Chapter

Introductory Chapter: Climates, Change, and Climate Change

John P. Tiefenbacher

"There is an infinite amount of hope in the universe … but not for us."
Franz Kafka, c. 1920

1. Introduction

Global warming is no hoax. It has been amply substantiated [1]. That is not to say that "science" knows everything there is to know about global warming, only that there is no doubt that it is happening and that it is indisputably due to human activities that have loaded unnatural levels of greenhouse gases into Earth's atmosphere over the last 200 years [2]. Global warming is generating many significant challenges that will affect humans' superficial comforts and threaten the foundations of our survival [3, 4]. Changing climates are only one of the complications that we will face. Some of the other complications are: rising sea levels; acidifying oceans; diminishing extents of components of our cryosphere, particularly glaciers, permafrost, Greenland's ice sheet, and the ice cap of Antarctica; changing distributions of fresh and saltwater; changes in habitat size (shrinking for native species and growing for invasive species) and distribution; the spreading of diseases that have been limited by climate conditions of the past; destabilization of ecological systems, particularly the loss of coral reefs; mismatches between soils and climates, hydrological patterns, plant and animal life, weather processes, and seasonality undermining global and local food production; and changing patterns of hazard related to and linked to all of these impacts that will dislocate and force relocation of human populations, causing further tumult [5].

While scientists have examined many analogs to the prospective consequences of global warming by studying isolated processes on isolated places at times when they were of rather limited concern, many of the emerging changes are challenging the limits of knowledge and understanding of how Earth's natural systems function. We often lack detail that might allow us to "predict" (we really need to be able to *project* the expected changes onto today's conditions and into) the future precisely and accurately so that we can design, plan, and direct our collective life-trajectories toward survival practices that are sustainable. The task is clear enough to know that most human beings have myopic, narrow, limited understandings and views of the consequences of global warming, and an even narrower and substantially superficial view of what climate change means to their lives, and what it means for the future for humans [6, 7].

This chapter discusses the concepts behind understandings of global warming and climate change. It emphasizes the need to encourage change that not only mitigates the behaviors that are contributing to the problem of global warming, but also promotes a deeper, more profound understanding of climate change, so that we can meaningfully probe the dark future to fathom what we can expect from global warming. The meaning of the term "climate change" may have already been lost as it has been commonly subsumed into the mistaken belief that *Earth's* climate is shifting to a new normal; like one is turning the dial and increasing the heat under the pot on a stove, inferring that it is simply a matter of turning down the flame. We must systematically obliterate and reconstitute its meaning in public discourse, so that an accurate meaning of "climate" and the ramifications of "change" can be applied to our worlds. As people come to viscerally understand climate change and its consequences, the change can be more intelligently imagined in terms of every geo-, bio-, social, and economic system one might depend upon, as well as on every product upon which one relies. The term "climate change" is used by some to scare (or at least motivate) people into "pro-climate" action [8] (because it is a threat to our existence), even though climate is not actually a tangible "thing" at all. It can be used and then casually dismissed by signifying that it is only a childish fear of a bogeyman (it is just a figment of *your* imagination) and that climate change is not real. Some arrogantly express their lack fear (because our might and our intellect make it easy to manage). The reality is probably far beyond either end of that spectrum: the changes we experience will be more profound than we can imagine and it would be easy to "fix" if we were to do what is needed and accept the long period of time for the world to right itself. But we cannot simply stop our greenhouse gas production and expect a miraculous return to normal (as many have long tended to believe) [9]. Normal is gone. And all of Earth's human and nonhuman inhabitants may not see a new "normal" for a very long time.

2. Climates, change, and changing climates

If one listens to or reads the media of journalists, commentators, and public servants (particularly politicians)—people from whom the public normally receives new information and upon which they (often) base their understanding of their lifeworld—it is evident that few of the messengers have accurate and clear grasps of the concept "climate," and yet they have a deep desire or feeling of responsibility to provide a clear explanation of climate to the public [10, 11]. The most egregious misapprehension of climate is that Earth has one (and only one). Our planet does not have "a climate." The climate is a conceptualization created to intellectually portray the combined conditions of temperature AND precipitation conditions of a region. Earth does have a "global" atmospheric temperature (this is how the globe's temperature can be said to be rising—global warming). But it is wrong to believe that there is a measure of global precipitation. In terms of water, Earth is a closed system. There is a fixed and finite amount of water on Earth and it circulates globally in all its forms (vapor, liquid water, and ice) constantly, we call this the hydrological cycle. Water changes state and spatial distribution continually because of seasons, atmospheric and oceanic circulation patterns, weather events, precipitation, evapotranspiration, and thermal conditions. The Earth has MANY climates. The number depends upon the mathematical detail, sophistication, and characteristics upon which climates are defined and distinguished.

The term "climate" is often (mis)used interchangeably with weather, particularly when people are talking about their personal, empirical (past and present) experiences of the conditions of the atmosphere in which they live. Their fundamental mistake is that they believe that it (climate) is a phenomenon, is tangible, that it is something "real" that people can viscerally experience, and that it can be sensed and measured in real-time. Climate, in fact, is not real. It is knowable through either of two methods: statistical analysis or inductive inference.

2.1 Knowing climate statistically

Climates are usually defined statistically. Climate is a mental visualization, if you will, of atmospheric tendencies devised to explain the differences and similarities between (large and small) terrestrial (i.e., land) regions of the world. A climate-classification system allows one to categorize climates by averages and ranges of temperatures, available moisture, and weather phenomena over (*at least*) 30-year periods. The most meaningful climate-classification schemes are based on large datasets containing long records (again, at least three decades' worth) of weather data distributed over Earth's terrestrial surface (oceans do not have climates in our conceptualization). Daily thermal and precipitation records are used to characterize "normal" weather conditions (i.e., tendencies) at and near each weather station (which are proxies for larger zones in lieu of a dense array of instruments measuring the atmosphere). Climates are also characterized by means, extremes, and seasonal patterns distinguished as regular occurrences of major shifts, or of extreme conditions, like frosts or freezes, monsoons, and hydrological droughts that occur annually. Why were climates created? The most basic need was to discern the opportunities and challenges one might expect for day-to-day and long-term survival and comfort. Having and knowing climates establishes a basis upon which we can consider our life-prospects, particularly for planning future activities (getting water, growing or gathering food, keeping our bodies healthy and maintaining our comfort) in the context of weather and seasonal weather patterns.

2.2 Knowing climate through inference

Climate statistics, however, do not magically reveal the implications of weather data. Even long ago, when Greeks talked about torrid, temperate, and frigid zones, they were reflecting on the prospects for or challenges of life in other regions of the world (naming parts as "summer-less," "intermediate," and "winterless" might predict opportunities and limitations for agriculture). Modern climates are much more sophisticated and more complicated, as is our need to know whether our more sophisticated and more complicated activities can be safely or profitably conducted in places around the world. In the absence of weather data upon which a classification schema can be based, scientists and nonscientists before them inferred climate conditions based on the empirical evidence on the ground, particularly on the vegetation, the least mobile occupant of any environment. The vegetation that grows anywhere can logically be regarded as the plants that have survived the conditions in that place. By observing the compositions of plant communities and considering each plant's characteristics (anatomy, physiology, and hardiness), one might inductively determine (using higher order, more sophisticated understanding of plant biology) the thermal and hydrological conditions that have prevailed in that place. Major ecosystem types are often associated with (and they even supply the names for) the spectral product of these variables: rainforest, tropical savanna, desert, steppe, and tundra are terms that are often used to identify "climates." So, it might not be difficult to understand how someone might believe that because plants are used to name climates and because plants are evident in the landscape, climate must be apparent … visible. We must be capable of perceiving climate right now.

The problem is, looks and logic can be deceiving. Some plants have features that may fit well in other places, in other ecosystems. Plants can be unnatural (due to invasion) in a place, perhaps promoted by natural and unnatural disturbances of landscapes. Some plants might have been introduced from other regions with markedly different climates. Transplants or invaders may be found outside of their normal zones, supported artificially for aesthetic purposes. Plants are not always the best indicators of climate. For example, certain characteristics (thick, moisture-rich tissue) of so-called succulent plants are commonly thought to be drought- and heat-resistant features. These plants might be most often found in arid and hot regions like deserts or in places that experience periods of drought each year. Every continent, other than Antarctica, is home to succulent species. But not all succulents reside in arid regions or in places having annual dry seasons. For example, *Opuntia humifusa* (the eastern prickly pear cactus) is found in southeastern Ontario, Canada (near Lake Huron) in the remnants of the Carolinian forest (a region that is certainly not a desert, certainly not hot, and not an arid place). Similarly, "evergreen" (non-deciduous) plants are found from the tropics to the subarctic (notwithstanding that some lack cones which distinguish conifers from other evergreens). In fact, humans have modified landscapes to the point where hydrophilic plants can be grown abundantly in desert climates, assuming that sufficient irrigation is provided. Plants (by themselves) are not perfect indicators of climate.

2.3 Recognizing climates is best left to science and scientists

Temperature and precipitation patterns and moisture and thermal regimes may, during any given week, month, year, or decade, depart from the norm and leave a false impression of a region's climate. Personal experience is not input into the process of climate classification. Only carefully and consistently collected data are used. One's personal observations about trends in weather (or climate) do not supersede (or even complement) scientific data because people are ill-equipped (eidetic memory or otherwise) to gather and analyze the factors upon which climates are based. Metrics of temperature and precipitation are significantly more precise, reliable, and consistent than personal observation. The data are also more durable. The data are likely to be different from place to place, and this creates patterns of difference across space. Some proximate places may have dramatically different, even contrasting, averages, extremes, and event frequencies. At some point at some distance from a weather station, the long-term conditions may be so different that they can reasonably said to be in different "climates." The variation of data gathered at set locations over time can be analyzed to tell us whether there has been change in local and regional climates.

Every location on Earth has a climate and locations are grouped into regions of similar conditions, ultimately yielding a global map of climate regions, which is a pastiche of similar and seemingly static conditions. It should be noted, however, that the limits of a climate are somewhat arbitrarily established (usually based on round numbers, like 20, 40, or 60 inches of precipitation, for instance). Periodically (perhaps each decade), the patterns of the local conditions can be reevaluated and the boundaries on the map of climate regions can be shifted to more accurately reflect the data for the most-recent 30-year period. This is usually done each decade (2020 is prompting a reconsideration of the map).

2.4 Knowing the agency of climate

Very importantly, "climate" is believed to determine many aspects of localities' natural environments. Climates (it is truer to say very long-term—centuries, millennia—weather conditions) influence soil development: soils form very slowly and reflect the prevailing physical and chemical conditions that affect weathering of the parent material and availability of organic matter from decomposing vegetation. Climate, then, also influences the types and abundance of flora and fauna that shape soil development. Climate dictates long-term water supplies. Plants, specifically trees, that live longer than the 30-year climate period also record the past's weather. They aid us in gaining an understanding of the distributions of past climates. Dendrological and palynological records provide additional pieces of information to the nature of the climates of the past.

Over very long periods (tens of thousands to millions of years), climates (and therefore soils) also reflect the planet's context—solar activity, axial rotation, revolution around the sun, and global events like asteroid impacts, eruptions of super volcanoes, periods of continental glaciation, etc.—which may destroy our ecosystems and perhaps even eliminate species from Earth. Climates of the past are imprinted on the landscape and in the lithology of the planet. These sources offer more, very lengthy records of the conditions of the distant past. It is the millennia-long records that enable us to compare past climates to contemporary climates to discern the radical modification of climates that is currently afoot. Climates are being wrenched from their old consistent conditions and the changes will have substantial influence on regional conditions into the distant future.

3. Change

As a verb, change can be either passive or active. It can refer to a one-time modification of one set condition to another setting. It is therefore passive, one and done (i.e., there was a change, or something has changed). Or it can refer to an ongoing process (in a sense, an evolution), a process that has not stopped and may never stop. Changing or being "in flux" can complicate circumstances when stable conditions (like a climate) are expected and are relied on to plan for short- or long-term futures.

3.1 Implications of change

For instance, to be successful in producing massive yields per hectare, modern commercial agricultural activities may require heavy commitments for capital and services that are investments based on forecasts of future production. To grow a specific crop may require specific tools, equipment, pesticides, fertilizers, minimum volumes of water, and other inputs. The fiscal nature of farming necessitates financial planning to survive each year and to survive in the long run. When the circumstances (both intrinsic—environmental, social, personal conditions, et al.—and extrinsic—conditions of markets, competition, labor and supply costs, consumer demand, et al.) of farming change, reevaluation of the plans is necessary. How these changes are occurring and what the long-term picture for the array of conditions may evolve are important aspects of the information that industrial agricultural producers desire for their decisions to continue, to modify their plans, or to quit the activity because they can expect it to fail, before they end up in debt. What if we can no longer be confident about our (old) assumption that "next year" will be much like this year, weather-wise? The extrinsic context of farming, in this example, is the foundation of the activity in which farmers participate. Most of these intrinsic and extrinsic conditions are anthropogenic and can be manipulated by people, by businesses, by trade, or by government actions and policies. But the environment is different—many environmental conditions, like seasonal or annual weather conditions, particularly extremes and changes to the periodicities and durations of conditions (growing seasons and plant phenology, for instance), may become insurmountable if they are continuing to change, particularly if the changes are unexpected or unpredictable [12]. Decisions may need to be made quickly, particularly if crop production is diminishing [13].

In the United States and Canada, as in many other parts of the world, the national and regional patterns of many economic sectors have evolved over several hundred years to fit into and thrive in specific environmental conditions, particularly regions' climates. More recently, agricultural development has used technological advancements and mechanical and economic efficiencies to reduce costs and increase profits and to establish roots in new places. We have seen the emergence of agricultural regions dedicated to specific crops (the Corn Belt, the Wheat Belt, the citrus-growing regions, fresh fruits and vegetables, wine growing) or to specific activities (dairying, cattle ranching) that coincide with climatic conditions that fit production best.

Modern societies and modern economies have been developed on assumptions about consistency in the patterns of nature, on the stability of natural systems, on the unwavering resilience of nature. But what happens when there are no longer patterns to depend upon?

3.2 Responding to change

It was observed during the development of the epistemological paradigm "systems analysis" in the 1960s that ecological communities can be stable in numerous alternative states [14]. Assuming the undisturbed landscape is the "ideal" state for a natural landscape, what happens when it is disturbed by humans' activities undertaken to live in or exploit that landscape? That disturbance of an ecosystem's conditions may lead to ecosystem responses, either returning to its "original" condition (i.e., a resilience response) or shifting to a new state with a new equilibrium of ecological relationships. The upshot of the revolution in thought was to clarify that there is extensive evidence of interactions between "systems" that produce positive and negative feedbacks. The experiences of pioneers, settlers, loggers, farmers, and landscape engineers demonstrate that people can have a profound influence on nature and that, though extinction of species or wholesale transformation of environments may not always result, human activities can cause significant disequilibria in the world [15].

Sudden change can be surprising and can disturb a system, particularly human economic and social systems. If it is only temporary change and the conditions return to the perceived "normal," the surprise may only have been troubling, not debilitating and destructive. Permanent change to a new condition, as some conceive of climate change, requires adaptation and the fomentation of resilience. Purveyors of this expectation think that they will only need to spend more money to cool their homes or that they will have to pay more for water because of the warming and drying of their weather patterns. But if the change to a new condition is only temporary and that change continues to move away from normal, perhaps even in nonlinear ways, then adaptation will need to be constant and resilience may be impossible. Conditions in the future may become unbearable and places may become uninhabitable because not only is climate changing, but so too are all of the other systems that are connected to and influenced by climates, like the changes that we continuously make to catch up to the new circumstances. What if the directions of the shifting conditions are not predictable? What if the changes seem to be chaotic, with rates of change constantly changing, and perhaps with retrograde shifts in some of the systems? The possibilities may become vast and unfathomable. Which adaptations will enable safety and survival? The information may be overwhelming, but systems-thinking can provide methods to understand how decisions about response to change can be made [16].

3.3 Ways not to respond to change

As soils are products of and are imprinted by the climate conditions of the geological past – it may take hundreds, if not thousands, of years to form a few centimeters of topsoil. A sudden shift in the climate at a location can create mismatches between weather regimes and soils. To survive, a farmer could shift to a different crop that fits the new meteorological reality, but that might have devastating economic financial impacts and there may be practical challenges [17]. Relocating the production of a specific agricultural crop to chase the "moving" climate may be a possibility if the land is accessible and free for the taking; this is how wildlife species occasionally respond to such changes [18]. But it is likely more difficult than one might imagine, particularly if the new location, with the right temperature and moisture regime, has inadequate soils (produced under dramatically different past climates) or soils that necessitate significant quantities of artificial inputs to grow the crop. Following the climate may be very difficult and unrealistic. Land ownership is an impediment to relocation of farming practices. Legal boundaries, political boundaries, social and cultural boundaries, and the logistical, infrastructural, and economic consequences and challenges in starting over, may prove to be insurmountable barriers. The choice may be to simply remain in place and change crops (i.e., adjust) or relocate and find ways to carry on (i.e., adapt). It is important to stress that even wild plants and animals cannot simply "move" and adapt with the changes [19]. There is often too much in their way, too.

Clearly, climate change would cause major interruptions in food production, globally. Completely giving in to the change and finding new ways to survive (because one rationally disposes of the luxuries and desires one had and accepts that it is most important to meet basic needs to survive) may be the most realistic use of human ingenuity to cope with new and evolving conditions if we choose not to mitigate the causes. This is an example of developing resilience. It used to be only the impoverished, landless, powerless, and desperate people who have lived this way for decades and centuries, but it may become reality for even those who were not impoverished, owned land, had power, and were not living in desperation [20]. Resilience at its most profound is the condition of learning to accept change by becoming immune to the threats, perhaps by simplifying life—coming to understand the difference between need and want, to have the fewest vulnerabilities possible, to survive by bending with the wind and flowing with the current, whichever directions they take you, to keep your head above the water until you find solid ground again.

Change may affect everybody and may impact every aspect of every life. The change to which one may be responding (like global warming-induced conditions, for instance) will also be impacting communities, societies, governments, other states of the world. There may be diminishing availability of assistance from friends, countrymen, strangers. The governments upon whom many depend for help may lack the resources to provide it. The structures of societies may begin to crumble. It may be every family, man, woman, and child for themselves as starvation, famine, poverty, dislocation, insecurity, and devolution ensue. An extreme future is no longer just science fiction. We are catching a glimpse of such a future in 2020 as the novel coronavirus "COVID-19" spreads around the world, disrupting normality. Perhaps it is a symptom of the changes that we have wrought.

An alternative may be to prevent what can be prevented before the changes become inevitable. We may preempt them so that they might not occur or will be muted. Instead of waiting for the forewarned changes, we could strive to understand their causes, and if possible, attenuate them. The prospects of forced adjustment, adaptation, and resilience may be so bleak and worrisome that the alternative, changing behaviors now to promote less future change, may be the preferred discomfort.

4. Climate change

So, global warming is happening and one of its consequences is that climates are changing. A warming Earth atmosphere-hydrosphere-biosphere system is not necessarily warming all climates. All of Earth's climates are not changing in the exactly the same ways (some may be warming, some drying, others becoming more hospitable to plant growth with longer growing seasons) or in the same directions (some may also be cooling, getting wetter, and seeing shorter growing seasons). And the pace of change is not consistent across space or time. Some are warming and some (particularly polar and high-latitude climates) are warming faster than others. Warming in Earth's polar regions is melting tundra permafrost [21], Arctic Ocean ice (and the Greenland ice sheet), and Antarctica's ice sheet. Antarctica's ice cap is shrinking in extent, it is thinning, and even hollowing out. The meltwaters from both poles are contributing to changes in ocean circulations, cooling of northward flowing warm currents like the Gulf Stream, furthering consequential shifts of atmospheric circulations from latitudinal to longitudinal flows in the northern hemisphere in the north Atlantic and in the Pacific [22]. The prospects of a colder Europe, caused by the diminishing flow of heat from the tropics, is troubling, given their regional agricultural production and dependence on regional production in many parts of the continent.

The belt of tropical climate (the intertropical convergence zone) is projected to expand due to increasing temperatures along the equator. This may intensify rainfall in the tropical rainforests and with added heat may widen the belt of rainforests and rainfall northward, southward, and upslope to higher elevations in mountainous areas, enabling spread of tropical weather conditions (hot and humid) that will last longer throughout the year [23]. The belt of low pressure will still migrate northward and southward with the progression of the astronomical seasons.

The expanded tropics may yield more and stronger tropical and subtropical storms (hurricanes, cyclones, typhoons), although the linkage of the changing "habits" of weather events to global warming is very tenuous [24, 25], primarily because weather is not climate. But this was one of the expected outcomes of global warming and changing climates expressed very early on in the discussion of the consequences of global warming as our experiences with subtropical storms is empirical (not theoretical), after all. We have not seen a rise in the number of storms annually, but the annual proportion of storms that are stronger does seem to be increasing. And another bit of a surprise to scientists, however, was a change in the storms themselves: they seem to be moving across Earth's surface (i.e., forward motion) more slowly, leading to longer and more devastating localized lashing by hurricane-force winds and extraordinarily heavy amounts of rainfall due to its increasing duration [26]. Both flooding and wind destruction have been increasing in the regions directly impacted by the storms. Warmer oceans strengthen and feed energy to extratropical storms, but they also swell (as water increases volume when it gets hotter and when it freezes) and inundate coastlines, adding to storm-surge problems on top of the flooding rains and high winds. We are finding that our present preparedness and planning for extratropical storms is being exceeded by the evolving nature of the storms. Future losses will be greater (and will spread farther into previously "safe" areas) and future costs for preparation, mitigation, and prevention of disasters will skyrocket alongside.

Sea-level rise is another problem on top of the complication of extratropical systems. Greater inundation extending further inland also "poisons" soils and water supplies with salty ocean water, causing additional problems, particularly for salt-intolerant vegetation (and people). Ocean water is also acidifying due to absorption of carbon dioxide (one of the three or four most important greenhouse gases) to create carbolic acid. Acidification is making ocean habitats less hospitable for ocean life like coral (another tangential consequence of global warming by greenhouse-gas loading of the atmosphere) [27]. Fish are one of the fundamental dietary proteins of people around the world. But fish stocks are declining, biodiversity is declining, and ocean-oriented coastal economies are declining globally. Some aquatic and terrestrial species will find ways to survive through biological adaptation, others may not [28]. But these consequences are technically not caused by changing climates, *per se*. They are warming-induced and are usually beyond the discussions had about "climate change." But as one might imagine, these are but a few of the changes produced by the problems derived from global warming.

5. Conclusion

Public discussions about contemporary human-induced global warming and climate change began to emerge in the early 1980s. Now, 40 years later, the discourse is mired in a polarized "debate," where those who desire action to counteract global warming and to prepare for changing climates are countered by a powerful minority of "deniers" and "skeptics" who refuse to even discuss the matter, because, they believe that the "problem" is not real (And even if it is, it is insignificant, because it is natural!) [29]. It is vital that we converse about the matter. Doing so is very fruitful [30]. It is crucial that the public (and many of the people who inform and "educate" the public) be inculcated with a deeper and clearer understanding of the concepts "climate," "change," and "climate change," by carefully, consistently, and meaningfully establishing standard definitions of these ideas and using them correctly all of the time. The implications of not understanding and not coming to terms with the threats we face are profound. The beliefs that we can empirically know "climate," that it refers to the entirety of "Earth's weather," that the "change" that might happen is either temporary or simply a one-and-done shift to a new steady-state condition, and that "climate change" means that it will be warmer everywhere on Earth in the coming decades, predetermine nonbelievers' responses, if they bother responding to global warming at all. At best, they expect that we may eventually need more air conditioning or assume we can just "move things" to more suitable places. Misunderstanding the basic terms of the problem begets a misunderstanding and a misinterpretation of the science behind the problem. Dismissing experts as elitist, calling global warming and climate change a hoax perpetrated by "the left" to destroy the economy, private wealth, freedom, and the world order, conservatives and libertarians push for collective social myopia and business as usual. Ironically, such an approach to the problems of global warming and changing climates will produce those very results.

Author details

John P. Tiefenbacher
Texas State University, San Marcos, Texas, United States of America

*Address all correspondence to: tief@txstate.edu

References

[1] Neukom R, Steiger N, Gómez-Navarro JJ, Wang J, Werner JP. No evidence for globally coherent warm and cold periods over the preindustrial common era. Nature. 2019;**571**:550-554. DOI: 10.1038/s41586-019-1401-2

[2] Crowley TJ. Causes of climate change over the past 1000 years. Science. 2000;**289**(5477):270-277. DOI: 10.1126/science.289.5477.270

[3] Vitousek PM. Beyond global warming—Ecology and global change. Ecology. 1994;**75**(7):1861-1876. DOI: 10.2307/1941591

[4] Dillon ME, Wang G, Huey RB. Global metabolic impacts of recent climate warming. Nature. 2010;**467**(7316):704-U88. DOI: 10.1038/nature09407

[5] Walther GR, Post E, Convey P, Menzel A, Parmesan C, Beebee TJC, et al. Ecological responses to recent climate change. Nature. 2002;**416**(6879):389-395. DOI: 10.1038/416389a

[6] Stamm KR, Clark F, Eblacas PR. Mass communication and public understanding of environmental problems: The case of global warming. Public Understanding of Science. 2000;**9**(3):219-237. DOI: 10.1088/0963-6625/9/3/302

[7] Whitmarsh L. What's in a name? Commonalities and differences in public understanding of 'climate change' and 'global warming'. Public Understanding of Science. 2009;**18**(4):401-420. DOI: 10.1177/0963662506073088

[8] Lehman B, Thompson J, Davis S, Carlson JM. Affective images of climate change. Frontiers in Psychology. 2019;**10**(960):1-10. DOI: 10.3389/fpsyg.2019.00960

[9] Sterman JD, Sweeney LB. Understanding public complacency about climate change: Adults' mental models of climate change violate conservation of matter. Climatic Change. 2007;**80**(3-4):213-238. DOI: 10.1007/s10584-006-9107-5

[10] Boykoff MT, Boykoff JM. Climate change and journalistic norms: A case-study of US mass-media coverage. Geoforum. 2007;**38**(6):1190-1204. DOI: 10.1016/j.geoforum.2007.01.008

[11] Carvalho A. Ideological cultures and media discourses on scientific knowledge: Re-reading news on climate change. Public Understanding of Science. 2007;**16**(2):223-243. DOI: 10.1177/0963662506066775

[12] Pfleiderer P, Schleussner CF, Kornhuber K, Coumou D. Summer weather becomes more persistent in a 2 degrees C world. Nature Climate Change. 2019;**9**(9):666-671. DOI: 10.1038/s41558-019-0555-0

[13] Sultan B, Defrance D, Iizmui T. Evidence of crop production losses in West Africa due to historical global warming in two crop models. Scientific Reports. 2019;**9**(12834):1-15. DOI: 10.1038/s41598-019-49167-0

[14] Lewontin RC. The meaning of stability. Brookhaven Symposium in Biology. 1969;**22**:13-23

[15] Wan XR, Jiang GS, Yan C, He FL, Wen RS, Gu JY, et al. Historical records reveal the distinctive associations of human disturbance and extreme climate change with local extinction of mammals. Proceedings of The National Academy of Sciences of the United States of America. 2019;**116**(38):19001-19008. DOI: 10.1073/pnas.1818019116

[16] Ballew MT, Goldberg MH, Rosenthal SA, Gustafson A, Leiserowitz A. Systems thinking as a pathway to global warming beliefs and attitudes through

an ecological worldview. Proceedings of the National Academy of Sciences of the United States of America. 2019;**116**(17):8214-8219. DOI: 10.1073/pnas.1819310116

[17] Khan Y, Bin Q, Hassan T. The impact of climate changes on agriculture export trade in Pakistan: Evidence from time-series analysis. Growth and Change. 2019;**50**(4):1568-1589. DOI: 10.1111/grow.12333

[18] Hofman-Kamińska E, Bocherens H, Drucker DG, Fyfe RM, Gumiński W, Makowiecki D, et al. Adapt or die—Response of large herbivores to environmental changes in Europe during the Holocene. Global Change Biology. 2019;**25**(9):2915-2930. DOI: 10.1111/gcb.14733

[19] Radchuk V, Reed T, Teplitsky C, van de Pol M, Charmantier A, Hassall C, et al. Adaptive responses of animals to climate change are Most likely insufficient. Nature Comunications. 2019;**10**(3109):1-14. DOI: 10.1038/s41467-019-10924-4

[20] Baarsch F, Granadillos JR, Hare W, Knaus M, Krapp M, Schaeffer M, et al. The impact of climate change on incomes and convergence in Africa. World Development. 2020;**126**(104699):1-13. DOI: 10.1016/j.worlddev.2019.104699

[21] Plaza C, Pegoraro E, Bracho R, Celis G, Crummer KG, Hutchings JA, et al. Direct observation of permafrost degradation and rapid soil carbon loss in tundra. Nature Geoscience. 2019;**12**(8):627-631. DOI: 10.1038/s41561-019-0387-6

[22] Zappa G. Regional climate impacts of future changes in the mid-latitude atmospheric circulation: A storyline view. Current Climate Change Reports. 2019;**5**(4):358-371. DOI: 10.1007/s40641-019-00146-7

[23] Colwell RK, Brehm G, Cardelus CL, Gilman AC, Longino JT. Global warming, elevational range shifts, and lowland biotic attrition in the wet tropics. Science. 2008;**322**(5899):258-261. DOI: 10.1126/science.1162547

[24] Coumou D, Rahmstorf S. A decade of weather extremes. Nature Climate Change. 2012;**2**(7):491-496. DOI: 10.1038/NCLIMATE1452

[25] Cutler MJ, Marlon J, Howe P, Leiserowitz A. Is global warming affecting the weather? Evidence for increased attribution beliefs among coastal versus inland US residents. Environmental Sociology. 2020;**6**(1):6-18. DOI: 10.1080/23251042.2019.1690725

[26] Chan KTF. Are global tropical cyclones moving slower in a warming climate? Environmental Research Letters. 2019;**14**(10):1040151-9. DOI: 10.1088/1748-9326/ab4031

[27] Pandolfi JM, Connolly SR, Marshall DJ, Cohen AL. Projecting coral reef futures under global warming and ocean acidification. Science. 2011;**333**(6041):418-422. DOI: 10.1126/science.1204794

[28] Diniz-Filho JAF, Bini LM. Will life find a way out? Evolutionary rescue and Darwinian adaptation to climate change. Perspectives in Ecology and Conservation. 2019;**17**(3):117-121. DOI: 10.1016/j.pecon.2019.06.001

[29] Weber EU, Stern PC. Public understanding of climate change in the United States. American Psychologist. 2011;**66**(4):315-328. DOI: 10.1037/a0023253

[30] Goldberg MH, van der Linden S, Maibach E, Leiserowitz A. Discussing global warming leads to greater acceptance of climate science. Proceedings of the National Academy of Sciences of the United States of America. 2019;**116**(30):14804-14805. DOI: 10.1073/pnas.1906589116