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Surface processes, landscapes and 21st Century climate change: the scale gap (Ralph Alger Bagnold Medal Lecture)

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In this lecture I will argue that geomorphologists face a fundamental challenge over the next decade: how to address the challenges posed by 21st Century climate change. I will begin by setting up a dichotomy between what I see as two very distinct geomorphological traditions. The first, and embodied by the contributions of R A Bagnold, is in terms of the fundamental physics, chemistry, and increasingly biology, that we have available to describe earth surface processes. Underpinned by measurement technologies and deterministic mathematical models, at scales that range from a few seconds through to months and years, we now have a very good understanding of the processes responsible for landscape dynamics. The second, and enabled by a revolution in dating technologies over the last two decades, has allowed a re-enchantment with long-term, millennial and beyond, explanations of landscape dynamics. Geomorphology has been able to return to the landscape-scale explanations of the 19th and early 20th Centuries but equipped with a proper means of quantifying them.

Arguably, these two traditions leave geomorphologists with a third challenge: 21st Century climate change. Process studies typically suffer from a focus on measurement periods and mathematical models which, when extrapolated to longer time periods or larger spatial scales, typically have greater uncertainty than the signals that they provide. The dating methods that underpin landscape dynamics, with some notable exceptions, tend to be associated with significant noise when they are applied over decadal scales. Thus, the discipline has a scale gap, one that has to be filled if geomorphology is to deliver its required contribution to understanding of global change impacts.

In the main part of this lecture, I will illustrate some of these challenges and point to both ways forward and challenges that have to be overcome. First, I will discuss the challenge of a century when there is likely to be progressively greater disequilibrium between climate, landscape and critical landscape processes. I will use the example of high mountain climate change where the impacts of predicted temperature rise are likely to increase the availability of highly mobile sediment sources at a rate that is significantly greater than the rate of weathering and soil production required to sustain the vegetation response (tree line migration) necessary to stabilise those sediment sources.

Second, I will show how in these kinds of systems, very slight changes in event frequency can lead to disproportionately large changes in landscape sensitivity and hence geomorphological response. This arises from the interaction of processes with very different magnitude-frequency response curves coupled to feedback between landscape events and landscape sensitivity. In high mountain environments, especially those where sediment availability is out of equilibrium with (rapidly changing) climate, this may lead to very different rates of coarse sediment delivery to river systems and associated sediment-related environmental hazards.

Third, I will show that these processes aside, there remains a critical uncertainty associated with the underpinning hydrological impacts on geomorphological processes associated with climate change. Here, our process understanding points to the role of hydrological extremes that climate models are still not able to predict; but also that there may be synergistic interactions between the geomorphological effects of 21st century temperature and precipitation changes which may be critical drivers of landscape response.

Finally, I will argue that notwithstanding uncertainties over the potential for highly nonlinear landscape response to 21st Century climate change, the impacts of that change are likely to be significant for some communities. There is, therefore, an urgent need for geomorphologists to step into this 'scale gap'.