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Is the present the key to the future?

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ABSTRACT

The empirical and conceptual relationships between Earth surface processes and global changes are very complex. The concept that "the present is the key of the future" implies that we know enough the present to be able to extend our knowledge forward to focus on the future. Field and remote observations on the present-day Earth surface processes represent the methodological instruments for the forecasting. At the end of the 1980s, the scientific community predicted a significant increase of global warming followed by changes in the trends of related surface processes. Some processes, such as the Arctic and Antarctic snow melting are now accelerating and even irreversible; thus these trends show that we are now in an 'out of scale' discontinuity moment. Present-day measures and observations could be scarcely significant and may add uncertainty in the prediction of future trends. The 'out-of-scale' trend raises a fundamental question regarding the present, since it may provide a new angle of thought for contemporary theoretical approaches. The need for reducing the uncertainty in the trends of future processes requires a deep rethinking of the current paradigms in order to consider also the 'out of scale' trends.

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Contents

1. Introduction

The relationship between Earth's surface processes and global changes resulting from climatic fluctuations, tectonics and human impact's represents one of the most interesting aims of earth scientists (Rice and Macklin, 2008; Commitee on Challenges and Opportunities in Earth Surface Processes, 2010). Human-driven changes, in particular, are increasing the overall impact on the Earth System, which currently seems operating in a no-analogue state. This means that it is moving outside the range of 'natural variability' and works in different modes from previous geologic time periods (Kerr, 2013). 'Natural variability' refers to data recorded at least in the recent and better known geological past (Slaymaker, 2009). The proxy records vary from a few decades for instrumental observations up to several hundreds of thousands of years for some proxies, such as the amount of CO_2 in the atmosphere

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(Petit et al., 1999). According to the April 2014 readings from Mauna Loa Laboratory, the CO_2 amount is now exceeding 400 ppm, which is about twice as much as the levels evaluated for the last 800 kyrs of the Earth's history (Epica Community Members, 2004). Similarly, the frequency of out-of-scale processes, such as El Niño and other extreme events (Cai et al., 2014) and Antarctic accelerated snow-melting (Abram et al., 2013), is increasing. Lenaerts et al. (2013), Mouginot et al. (2014) and Rignot et al. (2014) even report fast and irreversible ice melting respectively in the Canadian Arctic Archipelago and in West Antarctica. Kundzewicz et al. (2012) suggested an emergence of a positive statistical trend in the severity and magnitude of large floods. A clear example is provided by the catastrophic rains and resulting floods that occurred during the winter of 2013-2014 in the southern part of UK, as well as the 2014 spring flooding in the Balkan Peninsula: in both these cases, the water levels exceeded or approached the maximum values of the historical records. These signs could indicate that, whilst some processes are at the 'tipping point' (Lenton, 2013; Lenton and Ciscar, 2013), others could be close to the their thresholds. These trends, may override any capability of self-regulation, as in the case of rising sea levels and the resulting erosion of low-lying coastal environments. Lenton and Williams (2013) recognised that human activities could trigger such a global event, but, as suggested by Hughes et al. (2013), there is a lacking of knowledge regarding the propagation of regime shifts and the globalisation of local tipping points.

The possibility of understanding the evolution of past landforms or predicting future events is based mainly on the assumption that the actual state is the 'normal' state, that current observations of systems are accurate enough for understanding their functional relations, and, moreover, that presently observed relations do not change with time (von Elverfeldt, 2012). This assumption represents one of the crucial principles of the geological and geomorphological studies, and is rooted in the uniformitarianism (Hooykaas, 1963; Gould, 1965), which supports the uniformity of rates in the past processes acting upon Earth today (Lyell, 1830). The main problem for geomorphologists is that they usually do not have enough time to observe how landscapes evolve, so it may be complicated to understand how observations of present-day surface processes made over a period of a few months or years may be related to longer-term landscape evolution (Paine, 1985).

Until a few decades ago, geomorphologists were mainly involved with explaining past processes and past evolutions of forms. Thornes and Brunsden (1977) noted that little has been said about forecasting in geomorphology, even though it is closely linked with geomorphological systems analysis. Favouring the retrospective rather than the prospective view in geomorphology has meant that little work has been done in this area. Despite the fact that climate change is the biggest challenge facing future landscapes, geomorphologists have played a surprisingly small part in the issue compared to other similar field-based experts such as climatologists, oceanographers, and ecologists (Goudie and Viles, 2010; Lane, 2013). On the contrary, assessments of the potential effects of future climate change on runoff, sea level change, etc., are crucial for the land managers and decision makers (Slaymaker, 2009; Church, 2010; Goudie and Viles, 2010; Gregory, 2010). The need to adapt to climate change and increasing temperatures (Meehl et al., 2009), and to know the trajectories of landscape evolution, has raised concerns among policy and decision-makers regarding short-term or decadal time scales. Earth sciences are now seen as 'applied instruments' for improving predictions and creating more effective environmental management (von Elverfeldt, 2012).

This paper revisits the metaphorical question of whether the present can be considered as the key to the future; it also reviews the fundamental paradigms that lie at the base of the knowledge of earth sciences. The paper is framed by these epistemological concepts, following the debates in geomorphology and neighbouring sciences and their related literatures. The concept of time and its related entities, namely past, present, and future, will be discussed in detail. The figurative significance of the term 'key', in terms of present and future knowledge and explanation, will also be explored.

We aim to stimulate the discussion on the use and significance of current observational data, for the near future forecasting of Earth's surface processes, at the 'human-scale' level. An important point is whether current out-of-scale processes offer useful input for predicting the future. At the end of the paper, some considerations about the growing uncertainties and the hidden challenges that modern geomorphologists have to face are presented.

2. The concept of time

Most of the vital problems of philosophy depend on the solution of the problems of time and space and their mutual relationship (Alexander, 1920). The definition of the relationship between time entities is complex both for ontological reasons, related to their a priori existence, and for instrumental reasons, related to their logical boundaries. However, a conceptual definition of the time and the relationship between time entities is that the past, the present, the future, and their relationship with space are fundamental to our discussion. The concept of time pervades all fields of Earth Sciences, from the most precise observation of a localised process to the global scale (Millar, 2013). Rhoads and Thorn (1993) suggested that geomorphology is a science mainly centred on the concept of time because time-scales are fundamental for the nature of geomorphic investigations. In fact, time and space define the fence of development of Earth's surface processes.

Augustine calls time a distention of the mind with which we simultaneously grasp the past by memory, the present by attention, and the future by expectation—Confessions 11.26. The topology of time assumes that it consists of a dimension in which events can be ordered from the past through the present into the future, following a single, non-branching, and continuous line (Zalta et al., 2013): the so-called 'time arrow'. The time is considered to possess the property of intrinsic direction, and, in the macroscopic sense, to be irreversible; on the contrary, the space can be considered multidirectional.

Events begin, endure, and end, and are fixed in their position relative to preceding and succeeding events, meaning the system cannot change past values in its feedback controls (Thornes and Brunsden, 1977). Focusing on the transitory and directed nature of time allows us to understand processes and their properties such as the rates of operation, direction, duration, memories of preceding events. Natural phenomena can occur as discrete or isolated events, or else they can be affected either by continuity or fluctuations, or be sequential. Compared to the human time-scale, phenomena can be considered slow-changing, such as sea level changes, isostatic rebound, etc., or dynamic, such as unidirectional or cyclical phenomena. A process can be reversible, such as steady state systems, or irreversible, such as landslide processes. In any case, if time moves forward and what has passed is lost, the system cannot anticipate the state of the system ahead of the present time (Thornes and Brunsden, 1977).

Originally, time in geoscience was related to the chronologers' quest to find the age of the Earth (Jackson, 2006), which has gradually increased from a few thousands to more than four billion years. Thus, time has increased in its importance to understanding the history of landscape evolution and the relationship between time and surface processes. This importance has also increased because of the interaction of processes at multiple scales (Cullingford et al., 1980; Thorn, 1988; Schumm, 1991; Starkel, 1999; Millar, 2013). The relationship between present-day and future process trends is vital to planning and engineering (Goudie and Viles, 2010). In the following sections we will define the time entities (past, present, future) and their relationships inside the 'time arrow'.

2.1. Past

'Past' is a term roughly used to indicate all the events that occurred before a given instant in time. The concept of the past is derived from the linear way in which humans experience time, and is accessed through memory and recollection (Sutton, 2012). Oxford Dictionaries (2014) suggests more definitions that deny the present-day existence of the past, in particular: (1) gone by in time and no longer existing, (2) belonging to a former time, and (3) expressing and action that have happened or a state that previously existed. The first two describe something that no longer exists, while the latter concerns an ended action. Explaining the past of the Earth is one of the main goals of the earth sciences. The heritage of the past represents the raw material of the studies in geoscience. Baker (2007) suggested looking into the past, forgetting physical laws but focusing on the signs left by past processes, since they could be different from present-day processes. Most future predictions are conducted with complex numerical models, but these models cannot be tested for scenarios outside of the modern times without the use of past climate data (Lunt et al., 2013). Past processes can completely disappear, leaving their forms as palimpsests with no relation to the present (Bloom, 2002), but they can persist into the present. Active long-lasting processes inside the Earth's systems are the result of the persistence of the processes, while landforms are the result of the present-day persistence of the forms. In other cases, a form can currently persist without the process that generated it, such as marine uplifted terraces, fluvial terraces, etc. (Huggett, 2011). Regarding the human-related history of the Earth, researchers have recorded the past via studies of natural remains or their interactions with human-made remains and activities (Trimble, 2008).

Also fundamental is the role of history and contingency in earth sciences (Schumm, 1985; Baker, 1999; Hargreaves and Annan, 2002; Phillips, 2007; Inkpen and Turner, 2012). The use of palaeo-data provides useful indications of the past to give clues at different time-scales, such as earlier civilisations or historical scale impacts (Trimble, 2008). This approach can be used to trace human-induced changes and to distinguish them from those occurring naturally. Moreover, past observations of proxies can help to predict the human contribution to future climate change (Hegerl and Stott, 2014) and to future impacts of climate change on Earth's surface processes.

Another commonly used approach in earth sciences is ‘analogy’ (Garner, 1967; Goudie and Viles, 2010; Baker, 2012). Analogues are used also for the comparison of extreme events (Kundzewicz et al., 2005), while no-analogues are used to study regions where current climates are no longer to be present in the future (Williams et al., 2007). The role of analogy is fundamental in the formulation of hypotheses which mainly rely on the logic of consistency, coherence, and consilience typical of historical sciences (Baker, 2012).

2.2. Present, or now

A serious epistemological debate on the present has been little discussed in earth sciences, though it could be important nowadays. When the term ‘present’ does not start from an agreement, such as the radiocarbon ages before present (BP) referred to as AD 1950, the philosophical definition of the present is very complex. It is, in fact, related to events perceived directly and for the first time, not as a recollection (past) or a speculation (future). Mead (1932) suggested that the present is the seat of reality, since the past and the future that appear in the present are merely the thresholds of an infinitesimal time window of an unbounded extension, i.e., an insignificant element that reduces the world into an instant. Therefore, the quantification of ‘now’ is a matter of uncertainty because the boundaries between past and future are barely defined. This definition is particularly interesting for geoscientists because the boundary of the present, usually defined in earth science research, recalls the concept of reality: the ‘reality’ used to infer the past or the future of the Earth. In other words, the reality is the knowledge and data we have available to model the Earth system, which begins in the present. A complicating factor is that, whilst a given observer would describe ‘the present’ as a spatial structure with a zero-length time lapse, other observers would associate both time and space with this structure and therefore would either disagree on what constitutes “the present”, or consider the present to be ‘local’ (Power, 2009).

The present can be defined using a functional definition that recognises the present as a time lapse during which we have a uniform set of data in order to address a geological reasoning and ‘understand’ the past or the future. The present is related to the observability of the Earth's surface processes. Observability itself introduces the aforementioned absolute time-scale of the human observation. The time-scale may change over the course of a century, such as for aerial photographs or sea level data, or over several millennia, such as for historical records (Haff, 1996). The capability of observing and measuring processes creating change and the resultant changes provides the opportunities for testing short-term predictions (Wilcock and Iverson, 2003). From a geological point of view, the present can be referred to as the so-called Anthropocene (Crutzen and Stoermer, 2000) because the human influence on the global environmental changes has become so significant that this term widely has been used by the earth science community since the 1980s (Steffen et al., 2011; Smith and Melinda, 2013).

2.3. Future and changes

The future involves events that will or are likely to happen in the time to come. The future is what will happen after the present. Its arrival is considered inevitable due to the existence of the ‘time arrow’ and the laws of physics. Due to the apparent nature of reality and the unavoidability of the future, everything that currently exists or will exist can be categorised as permanent, meaning that it will exist for the whole of the future. The future in earth sciences is related to forecasting and prediction. Since human activities are increasingly comparable to natural forces, the prediction of their future impacts on Earth's surface will assume increasing importance than they did in the past (Haff, 2003).

In the Fifth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) highlighted that it is ‘extremely likely’ that more than half of the observed increases in the average global surface temperature from 1951 to 2010 were caused by the anthropogenic increase in greenhouse gas concentrations and other forcings (Bindoff et al., 2013). Pretis and Allen (2013) observed that past changes in the rate of warming could be reasonably attributed to human influences. The close relationship between human activities and Earth processes drives different social approaches to the future, such as the knowledge and the governability of future landscapes (J. Anderson, 2008).

As previously highlighted, climate change is only one driver of landscape change, so the challenge to future landscapes might be more complex than commonly thought, since climatic change affects landscapes while landscape changes affect climatic change (Goudie and Viles, 2010).

3. The key: knowledge and explanation as the link between the past and the future

The relationship between present and future is an important issue explored by this paper. The etymology of the word ‘key’ is derived from the Latin verb *claudere* (to close). The figurative meaning of key is ‘a thing that provides a means of achieving or understanding something’, or that ‘involves something that serves to explain or that affords a means of access to achieve a particular purpose or a point of view’, but also ‘a means of access, control, or possession’, or something ‘of crucial importance or significance’ or ‘a vital, crucial element’ (Oxford Dictionaries, 2014).

Any study about the future should consider a theory of knowledge and explanation. Chiodo (2011) suggested that a scientific explanation highlights the identity that ‘links’ (Gr. *symballein*) the present to the future, the presence (present) with the absence (future), the particular with the universal, the empiricism (data) with the possibility (prediction). Therefore both explanation and forecasting are related to understanding. Explanations are the link between descriptions (present) and predictions (future) that allow us to answer to the most crucial scientific questions (Cox, 2007). Inkpen (2005) suggested that explanations and predictions are closely related to each other, and that explanations reduce uncertainties about reality. Acquired knowledge can be used to explain past forms and processes or to forecast their evolution in the future. Knowledge is an awareness provided by experience or by learning that allows us to explain the behaviour of something and consequently to understand the past and forecast the future (Inkpen, 2005). Pigliucci (2009) pointed out that science is not just about finding patterns, which is only part of the process, but is about finding explanations for the patterns. The most significant advances in earth sciences have been due to the formulation of general principles and simplifying concepts (Kirby, 2003). Held (2014) suggested that a creative tension between the acceptance of the complexity and the emergence of the underlying simplicity exists as well, helping the prediction, as suggested also by the approaches of the reduced complexity models (Bokulich, 2013), that play important roles e.g. in LEM (landscape evolution model) or when physical laws are not already known.

The background of the main explanations is the background for knowledge and the capacity to explain the processes and the development of landscapes in the Earth System. Baker (1996a) argued that geologists followed three methodological steps involving inspiration by analogy, impartial and critical assessment of hypotheses, and scepticism of authority. Geologists, geomorphologists and earth scientists interpret Earth's signs using different kinds of tools, such as measurements, quantitative modelling, and experimentation. Earth sciences, unlike the ‘hard’ sciences, are rarely able to reduce potential competing theories to one because they are not able to falsify (Inkpen, 2005). While analytical sciences are based on the conceptualism and reductionism models, mainly following Peirce's view, the analysis in the geosciences is based on the synthetic thinking, namely the comparison, connection and jointing of thoughts and perceptions (Baker, 1996a).

Earth scientists use different approaches, in particular the inductive approach, the deductive approach, and the abductive approach (Inkpen, 2005, 2008). The first uses observations of both causes and effects to test and develop theories and laws. The second involves knowledge of causes and the laws of nature to test and work out the nature of the outcomes. The third looks at the effects, and, following the knowledge of a law of nature, it searches for the causes. Inkpen (2008) conducted abductive reasoning to field evidences, which are the traces of the past and are interpreted within the context of the event they take into account. Baker (1996b) highlighted that geologists take the world as it is, or that the Earth ‘speaks’ to geologists through the traces. Earth scientists must extrapolate from observed to unobservable causes (Gould, 1965), but they can only explain landscapes and try to predict the results of landscape changes by studying the combinations in which a variety of geomorphological processes have operated, operate or will operate (Favis-Mortlock, 2013). To do this, the focus shifts to functional relationships and to regularities of dynamics.

Basically, the scientific method in earth sciences is related to the links between theories and observations. Explanations of landscape evolution are often based on close relationships between observations and the development of theories. It is almost impossible for Earth scientists to differentiate pure description from explanation because the description enforces the interpretation, and vice versa (Goudie and Viles, 2010). Measurements made by different methods are often compared to evaluate how much they agree, as are predictions from models and corresponding observations (Cox, 2006).

The production of a theory is followed by the experimentation, which involves an orderly procedure carried out with the goal of verifying, refuting, or establishing the validity of a hypotheses. The elements included in the earth sciences explanation are the reverence for field work, humbleness toward the natural events, discrimination between observed facts and the observer, and working hypotheses. Earth sciences often involve field work as a type of uncontrolled laboratory experiment. Field experiments offer the advantage that the outcomes are observed in an uncontrolled natural setting, so they are seen as having higher external validity than laboratory experiments. When experimentation is impractical, observational studies and exploration are used (e.g. Sendra and Reboleira, 2012; Furlani et al., 2014). The outcomes of observational studies can be quantified in order to provide more objective results. Observations, experiments and explorations are closely correlated, as suggested by Richards (2011), because experiments can detect a need for new exploratory investigations.

4. Paradigms, theories and approaches

A paradigm is referred to the set of practices and modes that define a scientific discipline in any particular period of time (Kuhn, 1962), or a universally recognised scientific achievements that, for a time, provides a model of problems and solutions for a community of practitioners. Thus, all theories, as well as the methods generated by them, are, ultimately, paradigm-based (Ratcliffe, 1983). A theory is a mental image of the external world (Giere, 1988). Considering its nature, it will be always underdetermined in relation to the reality of the world (Oreskes et al., 1994), so the reality of the world and its processes are more complex than any theory. An approach is a practical way to test a new theory. Kuhn (1962) drew attention to the fact that scientific truth is not separated from the context in which it is studied. He suggested that the concept of a paradigm is an overarching framework of theories that governs the degree to which proposed explanations are responsibly supported (Kennedy, 2006). In the end, a paradigm represents just a key that provides a means of achieving or understanding something, namely the explanation of a mechanism or the possibility of predicting it. New paradigms in earth sciences have partly risen as a sort of vision impossible to define with intuitive leaps by scientists, or also with common sense (Baker, 1996c), or through the exploration of areas that were previously completely unknown (Holton, 1973), such as the remote sensing.

4.1. Paradigms

The epistemological debate in the earth sciences, particularly in geomorphology, is complex and multi-faceted (Rhoads and Thorn, 1993, 1994; Baker, 1996a,b; Rhoads and Thorn, 1996; Baker, 1999; Brown, 2004). A clear distinction between paradigms and theories is sometimes difficult to achieve. Orme (2002) identified eight basic paradigms in the earth sciences: uniformitarianism, catastrophism, glacial theory, uniform flow theory, mass movement theory, cycle of erosion, continental mobility, and quantitative geomorphology.

Though these paradigms and their related theories are very useful in the earth sciences, we pay particularly close attention to uniformitarianism, and, consequently, the catastrophism, which is more closely related to the core of this paper. Gradualists and catastrophists polarise the debate spectrum about possible rates of change, suggesting that changes may be either gradual and gentle or abrupt and violent, with all grades between the two extremes possible (Allen, 2005). Baker (1998) studied the logical roots of catastrophism and uniformitarianism. Catastrophism is founded on the concept that Earth signifies its causal processes through landforms, while uniformitarianism guarantees inductive reasoning through its regulative method that includes simplicity, actualism, and gradualism. Many landscapes appear unchanging, or at least to be changing extremely slowly. The question that arises is related to their efficacy, since it is reasonable to assume that landforms may be the result of a combination of gentle and violent processes (Huggett, 2011). However, if it is true that the present is the key to the past, then this concept stresses the uniformity of principles more than the uniformity of the processes (Orme, 2013). The concept of uniformitarianism is closely related to the present, but it uses the word ‘present’ without explaining it, and only the relationship between a known present and an unknown past is considered. It includes several ideas that have been mixed together, alternatively recalled, and often misunderstood by many authors (Vic Baker, pers. comm).

Uniformitarianism was divided into several forms by Gould (1965) and Hooykaas (1963). The most important are substantive and methodological uniformitarianism. Baker (1999) also recognised the epistemological, which claims that the only proper way of knowing about the Earth is through an a priori assumption of process uniformity, based on the conception of the similarity of the geological reasoning to the physical reasoning (Baker, 1996a).

Substantive uniformitarianism endorses the uniformity of rates in the past processes acting upon the Earth (Lyell, 1830). The processes that we can see around us operating on the Earth today are those that were responsible for past changes. In the last two decades, the catastrophist paradigm in the earth and biological sciences has limited the substantive uniformitarianism (e.g. Berggren and van Couvering, 1984; Huggett, 1997).

Methodological uniformitarianism assumes that the natural laws of the past were no different from what they are today. This assumption was variously and sharply criticised both in its epistemological concept, such as the validity of the hyspothesis (Gould, 1965), and in its consequences to the geological debate, since it provided grounds for different attacks on the fact that uniformitarianism cannot explain many geological phenomena (Shea, 1982). In the end, uniformitarianism does accept that the operation rates of processes have varied in the past, but not in their essential nature (Goudie and Viles, 2010).

4.2. Theories and approaches

Thornes (1978) reminded others that a theory is the ultimate and desirable goal of a scientific discipline. Considering the scientific character of geomorphology, Rhoads and Thorn (1993) suggested that it is permeated by theory. Most of these theories are related to the explanation of the processes and the mechanisms that are responsible for the genesis and evolution of the forms in the Earth's history, or in the Earth's future. Moreover, as suggested by Phillips (2012), different interpretations of the same evidence can also be provided by different storytellings, or ways of reporting results and promoting ideas in the earth sciences. The role of theories in the formulation of new ideas is controversial, and it was criticised by Baker and Twidale (1991) and Oliver (1991). Anderson (2008b), the guru of informatics, has even declared the end of theory, since the modern era of petabytes of information and cloud computing is bypassing the typical approach of hypotheses, models or tests in science, and scientific theorising can no longer cope with the deluge of data.

The debate regarding appropriate modes or approaches of explanation is very rich and well-articulated (e.g. Lyell, 1830; Gilbert, 1886; Chamberlin, 1890; Johnston, 1933; Richards, 1990; Rhoads and Thorn, 1993, 1994; Frodeman, 1995; Baker, 1996a,b, 1999; Inkpen, 2005; Phillips, 2006, 2007; Inkpen, 2008; Phillips, 2012), and it is generally related to the study of interactions between processes and forms. A process is the action involved when a force, such as the climate, induces a modification of a landform. The balance between form and process is best described by considering these factors as systems or components of systems (Ritter et al., 2011) that are regulated by a combination of global laws and contingent factors (Phillips, 2006).

The so-called system theory is widely used to study geomorphic processes (Chorley and Kennedy, 1971; Schumm, 1977; Chorley et al., 1984; Huggett, 2007; von Elverfeldt, 2012). It is based upon the idea that the internal and the framework parts can be isolated to describe the current state of processes and landscapes (von Elverfeldt, 2012). Landscapes are complex systems in which a large number of geomorphic processes operate, so predictions are generally difficult. One of the main problems is related to the fact that geomorphic systems are usually nonlinear and dominated by thresholds (Phillips, 2006), which are the critical conditions at which a landform abruptly changes due to external or progressive changes (Schumm, 1977). There are other sources of nonlinearity, such as self-reinforcing positive feedback, that reduces the possibility of finding universal laws to predict geomorphic changes (Phillips, 2006). Moreover, Knight and Harrison (2014) recognised inherent problems with evaluating the impacts of ongoing climate change from past interglacial surface changes because the increased uncertainty is due to the increasing importance of nonlinear systems feedback.

Process geomorphology and climatic geomorphology are the two main actors in the assessment of landscape responses to climate change and human impact. Process geomorphology is related to field, laboratory and analytical methods of studying present-day processes (Baker, 1986). The landscape is thought of as a combination of elements related by flows of mass and energy. Analysis measures the inputs, outputs, transfers, and changes of these systems. Process geomorphology places emphasis on temporal and spatial variations in process rates; therefore their nature will be influenced by a change in any of these variables (Ritter et al., 2011). When the time is not sufficient to measure rates, rates for the longer term are inferred from the results of a group of processes (Favis-Mortlock, 2013). Quantification of rates represents the main tool for investigation in process geomorphology because it provides a useful way to simplify the complexity (Baker, 1986).

Climatic geomorphology is mainly related to the idea that there are recognisable sets of landforms and geomorphic processes associated with different climatic regimes. The significance of climate changes depends on the duration and magnitude of the changes (Summerfield, 1991). Climatic geomorphology is based on the concept that modern relief-forming mechanisms change as a function of climate, and their relief products define major morphoclimatic zones (Baker, 1986). The occurrence of landforms in climatic environments in which they could not have developed laid the groundwork for climatic geomorphology (Tricart and Cailleux, 1972; Bremer, 1988). Climatic geomorphology played an important role in earth sciences, but the weakness of the approach is that the generalisations obtained from regional and climatic zonation are made mainly on the basis of forms and inadequate sampling of river basin data (Slaymaker, 2009).

Process geomorphology is a very useful approach for local or process-based studies and is mainly related to micro- and meso-scale of space and time. On the other hand, climatic geomorphology is related to regional or global scale processes and it uses past climatic data for explanations, so space and time scales are much more extended than they are in process geomorphology.

5. Forecasting and prediction

The knowledge of the future is directly related to the concept of forecasting, which is the process of producing statements about events whose actual outcomes have not yet been observed or measured, and it involves what will happen under specific conditions. Forecasting methods can be divided into statistical forecasting, related to quantitative models, and judgmental forecasting, which incorporates intuitive judgments, opinions and subjective probability estimates (Wright et al., 1996). In forecasting, data must be updated to provide as accurate a forecast as possible. All forecasting methods involve some judgment because they play a primary role in human reasoning, so statistical results are often adjusted in accordance with expert judgment (Bunn and Wright, 1991). Uncertainty is central to forecasting and usually its degree is provided. Uncertainty is a state of having limited knowledge where it is impossible to precisely measure the existing state, the future outcome, or any other outcomes (Shi, 2010).

Numerical modelling is still one of the most-used approaches to driving spatial and temporal extended knowledge of landscape evolution (Martin and Church, 2004). The details incorporated into the equations of the numerical models have to be proportionate with the scale considered for the studied process. Validation, verification, calibration and confirmation are fundamental in model implementation.

Sensitivity analysis, which evaluates how the output uncertainty of a numerical model, depends upon different sources of uncertainty in the inputs and is often run together with the uncertainty analysis. In particular, the sensitivity analysis tests the robustness of a model, searches for errors, evaluates key variables of process operation, and can be undertaken within a modelling framework (Martin and Church, 2004).

Forecasting methods can use historic data to determine the direction of future trends as a result of studying and analysing of available pertinent data. The method used for prediction can overlap, but they can be distinguished in terms of likelihood and comprehensiveness (Carter et al., 2007).

Artificial experiments provide an overview of the future that follows a coherent logic in order to study a particular process, with no relation to plausibility (Carter et al., 2007).

The scenario analysis is a method of analysing possible future events by studying possible alternative possible outcomes. The type of analysis was divided into five classes by Carter et al. (2001): climate, socio-economics, land-use/land-cover, and other environmental and sea level changes. A scenario analysis does not try to predict one exact picture of the future, but it presents several alternative future projections and provides a range of possible future outcomes with the development paths leading to the outcomes (Steffen et al., 2004). The scenario analysis does not use extrapolation from the past, so it does not rely on historical data and does not expect past observations to remain valid in the future. It tries to consider possible developments and turning points that may only be related to the past in order to show possible future outcomes. This approach uses a global change scenario, usually for 50–100 years, to drive models of change in the environment. Integrated methods allow the interaction of several global change drivers and feedbacks of impacts/consequences within the scenarios, which are considered to be changing themselves.

Probabilistic impact studies were used to evaluate the impacts of climate change in Europe (Hewitt and Griggs, 2004), and to study the impact on water resources (Jones et al., 2005) and freshwater ecology (Preston, 2006). The impact assessment approach selects a particular environmental parameter, such as climate change, and tries to identify the most important consequences for a variety of properties. On the contrary, the vulnerability assessment approach selects a particular group or unit of concern, tries to evaluate the risk of specific adverse outcomes for that group due to a variety of stresses, and identifies a range of factors that may reduce response capacity and adaptation. Impact studies can be very useful when they are able to focus on a single stress that dominates a system's response. These approaches suffer from a number of limitations related to the propagation of uncertainties, to problems in identifying and simulating threshold effects and nonlinearities, or difficulties in handling multiple interacting stresses (Steffen et al., 2004). Moreover, climate feedback mechanisms within the Earth system can enhance or reduce the effects, and their magnitudes are much more uncertain (Hegerl and Stott, 2014).

6. Discussion of the relationships between present data and future trends

Many recent case studies, such as the increased or irreversible ice melting trends, highlighted significant uncertainties about the relationships between present and future forecasting. Only some decades ago, model assumptions predicted trends very different from the observed rates, as a result of both laboratory studies and field data (Haff, 1996). Some processes, such as CO_2 emissions, have increased faster than the more pessimistic predictions guessed and are now widely accepted as to be out of scale. The IPCC 2013 Report indicated that human activities are mainly responsible for this trend, while Steffen et al. (2004) highlighted no analogue trends since the Mid-Quaternary. The 2013 Arctic summer melting was unexpected even based on the more pessimistic predictions, with a dramatic dropped in the ice coverage (Scudellari, 2013). The Arctic summer melting could be responsible for the intensification of precipitations in Europe, as suggested by Screen (2013). The repeated strong rains that heavily hit Southern England during the winter of 2013–2014 produced large flooding, almost matching the historical records that began in 1766 (Source: Environmental Agency, Google). Also, in Serbia and Bosnia, during spring 2014, the BBC reported that ‘three months' worth of rain had fallen on the Balkans, producing the worst floods since rainfall measurements began 120 years ago. This could be the ‘straw that broke the camel's back’, a signal that other processes may approach the tipping point, causing sooner or later the emergence of other ‘out-of-scale’ Earth surface processes trends. Scheidegger (1983) suggested that significant deviations from balanced conditions could force the systems to self-reinforce. Although the precise amount of increasing in the global mean temperature is highly uncertain (Sherwood et al., 2014), extreme atmospheric events, such as strong hurricanes or the trends of rain intensification, together with resulting flooding, seem to either be in an early stage or near the threshold, but may soon follow the same ever-increasing trends. Even if the forcing of these ‘out-of-scale’ processes is not linked to human activities, the empirical and theoretical problems, discussed in this works, still remain unsolved because the over-scaled systems can hardly be explained using our common conceptual frameworks.

In a period of fast climatic change, other processes are considered to be in a ‘normal state’, but their real state might not be measured. For example, limestone surfaces in the Classical Karst landscape start to become completely covered by lichens or mosses, so micro-erosion measures are either hardly collected or totally prevented (Furlani et al., 2009). This indicates that many present-day processes are probably going ‘out-of-scale’ or they are changing their trends compared to measured historical records. This means that statistically-based prediction models will struggle to include new ‘out-of-scale’ data, because of the resilience of near-past trends. The fact that processes are changing faster than the more pessimistic predictions highlights ‘the low reliability’ of past and present-day forecasting modelling. This paradoxically occurs in a ‘present’ dominated by the collecting of a huge amount of data that unconsciously reassures us about our future capabilities in predictions. Despite the fact that the non-uniform distribution of data over the time represents a challenge, the intensity and accuracy of the present-day environmental data sampling are very high, also when compared to the more recent past, such as the last 10 years. Reliance on a very short period of detailed instrumental records and a long proxy system with a resolution not comparable to brief time data can give a false sense of the true variability of the earth System (Steffen et al., 2004). How to correctly input an exponentially large amount of data constitutes an intrinsic difficulty in every analysis based on time series without any guesses of the underlying dynamics. This represents a problem for all the methods using the frequency of sequences of states to evaluate the average of observables, in particular analogues with past states (Cecconi et al., 2012). The great uncertainty that can result from measuring overscaled processes, or ‘near-boundary’ processes, will propagate and increase in the forecasting output, so ‘big data computation’ will not automatically increase our ability to predict future process trends. In any case, the Anthropocene can be considered an era of post-normal science (Funtowicz and Ravetz, 1993, 2003), in which traditional methodologies of interpretation of the past and forecasting of the future can become ineffective due to an increase of uncertainty.

In present time, where rates and magnitudes of Earth's process changes are unprecedented in Earth's recent history, the forecasting uncertainty related to the non-linearity of the system responses has certainly increased (Knight and Harrison, 2014). Empirical problems are related to the significance of the present since their relationships involve the most direct and particular observations, from limited to larger scales, from the beginning of historical observations and the measurements of the processes. Despite decades of detailed direct observations, much attention returns to the difficulty in extrapolating trends from these results and to developing successful models of process trends evolution, especially if we accept that some thresholds are already or close to being passed.

7. Conclusions

The forecast of future trends in Earth surface processes has to be related to the knowledge of present-day processes. The concept that 'the present is the key to the future' implies that we know enough about the present to be able to extend our knowledge forward to focus on the future. It is not possible to foresee the future because the future, as mentioned earlier, is not an objective entity, but it is possible to see the future within the present, which is represented by present-day processes and forms. The present is still the key to the future, only if we are able to increase the solidity of the key that is represented by our knowledge: particularly in terms of the conceptual explanation of the relationship between present and future surface processes. Even if science, as suggested by Baker (2007), cannot aspire to certainty in the prediction of specific hazard outcomes, this epistemological concept may be limited by the current or near-future state of some processes. In other words, we have a lot of data providing a very precise background for the present, but we need to improve the conceptual framework to right analyse and use data in an organic way. Many models probably need to be re-calibrated against the outcomes of present-day processes, since the future may not echo the present or the past. A major question is: "do we have enough time to collect significant data if the degree of change is so fast?" Quickly changing trends are a major problem for the present, and for the temporal dimension, which we usually use to build the knowledge, explanations, and predictions. Present-day measurements and observations could be scarcely significant and add uncertainty to the forecasting. The need for reducing the uncertainty in the forecasting requires a deep rethinking of the epistemological foundations of the earth sciences in order to consider also 'out-of-scale' discontinuity. Far from giving a final answer, we underline that surveying, measuring and modelling the present-day trends are very important actions, but not sufficient enough, even when aided by big-data power calculations. Today, the conceptual debate should search for an underlying simplicity of the Earth system that can also explain very fast changing patterns. Being aware of the problems that arise from the 'current state' and the increasing nonlinearity of process responses, may at least provide some additional epistemic reflections for Earth scientists.

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References

Abram, N.J., Mulvaney, R., Wolff, E.W., Triest, J., Kipfstuhl, S., Trusel, L.D., Vilmeux, F., Fleet, L., Arrowsmith, C., 2013. Acceleration of snow melt in an Antarctic Peninsula ice core during the twentieth century. Nat. Geosci. 6, 404–411.
Alexander, S., 1920. Space, Time, and Deity. Macmillan & Co Ltd., London.
Allen, P., 2005. Striking a chord. Nature 434, 961.
Anderson, J., 2008a. The future landscape. Inst. Future Stud. 5, 1–18.
Anderson, C., 2008b. The end of theory: the data deluge makes the scientific method obsolete? Wired Magazine. 23rd June. http://archive.wired.com/science/discoveries/magazine/16-07/pb_theory.
Baker, V.R., 1986. Introduction: Regional Landforms Analysis. In: Short Sr., N.M., Blair Jr., R.W. (Eds.), Geomorphology from Space: A Global Overview of Regional Landforms. United States Government Printing, NASA.
Baker, V.R., 1996a. Pragmatic roots of American Quaternary geology and geomorphology. Geomorphology 16, 197–215.
Baker, V.R., 1996b. Modeling global change: why geologists should not let "system" come between Earth and science. GSA Today 6 (5), 8–11.
Baker, V.R., 1996c. Hypotheses and Geomorphological Reasoning. In: Rhoads, B.L., Thorn, C.E. (Eds.), The Scientific Nature of Geomorphology, pp. 58–85.
Baker, V.R., 1998. Catastrophism and uniformitarianism: logical roots and current relevance in geology. In: Blundell, D.J., Scott, A.C. (Eds.), Lyell: in the Past is the Key to the Present. Special Publications 143. Geological Society, London, pp. 171–182.
Baker, V.R., 1999. Geosemiosis. Bull. Geol. Soc. Am. 111, 633–645.
Baker, V.R., 2007. Flood hazard science, policy, and values: a pragmatist stance. Technol. Soc. 29, 161–168.
Baker, V.R., 2012. Terrestrial analogs, planetary geology, and the nature of geological reasoning. Planet. Space Sci. 95, 5–10.
Baker, V.R., Twidale, C.R., 1991. The reenchantment of geomorphology. Geomorphology 4, 73–100.
Berggren, W.A., van Couvering, J.A., 1984. Catastrophes and Earth History. The New Uniformitarianism. Princeton University Press, Princeton.
Bindoff, N.L., Stott, P.A., AchutaRao, K.M., Allen, M.R., Gillett, N., Gutzler, D., Hansingo, K., Hegerl, G., Hu, Y., Jain, S., Mokhov, I.I., Overland, J., Perlwitz, J., Sebbari, R., Zhang, X., 2013. Detection and attribution of climate change: from global to regional. In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Doschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, pp. 867–952.
Bloom, A.L., 2002. Teaching about relict, no-analog landscapes. Geomorphology 47, 303–311.
Bokulich, A., 2013. Explanatory Models Versus Predictive Models: Reduced Complexity Modeling in Geomorphology. In: Karakostas, V., Dieks, D. (Eds.), Perspectives and Foundational Problems in Philosophy of Science. The European Philosophy of Science Association Proceedings 2, pp. 115–128.
Bremer, H., 1988. Allgemeine Geomorphologie: Methodik-rundvorstellungen-Ausblick auf den Landschaftshaushalt. Verlin, Gebruder Borntrager.
Brown, J.D., 2004. Knowledge, uncertainty and physical geography: towards the development of methodologies for questioning belief. Trans. Inst. British Geographers NS29 pp. 367–381.
Bunn, D., Wright, G., 1991. Interaction of judgmental and statistical forecasting methods: issues and analysis. Manag. Sci. 37, 501–518.
Cai, W., Borlace, S., Lengaigne, M., van Rensch, P., Collins, M., Vecchi, G., Timmermann, A., Santoso, A., McPhaden, M.J., Wu, L., England, M.H., Wang, G., Guilyardi, E., Jin, F.-F., 2014. Increasing frequency of extreme El Nino events due to greenhouse warming. Nat. Clim. Chang. 4, 111–116.
Carter, T.R., La Rovere, E.L., Jones, R.N., Leemans, R., Mearns, L.O., Nakicenovic, N., Pittok, A.B., Semenov, S.M., Skea, J., 2001. Developing and Applying Scenarios. In: McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., White, K.S. (Eds.), Cambridge University Press, Cambridge, Cambridge, pp. 145–190.
Carter, T.R., Jones, R.N., Lu, X., Bhadwal, S., Conde, C., Mearns, L.O., O'Neill, B.C., Rounsevell, M.D.A., Zurek, M.B., 2007. New Assessment Methods and the Characterisation of Future Conditions. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp. 133–171.
Cecconi, F., Cencini, M., Falciani, M., Vulpiani, A., 2012. Predicting the future from the past: an old problem from a modern perspective. Am. J. Phys. 80 (11), 1001–1006.
Chamberlin, T.C., 1890. The method of multiple working hypotheses. Science 15, 92–96.
Chiodo, S., 2011. Io non cerco, trovo. Un empirismo contemporaneo. Bollati Boringhieri, Torino.
Chorley, R.J., Kennedy, B.A., 1971. Physical Geography: A Systems Approach. Prentice-Hall, London, p. 370.
Chorley, R.J., Schumm, S.A., Sugden, D.E., 1984. Geomorphology. Methuen, London.
Church, M., 2010. The trajectory of geomorphology. Prog. Phys. Geogr. 34, 265–286.
Commitee on Challenges and Opportunities in Earth Surface Processes, 2010. Landscapes on the Edge. New Horizons for Research on Earth's Surface. The National Academies Press, National Research Council, Washington.
Cox, N.J., 2006. Assessing agreement of measurements and predictions in geomorphology. Geomorphology 76, 332–346.
Cox, N.J., 2007. Kinds and problems of geomorphological explanation. Geomorphology 88, 46–56.
Crutzen, P.J., Stoermer, E.F., 2000. The 'Anthropocene'. Global Change Newsl. 41, 17–18.
Cullingford, R.A., Davidson, D.A., Lewin, J., 1980. Timescales in Geomorphology. John Wiley and Sons, Chichester.
EPICA Community Members, 2004. Eight glacial cycles from an Antarctic ice core. Nature 429, 623–628.
Favis-Mortlock, D. 2013. Systems and Complexity in Geomorphology, in: Shroeder, J. (Editor in Chief), Orme, A.R., Sack, D. (Eds.), Treatise on Geomorphology. Academic Press, San Diego, CA, vol. 1, The Foundations of Geomorphology, 257-270.
Frodeman, R.L., 1995. Geological reasoning: geology as an interpretative and historical science. Bull. Geol. Soc. Am. 107, 960–968.
Funtowicz, S., Ravetz, J., 1993. Science for the post-normal age. Futures 25, 735–755.
Funtowicz, S., Ravetz, J., 2003. Post-normal science. In: Internet Encyclopaedia of Ecological Economics. Retrieved from, International Society for Ecological Economics http://isecoeco.org/pdf/pstnormsc.pdf.
Furlani, S., Cucchi, F., Forti, F., Rossi, A., 2009. Comparison between coastal and inland Karst limestone lowering rates in the northeastern Adriatic Region (Italy and Croatia). Geomorphology 104, 73–81.
Furlani, S., Ninfo, A., Zavagno, E., Paganini, P., Zini, L., biolchi, S., Antonioli, F., Coren, F., Cucchi, F., 2014. Submerged notches in Istria and the Gulf of Trieste: results from the Geoswim Project. Quat. Int. 332, 37–47.
Garner, H.F., 1967. Geomorphic analogs and climax morphogenesis. Ark. Acad. Sci. Proc. 21, 64–76.

Giere, R.N., 1988. Explaining Science: A Cognitive Approach. Univ. of Chicago Press, Chicago, p. 321.

Gilbert, G.K., 1886. The inculcation of scientific method by example. Am. J. Sci. 31, 284–299.

Goudie, A., Viles, H., 2010. Landscapes and Geomorphology. A Very Short Introduction. OUP Oxford, p. 152.

Gould, S.J., 1965. Is uniformitarianism necessary? Am. J. Sci. 263, 223–228.

Gregory, R.J., 2010. The Earth's Land Surface: Landforms and Processes in Geomorphology. SAGE Publication Ltd.

Haff, P.K., 1996. Limitations on Predictive Modeling in Geomorphology. In: Rhoads, B.L., Thorn, C.E. (Eds.), The Scientific Nature of Geomorphology: Proceedings of the 27th Binghamton Symposium in Geomorphology held 27–29 September 1996. John Wiley & Sons Ltd., pp. 337–358.

Haff, P.K., 2003. Neogeomorphology, prediction, and the anthropic Landscape. Geophysical Monograph 135. AGU.

Hargreaves, J.C., Annan, J.D., 2002. Assimilation of paleo-data in a simple Earth system model. Clim. Dyn. 19, 371–381.

Hegerl, G., Stott, P., 2014. From past to future warming. Science 343, 844.

Held, I., 2014. Simplicity and complexity. Science 343, 1206–1207.

Hewitt, C.D., Griggs, D.J., 2004. Ensemble-based predictions of climate changes and their impacts. EOS 85, 566.

Holton, G., 1973. In: Holton (Ed.), Thematic Origins of Scientific Thought: Kepler to Einstein Harvard U.P., Cambridge, Mass.

Hooykaas, R., 1963. Natural Law and Devine Miracle: The Principle of Uniformity in Geology, Biology, and Theology. Brill, E.J, Leiden.

Huggett, R.J., 1997. Catastrophism. Asteroid, Comets, and Other Dynamics Events in Earth History. Verso, London.

Huggett, R.J., 2007. A history of the systems approach geomorphology. Geomorphol. Relief Processus Environ. 2, 145–158.

Huggett, R.J., 2011. Fundamentals of Geomorphology. Routledge Fundamentals of Physical Geography 3rd edition. .

Hughes, T.P., Carpenter, S., Rockström, J., Scheffer, M., Walker, B., 2013. Multiscale regime shifts and planetary boundaries. Trends Ecol. Evol. 28 (7), 389–395.

Inkpen, R.J., 2005. Science, Philosophy and Physical Geography. Routledge, London.

Inkpen, R.J., 2008. Explaining the past in the geosciences. Philosophia 36, 495–507.

Inkpen, R., Turner, D., 2012. The topography of historical contingency. J. Philos. Hist. 6, 1–19.

Jackson, P.W., 2006. The Chronologers' Quest. The Search for the Age of the Earth. Cambridge University Press, Cambridge.

Johnston, D., 1933. Role of analysis in scientific investigation. Geol. Soc. Am. Bull. 18, 44–45.

Jones, R.N., Durack, P., Page, C., Ricketts, J., 2005. Climate change impacts on the water resources of the Fitzroy River Basin. In: Cai, W. (Ed.), Climate Change in Queensland under Enhanced Greenhouse Conditions, Report 2004–05. CSIRO Marine and Atmospheric Research, Melbourne, pp. 19–58.

Kennedy, B.A., 2006. Inventing the Earth. Ideas on Landscape Development Since 1740. Blackwell Publishing, Oxford.

Kerr, R.A., 2013. A stronger IPCC Report. Science 342, 23.

Kirby, M.J., 2003. A consistent framework for modelling geomorphic processes and landform evolution. In: Wilcock, P.R., Iverson, R.M. (Eds.), Prediction in geomorphology, Geophysical Monograph Series, American Geophysical Union, pp. 95–102.

Knight, J., Harrison, S., 2014. Limitations of uniformitarianism in the Anthropocene. Anthropocene 5, 71–75.

Kuhn, T.S., 1962. The Structure of Scientific Revolutions. University of Chicago Press, Chicago, Ill.

Kundzewicz, Z.W., Ulbrich, U., Brücher, T., Graczyk, D., Krüger, A., Leckebush, G.C., Menzel, L., Pińskwar, I., Radziejewski, M., Szwed, M., 2005. Summer floods in Central Europe: climate change track? Nat. Hazards 36, 165–189.

Kundzewicz, Z.W., Pinskwar, I., Brakenridge, G.R., 2012. Large floods in Europe, 1985–2009. Hydrol. Sci. J. 58 (1), 1–7.

Lane, S.N., 2013. 21st century climate change: where has all the geomorphology gone? Earth Surf. Process. Landf. 38, 106–110.

Lenaerts, J.T.M., van Angelen, J.H., van den Broeke, M.R., Gardner, A.S., Wouters, B., van Meijgaard, E., 2013. Irreversible mass loss of Canadian Arctic Archipelago glaciers. Geophys. Res. Lett. 40, 870–874.

Lenton, T.M., 2013. Environmental tipping points. Annu. Rev. Environ. Resour. 38, 1–29.

Lenton, T.M., Ciscar, J.C., 2013. Integrating tipping points into climate impact assessments. Clim. Chang. 117 (3), 585–597.

Lenton, T.M., Williams, H.T., 2013. On the origin of planetary-scale tipping points. Trends Ecol. Evol. 28 (7), 380–382.

Lunt, D.J., Elderfield, H., Pancost, R., Ridgwell, A., Foster, G.L., Haywood, A., Kiehl, J., Sagoo, N., Shields, C., Stone, E.J., Valdes, P., 2013. Warm climates of the past—a lesson for the future? Philos. Trans. R. Soc. A Math. Phys. Eng. Sci. 371, 20130146.

Lyell, C., 1830. The principles of geology. Being an Attempt to Explain the Former Changes of the Earth's Surface, by Reference to Causes Now in Operation. John Murray, London.

Martin, Y., Church, M., 2004. Numerical modelling of landscape evolution: geomorphological perspectives. Prog. Phys. Geogr. 28 (3), 317–339.

Mead, G.H., 1932. Emergence and identity. In: Murphy, A.E. (Ed.), The Philosophy of the Present, La Salle. Open Court 3, pp. 32–46.

Meehl, G.A., Goddard, L., Murphy, J., Stouffer, R.J., Boer, G., Danabasoglu, G., Dixon, K., Giorgetta, M.A., Greene, A.M., Hawkins, E., Hegerl, G., Karoly, D., Keenlyside, N., Kimoto, M., Kirtman, B., Navarra, A., Pulwarty, R., Smith, D., Stammer, D., Stockdale, T., 2009. Decadal prediction. Can it be skillful? Am. Meteorol. Soc. 1467–1485.

Millar, S.W.S. 2013. Spatial and Temporal Scales in Geomorphology, in: Shroeder, J. (Editor in Chief), Orme, A.R., Sack, D. (Eds.), Treatise on Geomorphology. Academic Press, San Diego, CA, vol. 1, The Foundations of Geomorphology, 130-145.

Mouginot, J., Rignot, E., Scheuchl, B., 2014. Sustained increase in ice discharge from the Amundsen Sea Embayment, West Antarctica, from 1973 to 2013. Geophys. Res. Lett. 41 (5), 1576–1584.

Oliver, J.E., 1991. The Incomplete Guide to the Art of Discovery. Columbia University Press, New York.

Oreskes, N., Shrader-Frechette, K., Berlitz, K., 1994. Verification, validation, and confirmation of numerical models in the Earth sciences. Science 263, 641–646.

Orme, A.R., 2002. Shifting paradigms in geomorphology: the fate of research ideas in an educational context. Geomorphology 47, 325–342.

Orme, A.R. 2013. The Scientific Roots of Geomorphology before 1830, in: Shroeder, J. (Editor in Chief), Orme, A.R., Sack, D. (Eds.), Treatise on Geomorphology. Academic Press, San Diego, CA, vol. 1, The Foundations of Geomorphology, 11-36.

Oxford Dictionaries, 2014. Oxford Dictionary of English. Oxford University Press (on-line version).

Paine, A.D.M., 1985. “Ergodic” reasoning in geomorphology: time for a review of the term? Prog. Phys. Geogr. 9, 1–15.

Petit, J.R., Jouzel, J., Raynaud, D., Barkov, N.I., Barnola, J.M., Basile, I., Bender, M., Chappellaz, J., Davis, M., Delaygue, G., Delmotte, M., Kotlyakov, V.M., Legrand, M., Lipenkov, V.Y., Lorius, C., Pepin, L., Ritz, C., Saltzman, E., Stievenard, M., 1999. Climate and atmospheric history of the past 420,000 years from the Vostok Ice Core, Antarctica. Nature 399, 429–436.

Phillips, J.D., 2006. Evolutionary geomorphology: thresholds and nonlinearity in landform response to environmental change. Hydrol. Earth Syst. Sci. 10, 731–742.

Phillips, J.D., 2007. The perfect landscape. Geomorphology 84, 159–169.

Phillips, J.D., 2012. Storytelling in Earth Sciences: the eight plots. Earth Sci. Rev. 115, 153–162.

Pigliucci, M., 2009. The end of science? EMBO Rep. 10 (6), 534.

Power, S.E., 2009. A philosophical introduction to the experience of time. Neuro Quantology 7 (1), 16–29.

Preston, B.L., 2006. Risk-based reanalysis of the effects of climate change on U.S. cold-water habitat. Clim. Chang. 76, 91–119.

Pretis, F., Allen, M., 2013. Breaks in trends. Nature 6, 992–993.

Ratcliffe, J.W., 1983. Notions of validity in qualitative research methodology. Sci. Commun. 5 (2), 147–167.

Rhoads, B.L., Thorn, C.E., 1993. Geomorphology as science: the role of theory. Geomorphology 6, 287–307.

Rhoads, B.L., Thorn, C.E., 1994. Contemporary philosophical perspectives on physical geography with emphasis on geomorphology. Geogr. Rev. 84, 90–101.

Rhoads, B.L., Thorn, C.E., 1996. The Scientific Nature of Geomorphology. Wiley, Chichester.

Rice, S.P., Macklin, M.G., 2008. Geomorphology and Earth system science: a reflection. Earth Surf. Process. Landf. 33, 2118–2120.

Richards, K.S., 1990. ‘Real’ geomorphology. Earth Surf. Process. Landf. 15, 195–197.

Richards, K.S., 2011. The Field. In: Agnew, J., Livingstone, D.N. (Eds.), The SAGE Handbook of Geographical Knowledge. SAGE Publication Ltd., pp. 53–63.

Rignot, E., Mouginot, J., Morlighem, M., Seroussi, H., Scheuchl, B., 2014. Widespread, rapid grounding line retreat of Pine Island, Thwaites, Smith and Kohler glaciers, West Antarctica from 1992 to 2011. Geophys. Res. Lett. 41 (10), 3502–3509.

Ritter, D.F., Kochel, R.C., Miller, J.R., 2011. Process Geomorphology. Fifth edition. Waveland Press, Inc., Long Grove, p. 652.

Scheidegger, A.E., 1983. Instability principle in geomorphic equilibrium. Z. Geomorphol. NF27 (27), 1–19.

Schumm, S.A., 1977. The Fluvial System. John Wiley and Sons, New York, p. 338.

Schumm, S.A., 1985. Patterns of alluvial rivers. Annu. Rev. Earth Planet. Sci. 13, 5–27.

Schumm, S.A., 1991. To Interpret the Earth: Ten Ways to Be Wrong. Cambridge University Press, Cambridge.

Screen, J.A., 2013. Influence of Arctic sea ice on European summer precipitation. Environ. Res. Lett. 8, 044015.

Scudellari, M., 2013. An unrecognizable arctic. Global Climate Change, Vital Signs of the Planet. NASA.

Sendra, A., Reboleira, A.S.P.S., 2012. The world's deepest subterranean community—Krubera-Voronja Cave (Western Caucasus). Int. J. Speleol. 41, 221–230.

Shea, J.H., 1982. Twelve fallacies of uniformitarianism. Geology 10, 455–460.

Sherwood, S.C., Bony, S., Dufresne, J.-L., 2014. Spread in model climate sensitivity traced to atmospheric convective mixing. Nature 505, 37–42.

Shi, W., 2010. Principles of Modeling Uncertainties in Spatial Data and Spatial Analyses. CRC Press, Taylor & Francis Group, Boca Raton, Florida, USA.

Slaymaker, O., 2009. The future of geomorphology. Geogr. Compass 3 (1), 329–349.

Smith, B.D., Melinda, A.Z., 2013. The onset of the Anthropocene. Anthropocene 4, 8–13.

Starkel, L., 1999. Space and time scales in geomorphology. Geogr. Fis. Dinamica Quat. 3, 61–66.

Steffen, W., Sanderson, A., Tyson, P.D., Jager, J., Matson, P.M., Moore III, B., Oldfield, F., Richardson, K., Schnellnhuber, H.J., Turner II, B.L., Wasson, R.J., 2004. Global Change and the Earth System: A Planet Under Pressure. Springer-Verlag, New York, USA, p. 336.

Steffen, W., Persson, A., Deutsch, L., Zalasiewicz, J., Williams, M., Richiardson, K., Crumely, C., Crutzen, P., Folke, C., Gordon, L., Molina, M., Ramanathan, V., Rockstrom, J., Scheffer, M., Schellnhuber, H.J., Svedin, U., 2011. The Anthropocene: from global change to planetary stewardship. Ambio 40/7, 739–761.

Summerfield, M.A., 1991. Global Geomorphology. Pearson Education Limited, Edinburgh.

Sutton, J., 2012. Memory, The Stanford Encyclopedia of Philosophy. Edward N. Zalta.

Thorn, C.E., 1988. Introduction to Theoretical Geomorphology. Unwin Hyman, London.

Thornes, J.B., 1978. The character and problems of theory in contemporary geomorphology. In: Embleton, C., Brunsden, D., Jones, D.K.C. (Eds.), Geomorphology: Present Problems and Future Prospects. Oxford University Press, Oxford, pp. 14–24.

Thornes, J.B., Brunsden, D., 1977. Geomorphology & Time. Methuen & Co. Ltd., London, p. 208.
Tricart, J., Cailleux, A., 1972. Introduction to Climatic Geomorphology. Translated from the French by Conrad J. Kiewiet de Jonge. Longman, London.
Trimble, S.W., 2008. The use of historical data and artifacts in geomorphology. Prog. Phys. Geogr. 32 (1), 3–29.
Von Elverfeldt, K., 2012. System Theory in Geomorphology. Challenges, Epistemological Consequences and Practical Implications. Springer, Dordrecht.
Wilcock, P.R., Iverson, R.M., 2003. Prediction in geomorphology. Geophysical Monograph 135. AGU, pp. 3–11.
Williams, J.W., Jackson, S.T., Kutzbach, J.E., 2007. Projected distributions of novel and disappearing climates by 2100 AD. Proc. Natl. Acad. Sci. 104, 5738–5742.
Wright, G., Lawrence, M.J., Collopy, F., 1996. The role and validity of judgment in forecasting. Int. J. Forecast. 12, 1–8.
Zalta, E.N., Nodelman, U., Allen, C., Anderson, R.L., 2013. Time. Stanford Encyclopedia of Philosophy, Stanford.