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Self-organizing change? On drivers, causes and global environmental change

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ABSTRACT

Within global environmental change research, certain external drivers generally are assumed to cause the environmental system to change. The most commonly considered drivers are relief, sea level, hydroclimate, and/or people. However, complexity theory and self-organizing systems provide a very different framework and means of explanation. Self-organization — understood as the aggregate processes internal to an environmental system that lead to a distinctive spatial, temporal, or other organization — reduces the possibility of implicating a specific process as being causal. The principle of equifinality, whereby two or more different drivers can generate the same form, has long been recognized within a process-response framework, as well as the concept of divergence, which states that similar causes or processes result in different effects. Both ideas differ from self-organization in that they (i) deal with drivers external to the system and (ii) imply concrete cause-and-effect relations that might be difficult to discern. The assumption is, however, that careful study will eventually lead to the true causes and processes. Studies of self-organization deal with the ways in which internal processes interact and may drive a system toward an instability threshold, the so-called bifurcation point. At this point, the system develops by chance and no single external or internal cause for the change can be defined. For research into environmental change this is a crucial theory for two reasons:

- environmental reconstruction needs to take into account the possibility that past changes may have occurred without any change in the external drivers, and
- current changes may also be entirely caused by internal system dynamics, reflecting processes arising from the interactions between the system components.

Whilst some authors have inferred that environmental reconstruction is, in principle, impossible and that contemporary global environmental change is inscrutable, this paper concludes that such an argumentation is unnecessarily pessimistic. We argue that the focus on self-organization provides important caveats in relation to studies that attribute all environmental change to external drivers and that a multitude of independently existing geomorphological concepts — such as singularity, extrinsic and intrinsic thresholds, and sensitivity — can be well framed and combined within the concept of self-organization.

Contents

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1. Introduction: considering self-organizing change

Processes of change, whether slow changes over centuries and millennia or abrupt landscape or landform changes caused by large and disruptive events, are traditionally at the center of attention within geomorphology. In the past several decades, they have reached even more prominence within the framework of global environmental change research. This type of research is located ‘at the intersection of environment and society’ (Adger et al., 2005, p. 1) and focuses on the interaction of environment (or nature) and society. In this understanding, environmental change occurs because of reflexive relations between the respective sphere (e.g., the lithosphere) and external drivers (e.g., society) (King, 1970; Schumm, 1991; Wolman, 2002; Fraser et al., 2003): if one of the spheres experiences change, this change feeds back to those spheres with which it is connected.

Geomorphological research has a long tradition of acknowledging such reflexive or feedback relations, as well as the specific problems arising from studying long timescales and large areas: long-term and large-scale geomorphological phenomena ‘are neither reversible nor repeatable, and they are accomplished on a scale of time and space that precludes as a matter of course exact reproduction’ (Schumm, 1991, p. 4). Thus, the analyses of these phenomena are reconstructions and provide, at best, approximations to the hypothesized cause-effect relations. Our current knowledge of the Earth depends on different traditional cause-and effect concepts to explain the observed changes: to assign (i) multiple causes to an effect (convergence (equifinality)) as well as (ii) multiple effects to a single cause (divergence), (iii) delayed and/or complex responses to specific causes, and (iv) the sensitivity of a system (e.g., Brunsden and Thornes, 1979; Thornes, 1983b; Bull, 1991; Schumm, 1991). The core theoretical framework for many studies in this context is that of systems theory (e.g., Chorley, 1962; Chorley and Kennedy, 1971; Thornes, 1983a). Missing from this list, however, is another important concept for explaining change within a system, i.e., that of so-called autogenic events or self-organization. Self-organization results from nonlinear processes that are capable of self-enhancement and that can thereby drive the system into change (Phillips, 2000; Murray et al., 2014). Notably, however, the term *change* may refer to completely different types of change: either to *quantitative changes* such as decreased or increased rates of processes (e.g., of soil erosion) or to *qualitative changes* of the system at the global level such as the transition of ‘an eroding to stable or accreting condition’ (Phillips, 2014, p. 208). Furthermore, the rate of these changes is largely controlled by events of a moderate magnitude and frequency rather than by low frequency-high magnitude events (Wolman and Miller, 1960). The human-induced changes of the earth surface belong to these highly effective and cumulative processes of moderate magnitude and frequency (Wolman, 2002).

Whilst the (over)emphasis on climate as external driver of (global) environmental change has been criticized from within global environmental change research (Slaymaker et al., 2009), the concept of self-organizing internal change has received limited attention in geomorphology. Self-organization is considered within those concepts of environmental or landscape change that utilize the idea of ‘Panarchy and Adaptive Cycles’ (Gunderson and Holling, 2002; Slaymaker and Kelly, 2007, p. 196ff; Dearing, 2008). The concepts of self-organization and panarchy can be regarded as being complementary to each other in the sense that self-organization focuses on internal system dynamics only, whereas panarchy majors on the reflexive relations between the two systems of society and nature and the relative resilience of ecological and social systems. The focus on explanation of change by internal mechanisms does not imply, however, that the concept of self-organization excludes the possibility of externally driven change. The concept of self-organization offers an additional set of explanations to traditional concepts, as it is an explanatory frame for those cases where we observe system change without any discernable or sufficient external drivers of change (e.g., minerogenic salt marshes: Section 3 in this paper). The examination of the processes that characterize self-organizing systems thus seeks explanations of the inner organization of a system as well as of its evolution and predictability with respect to future system states and behavior.

Where possible, examples from the earth sciences are used in this paper to illustrate self-organizing change. Still, this is a difficult task: the concept of self-organization has been transferred to only a few small-scale phenomena such as patterned ground (Kessler and Werner, 2003) or beach cusps (Coco and Murray, 2007) and rill initiation and growth (Favis-Mortlock, 1998, 2013) and has even less frequently been tried for larger-scale phenomena (e.g., plate tectonics: Anderson, 2002, p. 69f.) relevant to global environmental change research. A major reason for this reluctance toward a theory transfer might simply be because it is a rather difficult task to adapt these theoretical considerations to earth surface systems. These difficulties might be partly attributable to the long reductionist history of earth system sciences, which favor plain cause-effect relations. Reductionism has a long success story, especially within the natural sciences, but it encounters problems in the case of complex and/or self-organizing systems (Harrison, 2001; Lau and Lane, 2001; Harrison and Stainforth, 2009; Church, 2013). For complex systems causation vanishes (or hides) behind a network of mutual dependencies (Church and Ferguson, 2015). From the perspective of the concepts of complex and/or self-organizing systems, many phenomena we observe result from an orchestration of different mechanisms, which is why we seldom are able to assign the causal role to an individual factor or process. However, this does not imply that the laws of physics do not apply, but that they cannot be parameterized.

These considerations illustrate why it can be helpful to consider self-organizing change within the context of global environmental change research. One might still ask, however, what difference it makes to our understanding of global environmental change to investigate systems with the assumption of self-organization rather than with the assumption of external factors that are driving systems into change. In order to answer this question, we have to look in more detail at the characteristics of self-organizing systems and the question of how we can discern self-organizing systems when we study global environmental change. In short: when can we consider earth systems to be self-organizing (cf. Gershenson and Heylighen, 2003)? The aims of the paper are twofold: (i) to discern self-organizing systems and (ii) to question the assumption that system change is solely caused by external drivers. Thereby we shall reinforce and broaden the claim to consider all drivers