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Stormy Geomorphology ESEX Commentary Paper

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Abstract: The degree to which the climate change signal can be seen in the increasing frequency and/or magnitude of extreme events forms a key part of the global environmental change agenda. Geomorphology engages with this debate through extending the instrumental record with palaeogeomorphological research; studying resilience and recovery of geomorphic systems under extreme disturbance; documenting the mediation by catchment organisation of transport processes during extreme events; applying new monitoring methods to better understand process-response systems; and illustrating how process, experimental and modelling insights can be used to define the buffering of geomorphic systems and human assets from the effects of extremes, providing practical outcomes for practitioners.

Keywords: climate change; disturbance regime; climate extremes; landscape recovery; Intergovernmental Panel on Climate Change

Introduction

In a previous ESEX Commentary, Lane (2013) reviewed recently published work relating to the relationship between climate change and geomorphology. Lane argued that, despite the poor representation of geomorphological research in the 4th Assessment Report (AR4, 2007) of the Intergovernmental Panel for Climate Change (IPCC), geomorphology was making important contributions in disentangling the complex linkages between climatically-driven and human-driven impacts of environmental variability (e.g. land-use change); in thinking about the challenges of modelling geomorphic futures; and in the appreciation of the role that geomorphic processes play in the flux of carbon and the carbon cycle. In this

Commentary, which follows the publication of IPCC AR5 (2013-2014), we introduce an ESPL Special issue concerned with the relations between geomorphology and another key concern in the climate change debate, the potential changes in the frequency and magnitude of extreme weather events[1].

Climate Means, Weather Extremes and Types of Environmental Change

Climate change includes not only changes in mean climate but also in weather extremes. These extremes can be characterised, either singly or in combination, by changes in the mean, variance, or shape of probability distributions (IPCC, 2012). For example, significant trends in heavy-precipitation and high-temperature extremes over the recent decades have been observed (Rahmstorf and Coumou, 2011; Perkins *et al*., 2012) and attributed to human influence, initially in relation to particular extreme events (e.g. Pall *et al.,* 2011; Otto *et al*., 2012; Schaller *et al*., 2016) but more recently by application to all globally occurring heavy precipitation and hot extremes (Fischer and Knutti, 2015; Stott, 2016). In this context, the IPCC AR5 identifies, in particular, the greater risks of flooding at regional scales and increases in extreme sea levels post-1970 (IPPC, 2014).

This emphasis on precipitation, temperature and sea level is perhaps not surprising. Environmental change can be seen as consisting of two components, systemic and cumulative change (Turner *et al.*, 1990). Systemic change refers to occurrences of global scale, physically interconnected phenomena, whereas cumulative change refers to unconnected, local to intermediate scale processes which have a significant net effect on the global system. Hydroclimate and sea level change, a prime focus of the IPCC Assessment Reports, are drivers of systemic change which is highly amenable to large-scale atmosphere and ocean systems modelling. By contrast, cumulative change refers to unconnected, local to intermediate scale processes which have a significant net effect on the global system and where the human footprint is strong, and often dominant. Topographic relief, and land cover and land use changes, are drivers of cumulative change but their spatial and (in the case of surface characteristics) temporal variability, and hence the difficulties of both definition and spatial resolution, make the incorporation of their effects into Global Circulation Models a continuing challenge (Slaymaker *et al.,* 2009). In addition, whilst hydrometeorological and sea surface datasets can be described by smooth time series distributions, their landscape impacts are decidedly non-linear, with clear thresholds to landscape change in the disturbance regime[2]. Any approach, therefore, that sees the land surface as a passive vehicle for the transmission of climate change, and adaptive strategies as a response to at best continental-scale changes in climatic extremes, can only provide a very simplified view of the implications of climate change for human lives and livelihoods. Furthermore, it offers few clues as to how to explore i) societally acceptable levels of landscape change and variability and ii) the extent to which landscapes can recover from extreme weather events and how locally-specific management strategies can improve the detailed trajectory of system recovery.

Stormy Geomorphology

In 2014, the British Society for Geomorphology (BSG) established a Fixed Term Working Group (FTWG) on 'Stormy Geomorphology' to help raise awareness of the ways in which geomorphological science can critically contribute to understanding, measuring and managing the impacts of two aspects of extreme weather events – coastal storms and river floods - on changing landforms and landscape systems and their human inhabitants. The aim of the FTWG has been to bring together world-leading experts in this field, combining state of the art syntheses alongside empirical papers documenting the impact of particular extreme weather events, or cluster of events, on the physical and ecological landscapes; the approach has been an interlinked International Discussion Meeting, held at the Royal Geographical Society (with IBG) in London in May 2015, and this Special Issue of Earth Surface Processes and Landforms.

When designing this Special Issue we identified five key ways in which geomorphological science contributes to a fuller understanding of the impacts of coastal storms and river floods. For the first theme, the fundamental role palaeogeomorphological studies play, both in extending the instrumental record and in improving flood risk estimates, is explored. The short length (generally ≤ 50 years) of systematic river flow records worldwide, most of which start in the mid-twentieth century, make forecasting hydrological extremes that have an annual exceedance probability of 0.01 or less highly problematic. Non-stationarity in flooding resulting from climate and catchment land-cover change also introduces further uncertainty in flood predictions based only on instrumental series. Coastal and fluvial sedimentary archives of past storms and floods with event-scale resolution are increasingly being used to extend flood records back over several centuries (Foulds and Macklin, 2016; Fruergaard and Kroon, 2016) and in some cases millennia (Toonen et al., 2016). These are providing new insights to the significant effects of short-term climatic variability on the incidence of extreme events which suggest that future flood estimation will need re-thought in the light of anthropogenic climate change. The second and third themes draw on research from both landform evolution and process traditions. In the second theme, current process and palaeogeomorphological research is used to examine how the magnitude and frequency of extremes influences the resilience and recovery of geomorphic systems to disturbances triggered by extreme storms and floods. The theme presents the empirical and theoretical dimensions of geomorphic responses to extreme events by characterizing and quantifying the shifts in boundary conditions generated by climate change (Yellen *et al.*, 2016), anthropogenic disturbances (Brandon *et al*., 2016), or the cumulative effects of both (Slater, 2016). In particular, these papers reveal the reach scale (Croke *et al*., 2016) and watershed scale processes (Dethier *et al*., 2016) that dictate the suite of geomorphic responses to extreme events and the potential for large scale system changes to geomorphic perturbations (Phillips and Van Dyke, 2016). The third theme uses a series of empirical papers to demonstrate the critical role that catchment organisation plays in mediating water and sediment transport during extreme events (Boardman, 2015; Boardman and Vandaele, 2016; Rigon *et al.*, 2016; Rickenmann *et al.*, 2016; Rinaldi *et al.*, 2016). The last two themes move into the realm of the process geomorphology tradition, employing novel technologies to gather empirical data and modelling to improve our predictive capacity. In the fourth group, a suite of empirical papers illustrate the fundamental role that near real-time, quantitative field measurements during extreme events can play in advancing our understanding of process-form responses in coastal (Brooks *et al*., 2016; Masselink *et al.,* 2016; Naylor *et al.*, 2016; Terry *et al*., 2016), hillslope (Rinaldi et al., 2016) and fluvial (Leyland *et al*., 2016) settings. Lastly, a series of papers (Smith *et al.*, 2016; Dixon *et al.*, 2016; Balke and Friess, 2016) demonstrate how geomorphological process knowledge, and particularly knowledge gained from physical and numerical modelling of water flows within and across estuarine and coastal landforms and associated ecosystems, can help to inform flood and erosion management approaches. Applied in this way, such knowledge has a direct impact on society; it points the direction towards practical solutions for the more sustainable and robust protection of human assets from the effects of extremes.

Conclusion

Geomorphology has an obligation to inform society as to what level of disturbance the Earth's landforms and landscapes can (and cannot) absorb and over what time periods the landscape will respond to, and recover from, disturbance. We hope that this series of papers helps take this debate, and this responsibility, forward, in relation to one of the key emerging environmental challenges for contemporary society: flood hazard.

Footnotes

[1] An 'extreme weather event' is defined by the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) (Seneviratne *et al.*, 2012) as one that is rare at a particular place and/or time of year. Definitions of 'rare' vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations.

[2] It is debateable whether extreme events should be separated from 'normal' events. As Trenberth (2012, 289) perceptively comments 'Scientists are frequently asked about an

event “Is it caused by climate change?” … In reality the wrong question is being asked: the question is poorly posed and has no satisfactory answer. The answer is that all weather events are affected by climate change because the environment in which they occur is warmer and moister than it used to be.’

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