyth University, Ceredigion SY23 3DB, United Kingdom

ARTICLE INFO

Article history:
Received 18 November 2013
Received in revised form 27 March 2014
Accepted 1 April 2014
Available online 12 April 2014

Keywords:
Extreme floods
Lichenometry
SNAO
Climate change
Arctic amplification

ABSTRACT

Extreme rainfall and flood events in steep upland catchments leave geomorphological traces of their occurrence in the form of boulder berms, debris cones, and alluvial fans. Constraining the age of these features is critical to understanding (i) landscape evolution in response to past, present, and future climate changes; and (ii) the magnitude–frequency of extreme, ungauged floods in small upland catchments. This research focuses on the Cambrian Mountains of Wales, UK, where lichenometric dating of geomorphological features and palaeohydrological reconstructions is combined with climatological data and documentary flood records. Our new data from Wales highlight a distinct flood-rich period between 1900 and 1960, similar to many other UK lichen-dated records. However, this study sheds new light on the underlying climatic controls on upland flooding in small catchments. Although floods can occur in any season, their timing is best explained by the Summer North Atlantic Oscillation (SNAO) and shifts between negative (wetter than average conditions with regular cyclonic flow and flooding) and positive phases (drier than average conditions with less frequent cyclonic flow and flooding), which vary from individual summers to decadal and multidecadal periods. Recent wet summer weather, flooding, and boulder-berm deposition in the UK (2007–2012) are related to a pronounced negative phase shift of the SNAO. There is also increasing evidence that recent summer weather extremes in the mid-latitudes may be related to Arctic amplification and rapid sea ice loss. If this is the case, continuing and future climate change is likely to mean that (i) unusual weather patterns become more frequent; and (ii) upland UK catchments will experience heightened flood risk and significant geomorphological changes.

1. Introduction

Large floods in small headwater catchments of the UK are highly effective geomorphological agents and their past occurrence can be readily identified from field evidence, including boulder berms, debris cones, and alluvial fan deposits (Carling, 1986; Harvey, 1986; Wells and Harvey, 1987; Coxon et al., 1989; Macklin et al., 1992; Merrett and Macklin, 1999; Johnson and Warburton, 2002; Macklin and Rumsby, 2007; Milan, 2012; Foulds et al., 2013). Dating of these features is critical to understanding (i) landscape evolution in response to past, present, and future climate changes; and (ii) the magnitude–frequency of extreme, ungauged floods in small upland catchments. The latter is especially important as it allows upland flood records to be extended beyond the typical range of instrumental data (ca. 35 years in the UK; Macdonald, 2013). In small, ungauged mountain catchments, combining geomorphological and documentary data offers a reliable way to investigate longer term changes in extreme weather and flood frequency over the past two to three centuries (Maas and Macklin, 2002; Macklin and Rumsby, 2007; Ruiz-Villanueva et al., 2013). Records of this length are important because short instrumental records do not cover flood-rich periods in the nineteenth century and the first half of the twentieth century (Bichet et al., 2013; Foulds et al., 2013). This can, in turn, lead to the underestimation of flood risk (Black and Fadipe, 2009). Indeed, following recent large flood events in the UK (e.g., summer 2007, 2012) reports of their 'unprecedented' nature and 'biggest in living' memory are common (Foulds et al., 2012). In contrast, analysis of documentary (Macdonald and Black, 2010; Macdonald, 2012; Pattison and Lane, 2012; Macdonald, 2013) and geomorphological records (Macklin and Rumsby, 2007; Foulds et al., 2013) often reveals a different story. That is, large floods have occurred frequently in the past associated with flood-rich periods and variability of the NAO, SNAO, and the frequency/persistence of different Lamb weather types (LWTs; Lamb, 1972), notably cyclonic and westerly flows (Rumsby and Macklin, 1994; Longfield and Macklin, 1999; McEwen, 2006; Macklin and Rumsby, 2007; Macdonald, 2012; Foulds et al., 2013; Wilby and Quinn, 2013).

Although geomorphological methods of flood series extension have been widely used in the British uplands, records for Wales are restricted to a single catchment in the Brecon Beacons (Macklin and Rumsby, 2007) and a series of debris flows in one valley in Snowdonia (Winchester and Chaujar, 2002). The Cambrian Mountains, which

* Corresponding author. Tel.: +44 1970 622606; fax: +44 1970 622659.
E-mail address: safoulds03@gmail.com (S.A. Foulds).

http://dx.doi.org/10.1016/j.geomorph.2014.04.003
0169-555X/

form the central uplands of Wales (Fig. 1), have yet to be studied in detail because of their remoteness and difficulties locating and integrating Welsh and English language documentary flood sources. However, the area is susceptible to high rainfall and flooding (Newson, 1975, 1980). Following one such event in June 2012 (Foulds et al., 2012), several small headwater valleys in the area appeared to contain significant evidence of geomorphologically effective historical floods (i.e., lichen-covered boulder berms) requiring further investigation.

The key aims of this study are to (i) elucidate the chronology of these extreme flood events in the Cambrian Mountains; and (ii) identify climatological and meteorological controls on flood generation. The latter aim is central to understanding local to regional scale catchment response to past, present, and future weather extremes, and inherent flood risk. Catchments investigated in this study are much smaller (<5 km^2) than typical down-scaled regional climate models (25–50 km^2), which have been shown to perform unreliably in small, steep catchments (Smith et al., 2013). These are precisely the areas where damaging flash floods occur, and we advocate in this paper a geomorphological approach to better understand future flood risk in catchments of this nature.

2. Study catchments

The Cambrian Mountains are located in mid- and west Wales, UK (Fig. 1). They include upland plateaux, typically higher than 300 m Above Ordnance Datum (AOD) (maximum relief is 752 m AOD on Pen Pumlumon Fawr), which are dissected by glacial troughs and the headwaters of some of the largest Welsh rivers, including the Hafren (Severn), Gwy (Wye), Rheidol, Teifi, and Ystwyth. This study focuses on the upper reaches of the Afon Ystwyth (Fig. 1), which rises at 535 m AOD and has a catchment area of 191 km^2. In the lowlands, at Pont Llolwyn, Q_{95} and Q_{10} are 0.60 and 14.33 m^3 s^{-1} (drainage area = 170 km^2), respectively, compared to 0.18 and 5.60 m^3 s^{-1} in the uplands at Cwmystwyth (drainage area = 32 km^2) (Afon Ystwyth gauged data are available through National River Flow Archive: www.ceh.ac.uk). Flood hydrographs in small catchments of the Cambrian Mountains are typically very flashy, with short lag times (<2.5 h; Newson, 1975).

The climate of the Ystwyth catchment is typically mild and wet. Mean annual rainfall is 1876 mm at Cwmystwyth (301 m AOD) and 1217 mm at Trawsgoed (63 m AOD). Mean annual temperature is 9.9 °C in the lowlands, and average annual temperatures at Cwmystwyth are 7.1–9.2 °C (meteorological data for the Ystwyth catchment are available through the Met Office: www.metoffice.gov.uk). The Cambrian Mountains tend to be affected by frontal rainfall associated with Atlantic depressions at any time of the year, as well as slow moving, convective summer storms (Newson, 1975, 1980). An average winter may also see several short-lived snow accumulation and subsequent melt events and ca. 60 days of air frost per year at Cwmystwyth. Geologically, the area is dominated by Silurian deposits of the Llandovery series (shales, siltstones, sandstones, and mudstones of the Cwmystwyth Grits Formation).

This study concentrates on a series of boulder berms (Fig. 2A–C), alluvial fans, and debris cone deposits (Fig. 2D) that were identified within the small, steep, headwater tributaries of Nant Cwm-Du (Lat. 52°21′18″ N., Long. 3°44′40″ W.; area = 0.9 km^2, average channel bed slope = 0.132 m m^{-1}), Nant Gau (Lat. 52°19′57″ N., Long. 3°47′37″ W.; area = 2.7 km^2, average channel bed slope = 0.079 m m^{-1}), and Nant Milwyn (Lat. 52°20′18″ N., Long. 3°46′05″ W.; area = 3.7 km^2, average channel bed slope = 0.096 m m^{-1}), which are northward-draining, left (south) bank tributaries of the Afon Ystwyth, as well as several berm and cone deposits in the upper reaches of the Rheidol and Leri catchments.

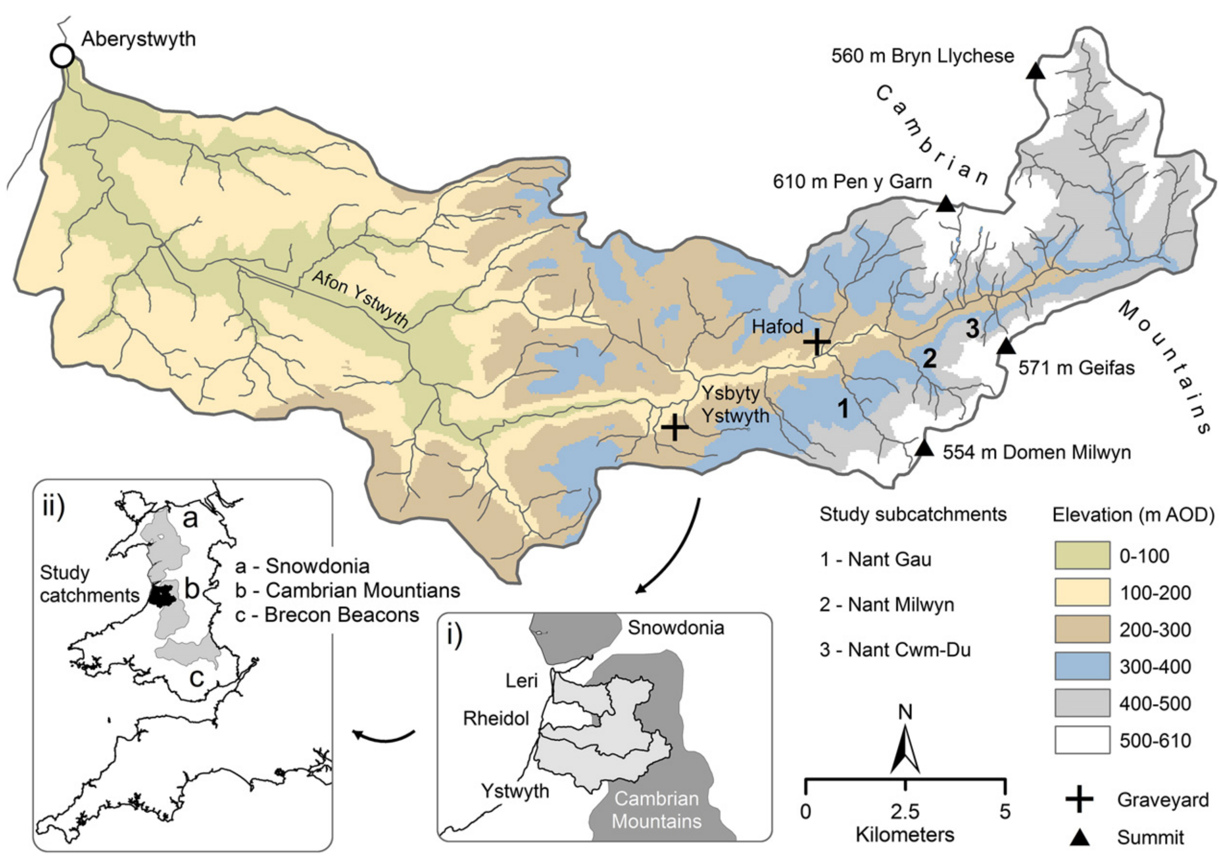

Fig. 1. The upper Ystwyth study area showing locations of the main headwater tributaries where boulder berms have been dated (numbered 1–3). Graveyard locations used to construct lichen size–age relationships (Hafod and Ystbyty Ystwyth) are also shown. Inset map (i) shows the neighbouring upper Rheidol and upper Leri catchments, where a small number of boulder berms and debris cones were identified; this expands to inset map (ii), which shows the wider UK context.