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Newsletter

Integrated Land Ecosystem - Atmosphere Process Study

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Extreme Events and Environments

International Geosphere-Biosphere Programme
GLOBAL IGBP CHANGE

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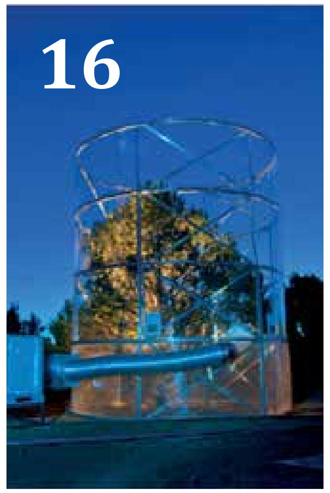

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Observations of increased tropical rainfall preceded by air passage over forests

In a new Nature publication, Spracklen *et al*. used satellite remote-sensing data of tropical precipitation and vegetation combined with simulated atmospheric transport patterns to assess whether forests actually have an influence on tropical rainfall. They found that for more than 60% of the tropical land surface, air that had passed over extensive vegetation in the preceding few days produced at least twice as much rain as air that has passed over little vegetation.

The article can be found here: http://www.nature.com/nature/journal/v489/n7415/full/nature11390.html

Future Earth forming its final structures

The nominations for the Future Earth Engagement Committee and the selection for the permanent, globally distributed secretariat take place during spring 2014, and the official website is ready to go live in the spring as well. The new Future Earth blog can be found at http://www.futureearth.info.

Intended to be a home for innovative new ideas and essential reading for everyone engaged in global sustainability, this online magazine will be a showcase and discussion forum for the latest ideas and developments in research in this area, both in the projects that form part of Future Earth's network and beyond.

Annual global carbon emissions estimated to have reached record 36 billion tonnes in 2013

Global emissions of carbon dioxide from burning fossil fuels were set to have risen again in 2013, reaching a record high of 36 billion tonnes - according to new figures from the International Geosphere-Biosphere Programme's Global Carbon Project.

More information on the global carbon budgets and trends can be found on website of Global Carbon Project: http://www.globalcarbonproject.org/carbonbudget/index.htm

New research project endorsed under iLEAPS umbrella

"Methane loss from Arctic: towards an annual budget of CH_4 emissions from tundra ecosystems across a latitudinal gradient" is a new interesting research project endorsed by iLEAPS. This project will be among the first efforts toward the estimation of a full annual budget of both CH_4 and CO_2 net emissions from three tundra ecosystems across a transect in Arctic Alaska. Of primary importance is the quantification of non-summertime CH_4 emissions because of the potentially large impact on overall climatic effects. This information has historically been very difficult to collect because of severe weather and remote monitoring stations. Recent advances in measurement technology will make these studies feasible in remote locations and under extreme weather conditions.

Climate extremes can negate the expected increase in terrestrial carbon uptake

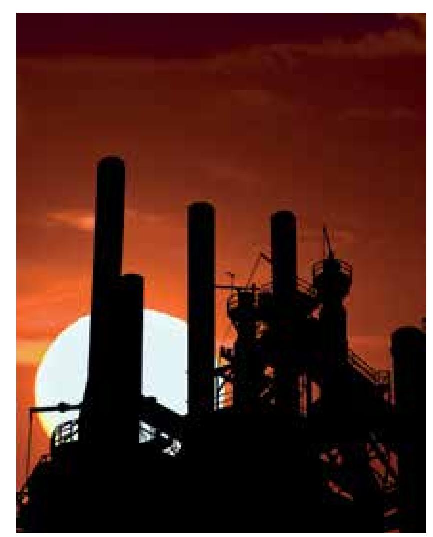
The terrestrial biosphere is a key component of the global carbon cycle and its carbon balance is strongly influenced by climate. Continuing environmental changes are thought to increase global terrestrial carbon uptake. But evidence is mounting that climate extremes such as droughts or storms can lead to a decrease in regional ecosystem carbon stocks and therefore have the potential to negate an expected increase in terrestrial carbon uptake. The article by M. Reichstein *et al.* explores the mechanisms and impacts of climate extremes on the terrestrial carbon cycle, and propose a pathway to improve our understanding of present and future impacts of climate extremes on the terrestrial carbon budget.

The article can be found here: http://www.nature.com/nature/journal/v500/n7462/full/nature12350.html

New phase for the European Alliance of Global Change Research Committees

In the 5th meeting of the European Alliance on 3-4 Dec 2013 in Helsinki, Finland was elected as the new chair country and a host for the secretariat for 2014-2016.

National committees have always been an integral part of the GEC programmes but now, under Future Earth, they will become important instruments for co-design and co-production of knowledge. Solutions to sustainability problems are local and depend significantly



on local conditions. As Future Earth aims not only at advancing understanding of global change and sustainability issues but also at contributing to solutions, it will require understanding of local economic and political systems and cultures and an access to local decision-makers and stakeholders that are instrumental in implementing the solutions. This can only be achieved through national bodies such as global change national committees.

The 6th meeting of the European Alliance will take place on 28-29 October 2014 in Switzerland.
www.euroalliance-globalchange.org

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Extreme events and environments - complementary components of global change research

The need to make informed guesses (that is, projections & scenarios) with respect to the response of the land biosphere to the global changes currently underway is a challenge that motivates much of the research in the IGBP/Future-Earth and iLEAPS contexts. Increasingly, a distinction is made between the possible impact of changes in the frequency and intensity of extreme events (such as droughts, flood, heat and cold waves, insect outbreaks), and changes in the mean climate with possible shifts in climatic zones where environmental conditions are more extreme. In extreme environments, such changes can expose new resources for human exploitation (such as new arable soil associated with receding ice cover; see Williams, this issue) with implications for productivity, and sustainability of fragile environments. Both, changes in climate extremes, and climate change in extreme environments, pose distinct challenges for research and society (Fig. 1). To a significant extent, meeting these challenges also requires that we improve our observation systems (Schimel and Cox, this issue), our dynamic vegetation and other models (Mahecha *et al.*, this issue), and our ability to reduce human pressure on the natural system (Cheeseman, this issue).

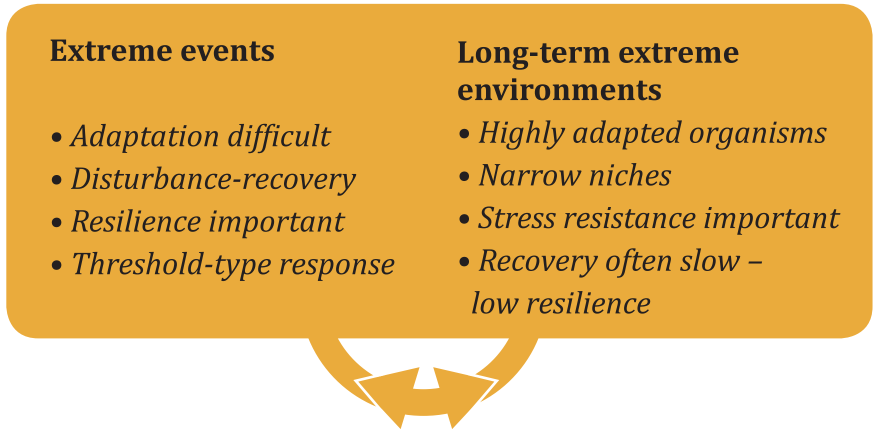
Climate extremes have been shown to be able to undo several years of carbon dioxide uptake by ecosystems [1] and globally integrated negative extremes in photosynthesis or gross primary production have been estimated to be on the order of the global land carbon sink [2]. On the other hand, the biosphere as a whole has been vigorously taking up CO_2 during the last decades [3-5], indicating that the effects of extreme events may be reversible and may be balanced by the biosphere at a global scale. However, if certain thresholds are passed (McDowell & Chamber, this issue), extreme events could lead to irreversible changes in organisms and ecosystems, and to mortality. As Mahecha *et al.* point out, the threshold is not necessarily a change in one variable only, for instance a hot or dry spell, but rather a multivariate boundary line, for instance hot and dry, or a surface representing different combinations of variables and their intensities within the environmental space considered.

In addition, continuously extreme environments (such as deserts, alpine and polar regions, salt-marshes or hot springs; Williams, Cheeseman) have led to a wide range of ecophysiological and structural adjustments [6] and biological adaptations (Cheeseman), yielding organisms and ecosystems that can survive under extreme conditions. Furthermore, although various extreme environments, such as deserts, exhibit low productivity and carbon stock, Schimel and Cox point out that in other cases very warm or very cold regions may have relatively low productivity, but they can accumulate large carbon stocks because, for example, primary productivity is enhanced relative to decomposition, or decomposition is depressed relative to productivity. Such aspects of extreme environments may therefore contribute to the resilience of the biosphere.

Finally, ecosystems and species in extreme environments, while fully adapted to such environments, may also operate near their limits (Cheeseman) and are therefore still threatened both by chronic climate changes and by unprecedented extreme events. In such cases, ecosystems in extreme environments may go extinct, but this can potentially be accompanied by compensating shifts of other extreme environments into milder ones.

Overall, recent research has clearly shown that both extreme events and environments must be considered when predicting the response of the biosphere to climate change. How strongly climate extremes will change the land biosphere remains largely elusive. It will depend on the rate of changes, both in mean climate and frequency of extreme events, and on the rate of adjustment and adaptation. The bottom line is that research in extreme environments can continue to tell us how adaptation can work, while unprecedented extreme events tell what happens when environmental conditions (suddenly) exceed the range organisms and ecosystems have adapted to.

Fig. 1. Contrasting aspects of extreme events versus extreme environments



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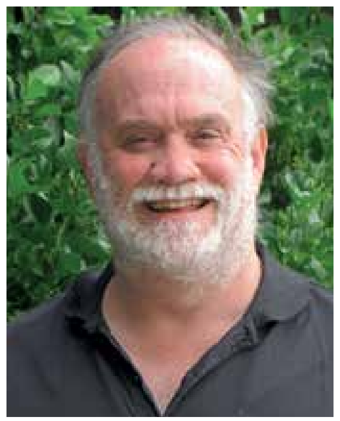
Permanently extreme environments and the need to observe the two poles of the carbon cycle



David Schimel is currently a Senior Research Scientist at the Jet Propulsion Lab, leading research focused on carbon-cycle climate interactions, combining models and observations. For the previous five years, Dr Schimel led the National Ecological Observatory Network (NEON) project, was responsible for the top-level science design, site selection and observing system simulations. Before this, Dr Schimel worked at the National Center for Atmospheric Research (NCAR) and the Max Planck Institute for Biogeochemistry in Jena, Germany. He served as convening Lead Author for the first Intergovernmental Panel on Climate Change (IPCC) assessment of the carbon cycle, and has since served as an Coordinating Lead Author four times, and as a Lead Author twice.

Peter Cox is co-chair of the IGBP (International Geosphere-Biosphere Programme) project AIMES (Analysis, Integration and Modelling of the Earth System), and Professor of Climate System Dynamics at the University of Exeter in the UK. His personal research has focused on interactions between the land-surface and climate, including the first climate projections to include vegetation and the carbon cycle as interactive elements. Peter Cox is a Lead Author on the (IPCC) 4th and 5th Assessment Report, and is also a member of the Science Advisory Group for the UK Department of Energy and Climate Change.

The influence of temporary climate extremes on the carbon cycle is attracting more and more attention. In recent years, heat waves and droughts have caused observable changes in regional and global carbon fluxes [1]. However, climate-related disturbances also include wildfires and insect outbreaks [2, 3]. By combining in situ and global analyses, we are increasingly able to quantify the influence of such extreme events. Furthermore, we now know that climate variations provide vital insights into the sensitivity of the carbon cycle to anthropogenic climate changes [4]. Such "Emergent Constraints" provide a bridge that links the measurement of short-term flux variations in projects such as iLEAPS (Integrated Land Ecosystem – Atmosphere Processes Study) to the modelling of long-term climate-carbon cycle feedbacks in projects such as AIMES.

The role of permanently extreme environments (such as drylands, deserts, regions with extreme rainfall or permafrost) is less obvious but equally important. As the climate changes, environments considered extreme relative to current conditions may become more or less common. For instance, the expansion of the arid zone could have significant effects on carbon storage if the zone expands into currently productive, high carbon ecosystems that then begin to lose carbon. However, woody biomass and carbon storage are also increasing in many arid ecosystems. As another example, zones of extreme rainfall may shift geographically as a result of the intensification of the hydrological cycle. This could affect regional-to-global storage of carbon directly, through temperate and tropical rainforest biomass, and indirectly through altered geomorphic processes.

In today's environment, most of the world's carbon storage occurs in environments that have extremes of temperature (low and high), rainfall and insolation (Fig. 1)! Tropical rainforests store large amounts of carbon because the long growing season, high rainfall, insolation and temperature allow high rates of plant growth and high carbon storage in biomass. High latitude ecosystems have low rates of plant growth, as a result of temperature, insolation and growing season length, but have even lower respiration rates, leading to high carbon storage in detrital material. These two zones are the north and south "poles" of the terrestrial carbon cycle and any change in their area or conditions is likely to influence the global carbon cycle.

The tropical forests have the ability to adjust carbon storage quickly since they have high rates of plant productivity, but the resulting carbon is largely stored in plant biomass (wood) that can decline or be lost quickly [5]. If disturbances increase oxidation of biomass through fire, losses can be essentially instantaneous. The combination of high productivity and short residence times of storage in biomass allow the tropics to respond quickly to climate shifts.

"As the climate changes, environments considered extreme relative to current conditions may become more or less common."

The polar regions are extreme in their climate, but also in their combination of insolation and temperature. The region of extreme winter cold is almost certain to decrease with warmer climates, but as noted in Williams (this issue), much else is less clear. As high-latitude ecosystems warm, the potential for respiration of the vast soil carbon reservoirs to increase is large, while the potential for GPP to increase may be limited by light and short sunlit season length [8]. This is one of the most worrisome tipping points in the Earth System, as it creates an environment where photosynthesis is limited to a shorter period than respiration, in the presence of large reservoirs of carbon.

The two poles of the carbon cycle present a great challenge to carbon scientists. The bulk of our carbon observing system is in the northern hemisphere mid-latitudes. For example about 85% of all eddy covariance sites are located between 30° and 50° N; similar statistics apply to most other carbon-related observations [9]. While the current network of ecosystem research sites spans climate space (temperature and precipitation) fairly well [10], the highest photosynthesis and carbon storage regions are sampled extremely sparsely compared to the mid-latitudes. The most diverse regions of the world, such as the humid tropics, where carbon responses to climate could be the most variable between species are the worst sampled!

The temperate mid-latitudes may have played a disproportionate role in recent carbon uptake [11], but they have relatively low stocks of carbon compared to the tropics and high latitudes and so are not forecast by models to play a major role in future carbon-climate feedbacks. The tendency of scientists and funding agencies in the developed world to prefer local projects has limited the acquisition of data in the crucial regions. But this is not the whole story. The cost and effort to observing carbon dynamics in the high and low latitudes is formidable, with limited access, to power and other infrastructure restricting the amount of data collection (for instance: http://www.zottoproject.org/, http://earthobservatory.nasa.gov/Features/LBA/), yet these extreme environments dominate carbon fluxes and storage and will dominate 21st century carbon cycle feedbacks.

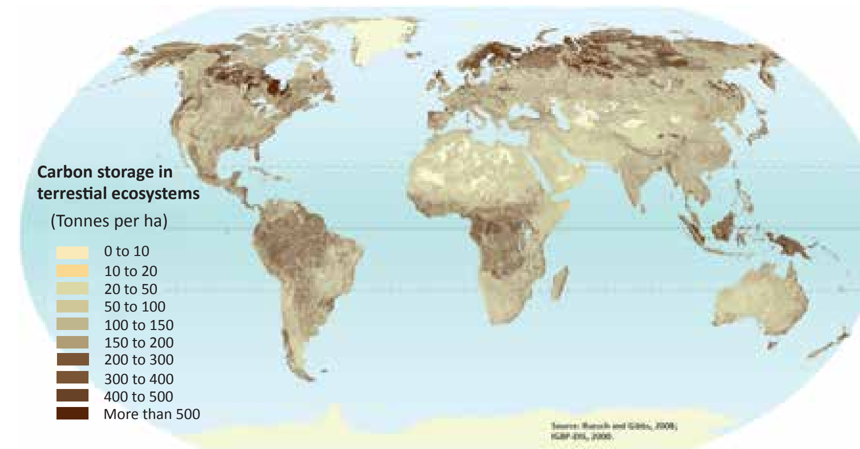


Figure 1. Mapped terrestrial carbon stocks, showing the concentration of high storage per unit area in high and low (tropical) latitude regions. These regions are crucial to future carbon-climate coupling yet are poorly understood and poorly observed (http://www.grida.no/publications/rr/natural-fix/page/3724.aspx).

Our current observations in the world's extremes of temperature and rainfall are inadequate to constrain models of the future, which continue to diverge [12]. Redoubled effort to sample these regions in situ is crucial (see, for instance, http://above.nasa.gov/) as are creative new remote sensing approaches (http://science.jpl.nasa.gov/projects/CARVE/). Hopefully this issue's highlighting of the challenges of understanding both temporal and geographic extremes will lead to increased focus in the iLEAPS and broader community of the gaps in the global science program and innovative efforts to address them. IGBP has tabled a plan that includes some of these elements,

"In today's environment, most of the world's carbon storage occurs in environments that have extremes of temperature, rainfall and insolation."

including a focus on under-sampled regions, careful coupling of in situ and remote observations and new partnerships to reduce sampling bias outside the developed world. The effort, dubbed the “Merton Initiative” [13], is an effort to focus the international science community’s attention on the opportunities resulting from a more integrated approach to global observations and field projects. iLEAPS can play a leading role in realising this vision!

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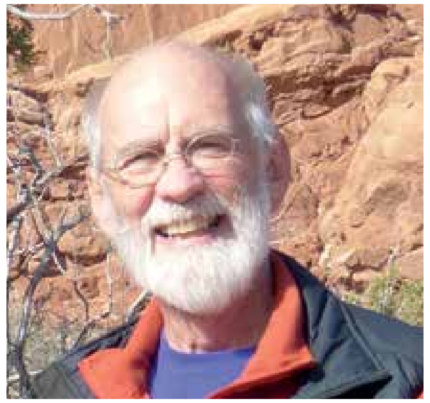
Exploiting plants from extreme environments: have we both world enough and time?



John Cheeseman is professor emeritus in the Department of Plant Biology at the University of Illinois. He is an organismal biologist, having begun his career as an environmental physiologist and expanded his studies to both the molecular and the ecosystem levels. His major research has been on halophytes (salt-adapted plants), especially mangroves. His work has taken him to both terrestrial and coastal ecosystems throughout the US, in the Caribbean, Western Australia and Queensland, New Zealand, Tanzania, and Saudi Arabia.

The increases in global temperature over the last four decades, coupled with more severe droughts in many areas and more generally extreme weather variability are seriously challenging many marginal, already stressed ecosystems [1]. Unfortunately, one of the main lessons already available from such environments (such as deserts and saline ecosystems) is that, with the proper attention (or lack of it), anything can be killed.

Plants in extreme environments are often already operating at their limits. For example, mangroves and salt marshes, adapted to living with frequent seawater inundations, are nevertheless both vulnerable to sea level rise. And although they have always weathered severe storms, they are at risk as the violence of those storms increases [2, 3]. Both systems are also very slow to recover if degraded. Moreover, their degradation results in significant release of greenhouse gasses, mobilised through decay of their highly organic soils [4].

Similarly, in deserts, despite adaptation of endemic species to generally warm, dry conditions, they can be made vulnerable by prolonged drought, even if it is not apparently prolonged or severe enough to kill them. Then, given another similar event even a long time (in human terms) afterwards, they succumb [5] (Fig. 1).

To understand the potential future effects of changing climates, with the goal of mitigating at least some of them, one approach is to develop new plant genetic models based on species already adapted to the more extreme conditions. Advances in genomic research have shown such promise, based especially on comparative genomics of hal-

> *“The challenge for society is to produce more food and other agricultural commodities at least sustainably enough to prevent the total collapse of the world’s ecosystems.“*

ophytes (salt-adapted plants, such as the Thellungiella spp.) and their non-adapted relatives (Arabidopsis thaliana). Modern sequencing techniques are setting the stage for understanding how genomes have evolved to deal with extreme environmental conditions. Such “extremophiles” may both show what plants can actually do under sever conditions and how, and unveil genetic traits that may be usefully transferred to crops [6].

While working from such “first principles” may be an attractive approach for molecular geneticists, biochemists and physiologists, exactly what this means in practise is still far from clear. This is true in particular about some central but poorly defined concepts, such as the definition of "tolerance", the requirements for salt management by the plants themselves, or the mechanisms of water acquisition

"Both natural and engineered plants with extreme stress tolerance must be part of the solution. It only remains to be seen how – not if – we will do this."

and transport in dry soil. It requires not only understanding the mechanisms by which tolerant plants are tolerant, but also those by which intolerant plants are sensitive [7].

Alternatively, in this new world, some already adapted species may be useful directly in mitigation or in crop substitution. There are a large number of extremely tolerant plants currently used for food which could potentially be cultivated much more widely or which could potentially tolerate even future changing climates. Harlan [8], for example, while noting that a mere handful of crops form the basis of the world's diets, provided an 11-page "short list" of other world crops that could be useful. However, he noted that the current trend is unquestionably for the major cereal crops to become even more major and for lesser crops to become even more "lesser".

Nevertheless, attention to halophytes in particular has increased over the last 20 years, associated with increasing, often total, losses of agricultural lands to salinisation. Potential biomass production by some halophytes rivals or exceeds that of non-halophytic crops, especially those used for forage or oil production. For example, the seeds of Salicornia bigelovii contain up to 30% oil and 35% protein, and its productivity under saline conditions can be significantly higher than the current world average for other major oil crops, such as sunflower, under non-saline conditions [9] (Fig. 2).

"But at my back I always hear
Time's wingèd chariot hurrying near;
And yonder all before us lie
Deserts of vast eternity."
*- **Andrew Marvel***

Clearly, large-scale exploitation of either native or engineered plants will take time. Time, however, may be in short supply: at least as important as climate change itself and too often ignored in discussing its effects is the increasing human population. This can- projected increase in the next 36 years is nearly equal to the current combined populations of China and India [10]. No ecological or social difficulties brought on by climate change will be reduced by a higher population.

Already in the current climate, the UNDP estimates that 44% of the world's cultivated systems are drylands. These are home to 2.3 billion people in 100 countries, including half of the world's poor [11]. Further, nearly 40% of irrigated agricultures depend on ground water reserves that are also being depleted and degraded. Nearly one third of the world's irrigated areas are affected by salinity or salinity-related problems, mostly associated with poor irrigation practices [12]. This includes both developing and developed countries, the two most affected being India and the US. Layered on top of this is the competition between agriculture and development, a competition that is increasing because of both climate change and shifts in population from the countryside to cities. The net effect, a decline in water available for growing food and an even greater decrease in the available land per capita can only be exacerbated by accelerating land and water degradation.

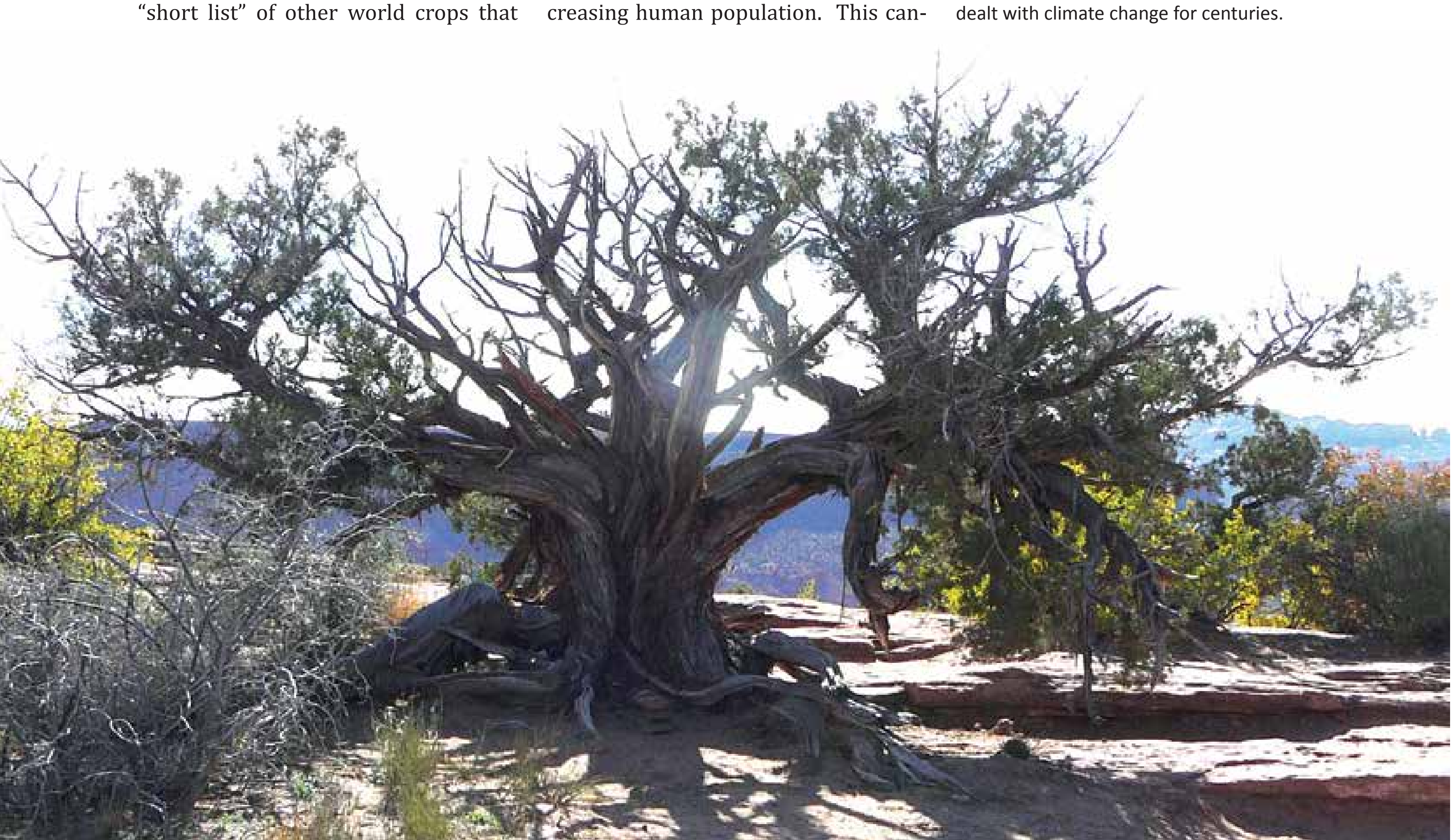


Figure 1. An ancient Utah juniper (*Juniperus osteosperma*) in Arches National Park, Utah, USA. The oldest known individual in Utah is more than 1275 years old. While they can grow at high altitudes, on very thin, nutrient poor, rocky soil in severely water-limited conditions, they are also highly sensitive to the "correct" duration and repetition of drought [5]. As is indicated by the amount of dead wood on this tree, one of their mechanisms for survival is to grow slowly and, during droughts, to decrease the amount of living material that needs to be supported with nutrients and water. Nevertheless, plants such as these harbor a wealth of genetic information, including a genetic history of having dealt with climate change for centuries.

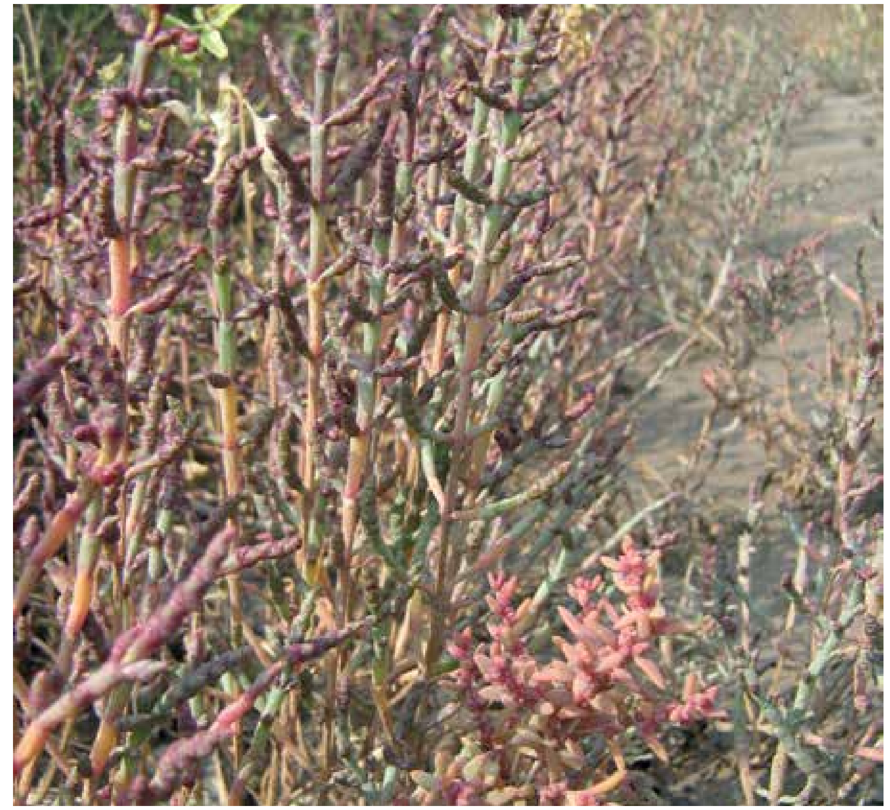


Figure 2. *Salicornia europaea* (saltwort, glasswort, samphire and other common names) is one of a number of *Salicornia* species being investigated for fodder and oil production using seawater irrigation. The plants themselves are edible, but the seeds are the primary target for halophyte agriculture, being high in oil and protein. The oil is suitable for biodiesel production. The plants shown here were growing on the side of a 5M NaCl stream at the base of a nearly pure NaCl mountain at the K&S potash mine near Gransee, Germany. Production trials are currently underway in the Middle East (Kuwait, Saudi Arabia), Eritrea, and Mexico.

The challenge for society is clearly to produce more food and other agricultural commodities on less land with less water, and to do so at least sustainably enough to prevent the total collapse of the world's ecosystems. Whether this can be done for even the current population is doubtful. It is equally doubtful that a global scale techno-fix based on plants adapted to extreme environments is possible. On the global scale, there are no potential new crops - pre-adapted to stress or manipulable to increase yield while preserving stress tolerance - that have the potential to produce the calories and proteins consumed from our current major crops (such as rice, wheat, maize, pulses and potatoes). Moreover, were they available, if conversion to those crops were limited to, or seemingly forced upon, developing countries, yet another gap between rich and poor nations would be created. The sociological aspects of this may well make their adoption distasteful or even impossible, as it has for GMO crops already [13].

In 2009, a documentary film on the history and future of our planet, Home, concluded with the statement that "it is too late to be a pessimist" [14]. The problems of food supply and security facing the earth's entire human population are daunting, but the alternative to solving them is unspeakable. Both natural and engineered plants with extreme stress tolerance must be part of the solution. It only remains to be seen how – not if – we will do this. ■

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Challenges in quantifying global carbon cycle extremes

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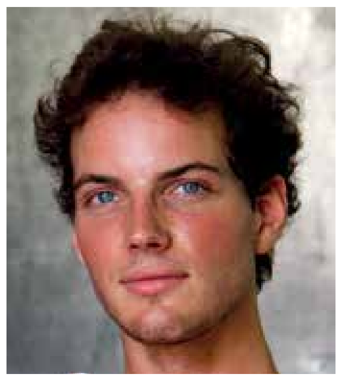


Jakob Zscheischler obtained his degree in mathematics from the Humboldt University in Berlin in 2010. Since then he has been pursuing his PhD at the interface between geoscience and machine learning at the two Max Planck Institutes: Biogeochemistry and Intelligent Systems. His research focuses on the detection and quantification of extreme events in variables describing the state of the ecosystem and their attribution to climate conditions and other drivers.

Anja Rammig is a scientist the "Earth System Analysis" department at Potsdam Institute for Climate Impact Research (PIK), Germany. Her research focuses on forest ecosystem responses to climate change, in particular on extreme events. She is interested in developing process-based dynamic global vegetation models for site-specific applications and testing models with observational data.

The question of how frequencies, intensities, and spatial extents of climate extremes change in the wake of climate change is increasingly in the focus of climate science and emphasized by the IPCC [1]. Multiple lines of evidence further suggest that these pulses of extreme climate conditions can affect the terrestrial carbon cycle of most ecosystem types [2]. In particular, a series of well-documented case studies report that carbon-sequestering ecosystems ("carbon sequestration" is the process of capture and long-term storage of atmospheric carbon dioxide) forfeit their accumulation potential under climate extremes (recall the studies on the European heat wave 2003 [3], the 2000-2004 US drought [4], or the 2005 and 2010 Amazon drought [5]). Hence, we have good reasons to expect additional releases of land carbon if certain climate extremes intensify over the coming decades. One of the immediate goals of our studies is therefore to investigate to what extent extreme events constitute a positive feedback to global change.

To reach this goal we have to carefully analyse the ecological consequences of extreme climate events [6]. Moreover, it is particularly important to understand and quantify where climate extremes have led to extreme changes in the carbon cycle, that is, in changes of carbon stocks or fluxes [2]. For example, during the European heat wave 2003, most available monitoring data indicated clear changes in carbon fluxes implying depleted land carbon stocks [3]. Though one could deduce from studies of this kind that we are well equipped from an observational perspective, the current data archives are often sparse in space and fragmented in time.

This remark is in no way meant to downgrade the obvious merits of the steadily growing global carbon cycle data archives. Especially eddy covariance measurements of ecosystem carbon fluxes from the FLUXNET network (in tandem with regional initiatives) have substantially improved our process understanding. The main problem is that the probability of observing the impact of climate extremes is much lower than the occurrence probability of extremes anywhere in the world. To put it in other words: we are plagued by sparse sampling and short time series. Statistical frameworks built to estimate, for instance, the recurrence probabilities of 100-year floods are not (yet) applicable to carbon cycle research. Alternatives are, for instance, long-term data on tree ring width [7] or annual crop yields [8], both of which allow, however, only indirect assessments of extreme impacts on the carbon cycle.

Another option is to rely on either gridded, empirically derived or process-based modelled flux fields. Jung *et al.* [9] have shown that machine-learning methods are sufficiently powerful to learn the nonlinear relation between local CO_2 flux observations and remote sensing information. This integration can be exploited to generate spatiotemporally continuous reconstructions of land-atmosphere fluxes over the satellite era. Results from process-based models allow us to draw a longer-term picture of the impacts of climate extremes on the carbon cycle, for instance by differentiating types of extreme climatic constellations and investigating coincidences of these with extremes in ecosystem variables.

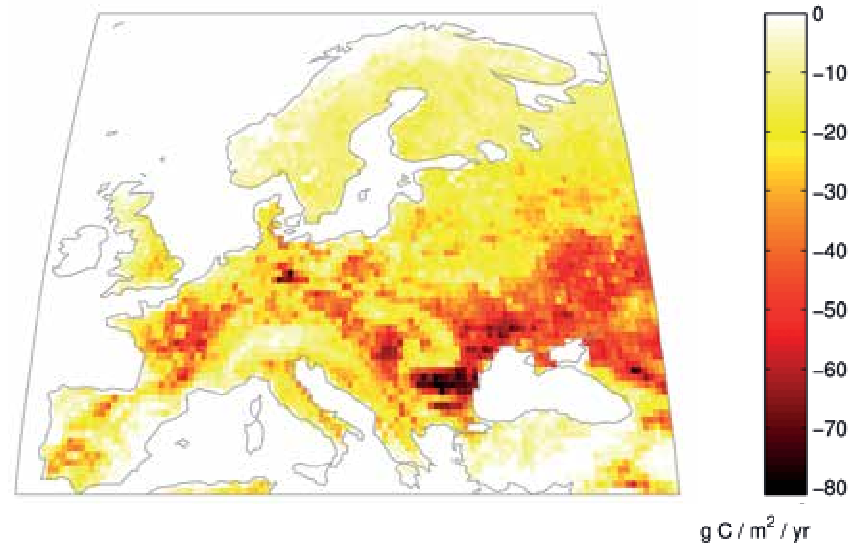


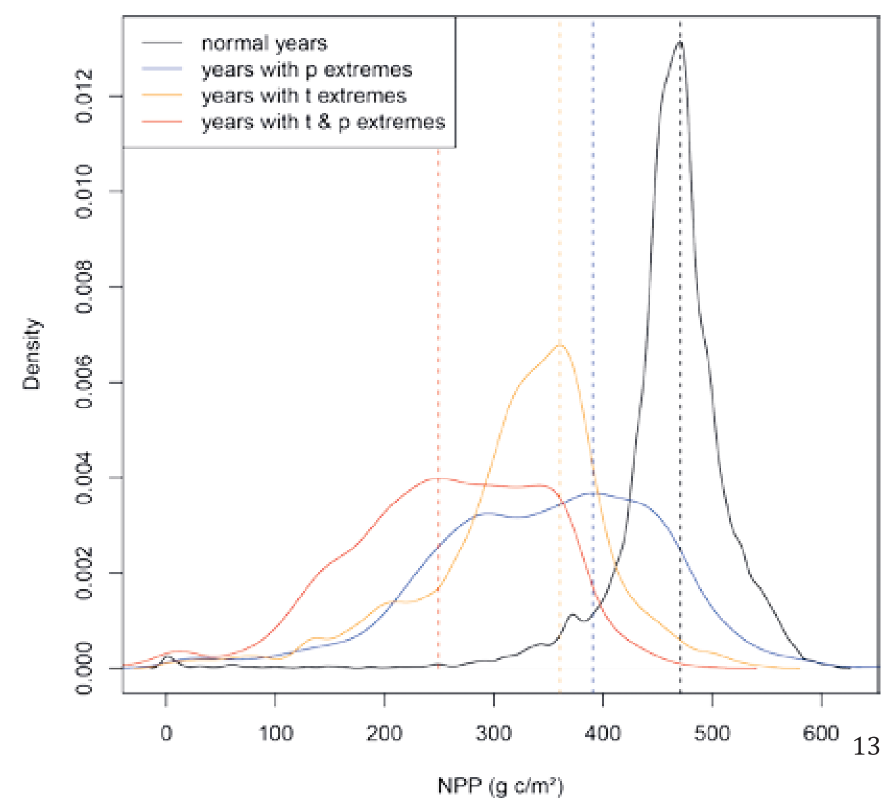
Figure 1. Average decrease in GPP caused by the 100 largest spatiotemporal extremes affecting the terrestrial biosphere.

As an example, we explore here extremes in empirically upscaled gross primary production (GPP; the total amount of carbon assimilated via photosynthesis into vegetation) over three decades in Europe [9]. Given that we cannot rely on long time series, we exploit the highly correlated spatial information to robustly identify extreme impacts. Using a three-dimensional (latitude x longitude x time) segmentation approach [10] results in spatiotemporally connected extremes that can be sorted by their spatial extents, length, or integral effect on GPP. The idea is that even if the data are noisy and locally uncertain, we can identify extreme impacts by analysing where the extreme behaviour affects large areas for longer time periods. With this approach it has been shown that a few extremes explain most of the interannual variability of GPP [11]. In Fig. 1, we show the integrated decrease in GPP during the 100 largest extremes over time. Clearly, the areas around the black sea, Germany and France are particularly prone to dramatic impacts on GPP.

A key question is what type of climate extremes has the strongest tendency to cause pronounced impacts on the carbon cycle. Hence, in a second example, we detect coincidences between extreme decreases of in net primary production (NPP; net CO_2 assimilated by the vegetation, i.e. GPP- autotrophic respiration) as simulated by the LPJmL dynamic vegetation model [12] and climate extremes during the growing season. We find that substantial reductions of NPP are driven by hot summers as well as by dry summers, but the largest decreases in NPP are found when hot phases coincide with dry periods (Fig. 2).

The second example analysis gives a hint that compound events may have the strongest effect on NPP (at least in

Figure 2. A modelling experiment: Central European growing season NPP (net primary production) during normal growing seasons (black) compared to years with extremely low NPP and coinciding extreme warm summers, extreme dry summers, as well as dry and hot summers.



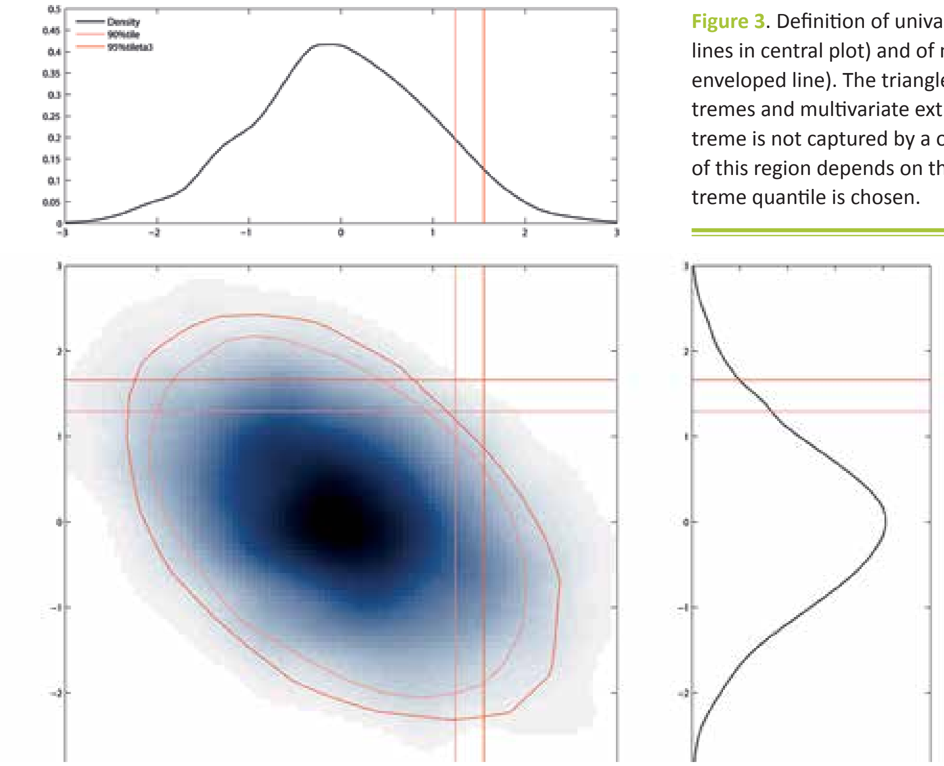


Figure 3. Definition of univariate extremes (external panels and straight lines in central plot) and of multivariate (compound) events (central panel, enveloped line). The triangle enveloped by the threshold of univariate extremes and multivariate extreme delineates the region of a (bivariate) extreme is not captured by a one-dimensional detection approach. The size of this region depends on the selected quantile and increases if a more extreme quantile is chosen.

our specific model run). Indeed, this perception is of a more general nature. For instance, Leonard *et al.* [13] show that in situations where various variables are extreme ("compound extreme"), we can expect the most severe impacts. However, non-extreme drivers can also cause extreme impacts especially if rare and unfavourable constellation of climatic drivers occur. While this can be easily imagined in a two-variable system (Fig. 3), it rapidly gets challenging as the number of considered variables increases. Clearly, future studies need to provide us with a better understanding of the consequences of compound extreme events for the terrestrial biosphere.

Besides analysing compound events, yet another important aspect currently discussed by climate scientists is the question of "unprecedented climate extremes" [14]. In the context of land-atmosphere interactions, one can think of an intensity of an extreme event that has not been experienced since the establishment of a specific ecosystem. Likewise, it is important to study the impacts of unprecedented spatial extents or durations of extreme events. Our immediate question here is whether it makes a substantial difference to ecosystems if certain thresholds are passed, e.g. plant specific drought tolerances ("You can only die once" [6]). In this context, one also has to understand to what extent ecophysiological adaptations at ecosystem level can attenuate the impacts of climate extremes, e.g. via changes in stand structure. The ultimate hope is to derive more general conclusions from field observations to improve our capacity in anticipating extreme impacts on the global terrestrial carbon cycle.

How robust are the results from terrestrial biosphere models when it comes to the analysis of carbon-cycle extremes? So far, most model benchmark systems emphasise the performance of models for reproducing mean fluxes, seasonal cycles, and long-term trends [15] rather than evaluating the tails of the data distributions (extreme events). Our objective, however, is to interpret these models under circumstances that were not in the focus of the initial developments. Polemically speaking, we are in a situation where unintentional model use meets observation scarcity. Consequently, our branch of science needs to consider the role of extremes when it comes to structural model-developments or model-data integration exercises. ■

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Measuring and modelling global vegetation dynamics in response to chronic and extreme climate changes

Nate McDowell has been a staff scientist in the Earth and Environmental Sciences Division at Los Alamos National Laboratory (LANL) since 2004. He received his PhD in tree physiology at Oregon State University in 2002. He has published approximately 80 papers since 2000, and advised approximately 20 graduate students and 25 postdocs. He was awarded LANL and the US Department of Energy's Distinguished Mentor Awards for advising undergraduates in 2008 and 2010 respectively, and testified before Congress regarding DOE's climate change research in 2009 and before the House of Representatives in 2012 regarding climate impacts on forests of the intermountain west.

Jeff Chambers is an Associate Professor in the Geography Department, University of California, Berkeley, and a Faculty Scientist in the Climate Sciences Department at Lawrence Berkeley National Laboratory. He received his PhD in ecology from the University of California, Santa Barbara, in 1998. He has authored and co-authored about 50 peer-reviewed manuscripts, including first-authored papers in Nature, Science, and PNAS, and has advised and co-advised over 30 postdocs and graduate students. He served as co-Director for DOE's National Institute for Climate Change Research (NICCR) Coastal Center, and has led a number of international science projects funded by the DOE and NASA.

Why must we understand, monitor, and simulate global vegetation disturbances?

Terrestrial vegetation is among the most important yet vulnerable climate regulators on Earth. Terrestrial ecosystems sequester ~30% of anthropogenic fossil emissions annually and regulate precipitation and temperature. However, these services are already diminishing through both chronic and abrupt events that lead to ecosystem disturbance [1,2]. Dynamic global vegetation models (DGVMs), the essential land-surface boundary component of climate models, require accurate treatment of disturbances to simulate terrestrial climate forcing and improve climate change predictions over the 21st century. Here, we highlight the importance of improving global measurements and simulations of disturbances in response to both chronic and extreme disturbance drivers.

Multiple biomes are exhibiting accelerating rates of vegetation mortality at continental scales in association with warming surface temperature (Fig. 1), and major regional "die-offs" have been associated with periods of low precipitation or wind storms superimposed upon this warming [3,4,5,6,7]. These are not just increases (for instance, from 1% to 2% mortality), but accelerations (for instance, increasing by ~1% each decade) [3, 6]. These increases in background mortality are insidious because they are relatively unnoticed by the casual observer, yet they cause long-term reductions in ecosystem services such as carbon storage. For example, a modelled doubling of the mortality rate from ~1 to 2% for a Central Amazon forest caused a > 50% reduction in above-ground biomass with a lag-time exceeding 50 years [8]. In more dramatic fashion, some regions have experienced massive, widespread "die-offs" recently [5,9]. Thus, both chronically increasing background mortality as well as extreme "die-off" events should cause large shifts

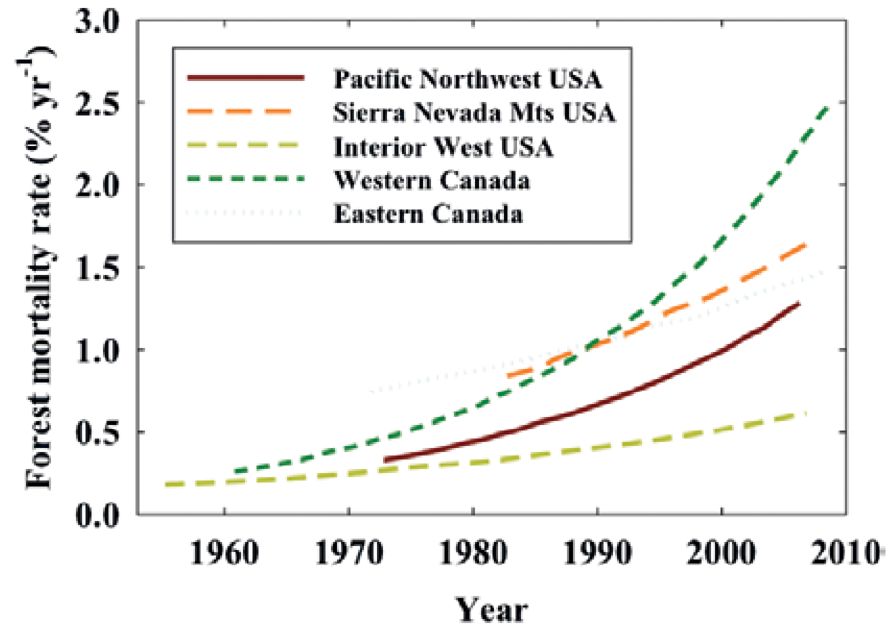


Figure 1. Background mortality rates are increasing throughout much of North America, regardless of regional climate, species, or land management history (reproduced from [3] and [6]).

in regional carbon and energy balances. A weakening of the terrestrial carbon sink is therefore expected if mortality and decomposition of forest necromass (mass of dead plant material) is a significant global process.

Predictions consistently suggest decreasing forest survival in the future. For example, both empirical models and DGVMs predict that North American forests will lose >50% of their current distribution before 2100AD [7,10] (Fig. 2). Despite the consistency between observations and simulations, our confidence in DGVM accuracy remains weak because of a paucity of knowledge regarding the physiological and abiotic mechanisms of disturbance [11,12]. Simulation of DGVM mortality mechanisms has recently improved in part through evaluation against ecosystem-scale climate manipulations [13,14,15] (Fig. 3), although considerable work remains. As a result, an untenably wide range of future carbon storage forecasts exist, making our confidence weak at best (although all forecasts predict a positive climate warming feedback due to a decreasing terrestrial carbon sink [12,16]).

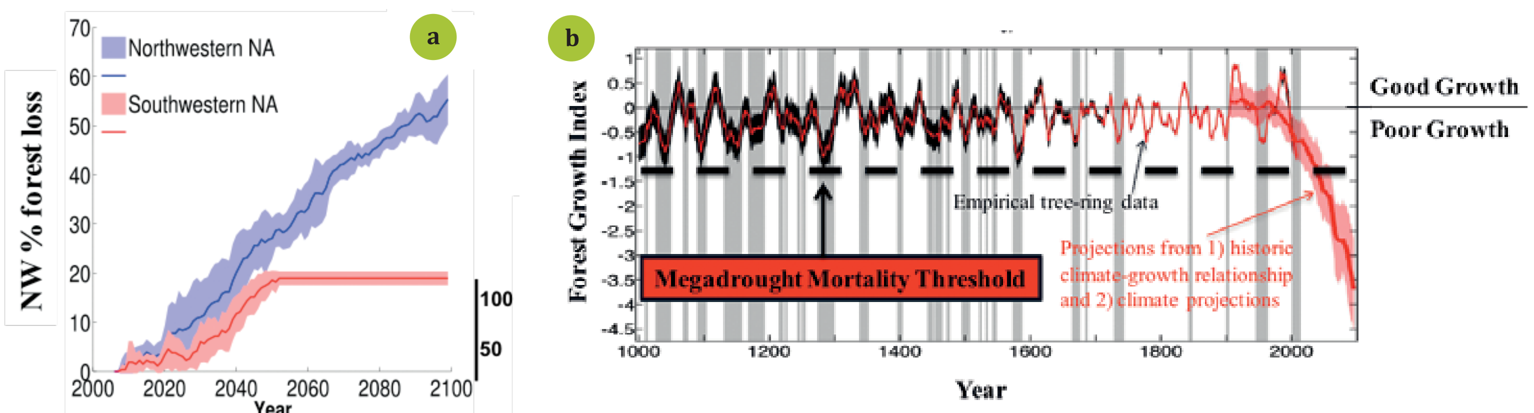
Disturbance mechanisms

Clarifying if increasing background mortality rates are anomalous and understanding the climate factors underlying increasing mortality are challenging because baselines for historic mortality rates are rarely of sufficient length to partition natural versus anthropogenic driven impacts. Theoretical and empirical understanding of temperature impacts on physiology, however, support the concept that rising temperature is underlying increasing mortality rates, both with and without increasing extreme precipitation or wind events.

Firstly, rising temperature has direct, negative effects on plant carbon storage because it increases respiration; it also affects the plant indirectly by increasing the vapour pressure deficit (VPD), which, in turn, leads to a higher likelihood of hydraulic failure, carbon starvation, and insect and pathogen attack [12,17]. This results in an exponential relationship between forest mortality resulting from biotic attack and VPD, and an ominous forecast for future forest survival (Fig. 2B) [7].

The negative impacts of increasing VPD are particularly concerning because VPD is rising faster than surface temperature and because it depends exponentially on temperature (despite rising humidity). This suggests that DGVM simulations currently underpredict mortality (compare Figs. 2A and 2B; note 2A also does not include fire simulation, making it even more conservative). These hypotheses must be tested by experiments designed to unravel cause-and-effect (Fig. 3). Strong support for the negative impact of temperature and VPD on plant survival has now been demonstrated in experiments with many species (numer-

Figure 2. a) DGVM simulations of forest loss from NW and SW North America show SW USA will have lost all of its current conifer forests by 2050, with NW following closely behind [10]. **b)** Forest mortality always occurred in SW USA when the unitless forest growth index (based on tree rigns) reached -1.4 (grey bars indicate severe droughts). Rising temperature along with minor changes in forecasted precipitation suggest all SW USA forests will have exceeded the megadrought threshold by 2050 [7]. **c)** A recently dead old-growth Pinus edulis tree in New Mexico, USA (next page).



ous examples can be found in [12,13]. These mechanistic experiments that kill trees are highly valuable for testing the underlying theory regarding the accelerating rates of mortality, and are essential for DGVM evaluation [13,14] (Fig. 3).

Secondly, the atmospheric energy cycle intensifies with the warming climate. This increases the intensity of cyclones and convective storms and leads to an increase in wind-driven tree mortality, creating another pathway for increasing disturbance regimes [4]. While storms such as hurricanes cause huge and immediate transfers of carbon from live to dead pools across regions [18], a chronically stronger wind can also increase mortality in a more subtle manner: an increase in natural "background" tree mortality via snapping, uprooting by wind, or partial canopy loss [19].

Ground-based observations are at least as important as mechanistic experiments (Fig. 3) for understanding mechanisms driving vegetation mortality because they can also be used for evaluating remote sensing observations and DGVMs at appropriate scales (Lichstein *et al.* in press). Unfortunately, key measurements such as agents of mortality are often not measured in forest field inventories, few inventories occur at an annual time step required for DGVM evaluation, and inventories are limited to regions of particular interest or affluence [reviewed by 11,12].

A near-term solution lies with validation of remote sensing products across regions where we have data and then application of evaluated algorithms to global remote sensing datasets [20]. A globally comprehensive disturbance and mortality monitoring system would allow substantial increases in our knowledge of the spatial and temporal patterns of mortality, thereby enabling analyses of climatic and anthropogenic drivers that precede mortality events. In addition, a global vegetation mortality monitoring system is absolutely necessary for DGVM benchmarking, parameterisation, and structural improvements to mortality algorithms. Currently, benchmarking for land-surface models includes (among other parameters) fluxes and inventory-based biomass; both of these are extremely valuable to assure that models are capturing critical processes that define carbon, water, and energy balance [21]. However, DGVMs simulate migration of plant functional types based on survival, mortality, dispersal and regeneration, and are run at regional or global scales, thus these processes must also be provided as benchmarks at the appropriate scales for DGVM evaluation.

"A global vegetation mortality monitoring system is absolutely necessary for DGVM benchmarking, parameterisation, and for structural improvements to mortality algorithms."

There are multiple significant challenges with any observational system of vegetation disturbance. Firstly, drought-induced mortality occurs to individual trees, often with a patchy distribution across the landscape at a scale that may be below the resolution of most remotely sensed products (for instance 250 m MODIS, 30 m Landsat). Recent developments suggest 30-m and 1-m-resolution imagery can be used to capture the bulk of mortality and disturbance suggesting this challenge can be surmounted [18,22,23,24].

Secondly, attributing the remotely sensed signal to mortality per se, as opposed to canopy litterfall or die-back that is (or is not) recovered in subsequent years [19], is difficult but can be extremely important to predicting future vegetation that is critical for accurate DGVM simulations. Active remote sensing such as LIDAR and radar can alleviate some of the challenges by providing information to changes in ecosystem structure (such as canopy height). Overall, attribution of cause(s) of changes in ecosystem structure may be the single largest challenge to a globally comprehensive vegetation dynamics detection system.

Preparing for the future

It is extremely difficult to predict future climate-terrestrial impacts and feedbacks because of the myriad complexities involved and because of the lack of evaluated global datasets. Multiple advances are required to move the predictive science of vegetation mortality forward. We need broad coverage of the Earth's terrestrial surface with field inventory plots that provide a) improved statistical samples of the state of regional vegetation, b) annual census, and c) tallying of agents of mortality in field notes, so that we can then understand patterns and drivers, and evaluate DGVMs [11,12,23]. An observational network of forest inventory plots that includes all six forested continents coupled with high-resolution remote sensing data would be extremely valuable for establishing baselines and then detecting shifts in mortality regimes that result in climate-relevant feedbacks to the Earth system. This network will be essential to test and calibrate global standardised high-resolution (30 m or less) remote sensing datasets [20]; however, this simultaneously requires that the remote sensing products are broadly available to the research community.

We must improve links among the modelling (Fig. 2), experimental (Fig. 3), and observational (Figs. 1, 4) science communities to ensure that advances in process-based understanding are relevant to DGVMs. Gaining confidence in our understanding of forest dynamics and their climate dependencies and in our ability to accurately sim-

Figure 3. Examples of experimental manipulations needed for testing DGVM process in relation to chronic and extreme events. A) Ecosystem scale precipitation reductions, such as this one shown in a moderately wet tropical forest in Caxiuanã, Brazil, allow investigation into the impacts of a sustained drought on forest survival and mortality [14]. B) The addition of heat to drought manipulations allows examination of the interactive impacts of multiple drivers of environmental stress on forest survival and mortality. Pictures in panel A and B are from Patrick Meir and Josh Smith, respectively.

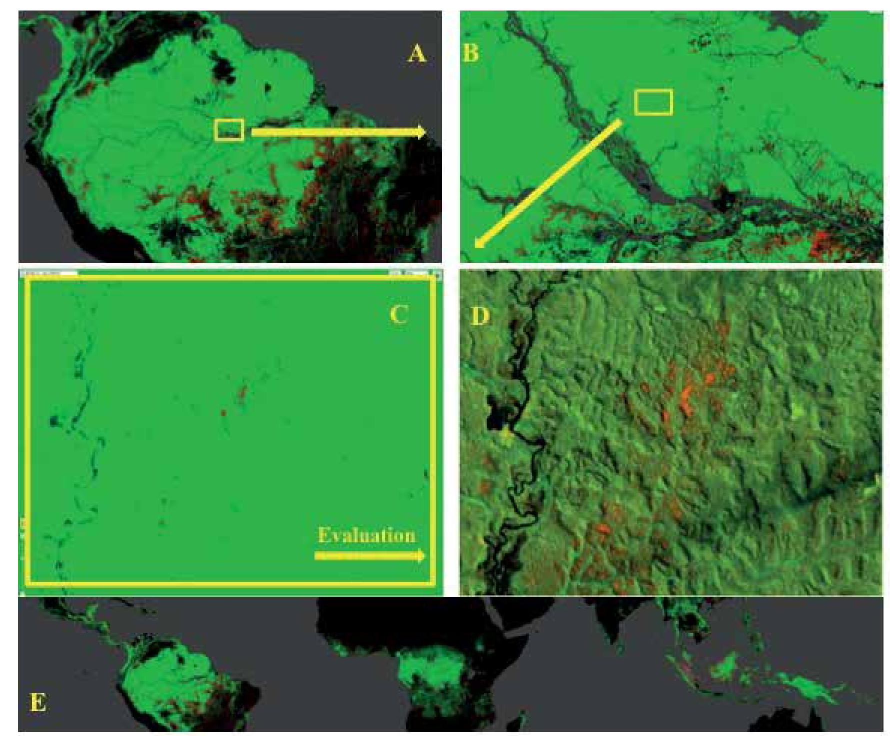


Figure 4. The first user-friendly, interactive web-based tool that allows examination of the global patterns of forest loss and gain since year 2000 via a 30-m resolution Landsat analysis constitutes a major breakthrough. Below is a series of scenes of forest gain and loss (blue is gain, red is loss, green is forest extent) [20]), zooming from A) the Amazon basin, to B) the Manaus region, to C) the ZF2 research site north of Manaus, and D) evaluation of (C) against field-validated mortality observations also using Landsat imagery from Negron-Juarez (2010). Comparing panels (C) and (D) highlights that while the new analysis is a great step forward, mortality flux datable with Landsat is missing at finer scales. E) Pan-tropical patterns of forest loss and gain [20] highlight strong regional differences, for instance, high disturbance rates (largely anthropogenic fire and forestry) in Brazil, Malaysia, and Indonesia versus lower disturbance impact in the Congo basin and Papua New Guinea.

ulate vegetation survival and mortality in relation to chronic and extreme disturbances could have a significant influence on policy as the Earth's climate continues to change and leads to anomalous effects on society. ■

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'The great, big, broad land 'way up yonder': biogeochemical cycling and climate change in the high latitudes

Mathew Williams is Professor of Global Change Ecology in the School of GeoSciences at the University of Edinburgh, UK. His research focuses on terrestrial ecosystem processes and on combining models and data to investigate climate sensitivity and response to disturbance. He has undertaken field research on high-latitude ecosystem processes since 1996, in Alaska, Canada and Fennoscandia. His current research involves improving simulations of carbon cycling in permafrost systems; multiscale measurements of greenhouse gas emissions from European managed landscapes, including crops, forest and grasslands; and using earth observation data to evaluate and calibrate global analyses of the terrestrial carbon cycle. Prof Williams is part of the European Space Agency BIOMASS mission advisory group: BIOMASS is a satellite scheduled for launch in 2020 that will measure forest biomass globally at unprecedented detail.

*"It's the great, big, broad land '
way up yonder,
It's the forests where silence has lease;
It's the beauty that thrills me
with wonder,
It's the stillness that fills me with
peace."*

Robert W Service,
'The Spell of the Yukon'.

Introduction

My goal in this article is to discuss the major challenges we face in developing our understanding of, and predictive capacity for, Arctic land-atmosphere interactions, with a particular focus on sensitivity to climate change.

The Arctic – the polar regions of the northern hemisphere – is a vast area of extreme environments. The definition of the Arctic is debated, defined sometimes by latitudinal boundaries, sometimes by temperature limits. But in this discussion, I will focus largely on the low Arctic, and sub-Arctic regions (~55-70°N). These are areas where permafrost (soil frozen year round at depth) is common or even continuous, but where extensive vegetation (tundra and/or boreal forest) and soil organic matter covers much of the landscape, leading to significant interactions with global biogeochemical cycles. While high Arctic (>70°N) environments are colder, drier, and more extreme, their dominant ecosystems are polar barrens, with much reduced rates of atmospheric exchange and biogeochemical cycling.

Motivation and complications

*"It's the cussedest land that I know,
From the big, dizzy mountains that
screen it
To the deep, deathlike valleys below."*

There are strong societal and policy reasons to focus land-atmosphere research in the Arctic. Stocks of carbon in frozen soil organic matter are extensive, enormous, and uncertain [1]. What is the fate of this carbon in a warming world? Climate change is occurring rapidly, and models suggest warming will be greatest at high latitudes. Warming may expose frozen carbon to more rapid decomposition and CO^2 release. The potential for climate feedback, enhanced warming, and more thaw is significant.

However, there are several complicating factors. If permafrost thaw leads to increased soil saturation, decomposition may be inhibited, while enhanced methane production may add a further climate change feedback. Coupled shifts in vegetation distribution, linked to warming, may enhance productivity and alter litter inputs to these systems, but these changes will be linked in complex ways to nutrient cycles. Changes in litter quality may influence microbial processes, and enhance decomposition. Finally, fire distur-

Figure 1. An extensive area of thermokarst on the North Slope of Alaska. The headwall of the melt feature is 2-3 m tall. The thaw has exposed large areas of previously frozen soil. Organic matter that has been frozen for centuries can now decompose more rapidly in warm, aerobic conditions. Mudflow can clearly be seen away from the headwall. Solifluction is visible in surrounding areas, where vegetation and soil is slipping downslope.

bance may be enhanced under climate change, disrupting ecosystem processes, and changing the timescales of response. Below, I examine these complexities in more detail.

The permafrost challenge

"The winter! The brightness that blinds you,
The white land locked tight as a drum"

The presence of permafrost in the Arctic means that a phase change will occur as thaw develops [2]. This change will alter the Arctic environment in unparalleled ways [3]. Current landscape drainage patterns are dictated by permafrost. Thaw will alter patterns of water flow, inundation, and erosion across vast landscapes. On the North Slope of Alaska, extensive areas of permafrost thaw, or thermokarst, have appeared in recent years (Fig. 1). The thermokarst manifests itself as solifluction (flow of water-saturated soil down a steep slope), earthflow and mudflow, in order of rapidity and disturbance magnitude.

Key questions arising from thermokarst include the following: How do permafrost landscapes reorganise following thaw? How, and over what timescales, do soils adjust, through erosion, decomposition and leaching? What are the response times of vegetation, including succession, to thermokarst? In areas of permafrost thaw in boreal lowlands, 'drunken trees' are visible, where the subsidence of melting organic soil destabilises stems that developed on permafrost plateaus (Fig. 2). Stem mortality and transition to wetland vegetation results. Methane production is stimulated by rising water tables. Over time, will wetlands drain, or infill from plant litter production?

Figure 2. An area of permafrost thaw, south east of Whitehorse, in Yukon Territory, Canada. Spruce stands dominate surrounding areas underlain by permafrost, but in this area thaw has led to subsidence, and a relative rise in the water table. 'Drunken' trees lean as soils thaw, and tree mortality rises in the extremely saturated soil conditions where thaw has occurred.

Biogeochemistry-climate interactions in Arctic environments

"The snows that are older than history,
The woods where the weird shadows slant"

We might expect climate to be the key limitation on productivity of Arctic ecosystems, and warming studies have confirmed its importance. However, nutrient addition experiments have also quantified the sensitivity of tundra production to nitrogen (N) and phosphorus (P) additions [4]. The low stature of tundra ecosystems in particular has made it possible to make very accurate measurements of CO_2 exchanges and link these to nutrients in vegetation (Fig. 3). These measurements have shown that primary production and net carbon uptake across the pan-Arctic tundra biome are largely determined by leaf area, foliar N, shortwave radiation from sunlight, and temperature [5].

Figure 3. Measuring gas exchange from an Alaskan Arctic shrub canopy using a chamber and infra-red gas analyser, near Toolik Lake, Alaska. Short stature canopies allow direct measurements of structure, gas exchange, leaf traits and soil states. The Arctic Long Term Ecological Research site at Toolik Lake has pioneered studies on tundra responses to global change.

We also know that leaf area and foliar N show tight coupling across Arctic ecosystems [6]. Warming is likely to result in increasing leaf area and extended growing seasons, leading to increased production. But coupled leaf area/foliar N changes will depend on concurrent shifts in N availability. Therefore, predictive models need to resolve the sensitivity and transient response of N cycling to climate change.

Plant-soil interactions add to model complications, particularly the issue of priming, whereby plant inputs to soils stimulate microbial action and decomposition [7]. Thus, even with rising litter inputs to soils from more productive vegetation, soil C stocks may decline if microbial decomposition is stimulated. Traditional models of soil decomposition cannot reproduce this observed behaviour, necessitating novel approaches [8].

Disturbance effects

"The flames just soared, and the furnace roared—
such a blaze you seldom see."

Fire is a common disturbance agent in high latitudes, particularly in boreal forests. The disruption to soils and vegetation generates complex landscape responses [9]. Combined with climate change, and shifts in species ranges, fire may initiate tipping points in vegetation dominance. But the timescales of response are relatively long (decadal) so current knowledge is too limited to generate reliable models. In boreal forests, fire initiates succession, but can leave a landscape with large C stocks in dead stems (Fig. 4). Post-fire, there are also varying degrees of soil organic matter loss, seemingly dependent on whether stems topple during fire, and generate intense heat at ground level. Smouldering fires are capable of removing significant depths of organic matter.

In many boreal areas, permafrost is ecologically protected: maintained by the insulation provided by dense organic matter and vegetation (often moss) cover. Fire disrupts this insulation, and therefore can remove permafrost protection. But if vegetation recovers quickly enough after fire, protection may be restored and permafrost stabilised. In a warming world, will more frequent fires accelerate the loss of ecologically protected permafrost?

Modelling Challenges

In the Yukon, over a century ago, Robert Service wrote
"It seems it's been since the beginning;
It seems it will be to the end."

But global change is now altering the Arctic and the consequences are seri-

Figure 4. A landscape north of Whitehorse, Yukon Territory, Canada, near Fox Lake. This area burned in 1998; this photo, taken in 2013, shows continuing evidence of this disturbance event, with many charred stems still standing and regeneration proceeding slowly. The landscape has varied depths of organic matter in soils, linked to intensity of fire.

ous for local communities, Arctic nations, and the Earth System. There is an urgent need to update land surface models to effectively simulate thermokarst, biogeochemical sensitivity to climate, disturbance impacts, and plant-microbe-soil interactions at high latitudes. Addressing these challenges will require combined efforts of ecologists, biogeochemists, hydrologists and geomorphologists, along with process modellers.

Progress has been hampered by scarcity of experiments and observations (with the notable exception of a few intensively studied locations). Major new initiatives in the Arctic are addressing the issue of data scarcity (US Dept. of Energy 'NGEE' projects, UK Natural Environment Research Council Arctic Programme, EU Page21 and others). However, the challenge for modelling the Arctic is significant – our understanding of the timescales of response of C and N cycles to warming and disturbance remains limited. Modelling must be better integrated with multiscale field studies and experiments to accelerate our learning [10].

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The European Alliance of Global Change Research committees

Building bridges among European scientists and stakeholders

The European Alliance is a bottom-up initiative of the European global change research committees. Its overall aim is to advance Future Earth research in Europe.

Main objectives:

- To facilitate science-driven discussion to help agenda-setting syntheses on European interests and priorities in global change research
- To link stakeholders and scientists in core project work towards global sustainability on national and regional level in Europe

The Alliance will increase the societal and policy relevance and visibility of the national science community and increase the integration of European scientists in Future Earth. It will work together with core projects to form operative networks of local and regional stakeholders, policy-makers, and scientists working on specific projects. The Alliance aims to merge these communities to jointly determine European research priorities and interests and to introduce them into the on-going discussion on research strategy on the European level.

The Alliance has launched the European Alliance – iLEAPS pilot programme that is reviewing the best ways to facilitate stakeholder – core project interaction. A key partner in this work is the Earth System Governance project whose long experience in exploring political solutions and in practical work on the science-policy boundary will help build bridges to the stakeholder community.

The Alliance welcomes new collaboration with other core projects. For more information, see our website or contact the secretariat.

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Societal adaptation to extreme events and environments

Societies have always adapted to their environment and climate variability, some better than others. Given the developments in observation methods, it is now possible for societies to engage in pre-emptive measures to alleviate the environmental conditions in extreme environments, as well as the resulting impacts from extreme events.

From the perspective of the society, the difference between extreme events and extreme environments lies in the temporal scale. Extreme events are considered to be "one-off" events within a particular time-scale, for example "a one-hundred-year flood" that is frequently used to describe an extreme flooding event. Extreme environments, on the other hand, are locations with constantly severe conditions for people. Whilst the population continuously living in extreme environments is relatively small globally, the thresholds of coping for those who live in extreme environments are also relatively close by all the time. Moreover, extreme events can also take place in extreme environments, further pushing the society beyond the threshold of coping.

Extreme events do not always lead to disasters from the perspective of society. In fact, it is the exposure and vulnerability of societies that determines this [1]. Exposure is defined as the nature and degree to which a system is exposed to significant climatic variations, whilst vulnerability within the climate change literature denotes the degree to which socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change.

Extreme events are also relative from the perspective of society as variation between the exposure and vulnerability of societies differs greatly, even within countries. This is exemplified by the fact that economic losses tend to be higher in developed countries compared to developing countries where fatality rates and economic losses (as a proportion of gross domestic product) are higher [1]. The overall increasing trends of economic losses (both direct and indirect costs [2]) related to disasters can be explained by the increased exposure of people and economic assets to extreme events, which further can be explained by increased trends of population growth and urbanisation globally.

Economic losses are not the only consequences of extreme events. These can also include losses of cultural heritage or ecosystem services, which can be harder to measure but nevertheless important. For example, human migration is considered as one potential consequence of extreme events. However, a recent study highlighted that whilst migration can be considered a response to environmental extremes and perhaps more so in the future, it is important to note that both those who move and who do not move may be equally affected by the events [3]. This further demonstrates the complex ways in which individuals by themselves and collectively through decision-making respond to environmental events.

From the perspective of society, there are a number of research needs related to extreme events and environments, and these can divided broadly into two feedback loops between the biosphere and society.

Firstly, there is a need to understand the complex processes in the biosphere and how they can affect the society. For example, improved information of extreme events is a good example of this whereby this knowledge is directly useful to the society. With regards to extreme events, knowledge of changes in the frequency and the intensity of these events are crucial in preparing societies to cope and adapt [4]. There are numerous ways that this information is already used to assist vulnerable people in developing [5] and developed countries [6], for example. There are further opportunities to develop societal preparedness for disasters.

Secondly, there is a need to understand how society and anthropogenic activities influence the biosphere and what the implications of this are. This includes, for example, a better understanding of changes in the mean climate in extreme environments in order to see how the changes are likely to affect the societal activities in these environments. These changes can be negative but they can also open up the possibilities for new activities, for instance in the polar region, which in turn affect the biosphere through increased exploitation of natural resources. ■

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Sally Archibald is a Principal Researcher at CSIR Natural Resources and the Environment and a Senior Lecturer at University of the Witwatersrand, South Africa. Dr. Archibald's research focuses on fire ecology, biogeochemistry, and savanna structure and function in the context of global change. She is involved in inter-continental and global comparisons of vegetation structure and function and is an associate editor for the International Journal of Rangeland Management.

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Tetsuya Hiyama is an Associate Professor at the Research Institute for Humanity and Nature in Tokyo, Japan. He specializes in the fields of ecohydrology and hydrometeorology. Prof. Hiyama's research interests include global warming and the human–nature dimension in Siberia; changes in forest–permafrost–groundwater dynamics due to global warming; and soil – vegetation – climate interactions. In iLEAPS, Prof Hiyama contributes to hydrological and natural-human system interface -related themes and acts as a member of iLEAPS-Japan.

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Meehye Lee is a Professor in Korea University in the field of atmospheric chemistry and land-atmosphere chemical interactions. Her expertise includes processes involving ozone, secondary organic aerosol, biogenic volatile organics, aerosol aging processes, aerosol chemical characteristics, and chemical oceanography. In iLEAPS, Prof. Lee is responsible for activities in Korea as the co-chair of the newly launched iLEAPS-Korea.

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Xuemei Wang is a Professor and Deputy dean at National Sun Yat-sen University, China. Prof. Wang specializes in atmospheric boundary layer physics and atmospheric environmental modeling studies. Her research focuses on physical and chemical impacts of urbanization on regional air pollution and land-atmospheric exchange for BVOCs emissions and reactive nitrogen deposition. Prof. Wang serves as an associate editor of Asia Pacific Journal of Atmospheric Science and the reviewer of AR5 for IPCC.

Donatella Zona
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Donatella Zona is a Research fellow & lecturer at the Department of Animal & Plant Science at the University of Sheffield, United Kingdom. Dr. Zona's interest ranges from the mechanisms that the tundra ecosystems adopt to adjust or avoid environmental stress, how climate change affects ecosystem functioning, and to the importance and the challenges of integrating different scales and approaches to understand the patterns and controls on CO_2 and CH_4 fluxes in the Arctic.

Regional iLEAPS activities

iLEAPS-Japan

2nd International Workshop on Future Earth in Asia
February 4-5, 2014
Research Institute for Humanity and Nature, Kyoto, Japan
http://www.chikyu.ac.jp/gec-jp/jp/future_earth/Announcement_FutureEarthinAsiaWS_R3.pdf

AsiaFlux Training & Seminar on Methane Flux and Carbon Cycle
February 23-27, 2014
Bangladesh Agricultural University (BAU), Bangladesh
http://asiaflux.net/asiafluxtc201402/

12th AsiaFlux Workshop
August 18-23, 2014
18-19.8. Pre-conference training course
20-22.8. Main conference
23.8. Field trip
International Rice Research Institute, Los Banos, Philippines
http://asiaflux.net/asiafluxws2014/

iLEAPS-Korea

On 23 August 2013, iLEAPS-Korea was launched with full support from KoFlux, a network linked with the regional AsiaFlux and the global FLUXNET. The research scope of iLEAPS-Korea encompasses the integrated land ecosystem-atmosphere processes and their interactions and feedbacks related to the hydrologic cycle, climate change, and air quality with national and regional emphasis. iLEAPS-Korea will bring together the two communities from ecological and atmospheric sciences and join expertise in atmospheric chemistry, agricultural and forest meteorology, and ecology. "iLEAPS-Korea expects to work in close collaboration with iLEAPS-China and iLEAPS-Japan.

Launch of iLEAPS-Korea
23 August 2013
AsiaFlux conference, Seoul, Korea

iLEAPS-Eurasia

iLEAPS-Eurasia is finalising the bottom-up Science and Implementation Plan for the Pan-Eurasian Experiment (PEEX) initiative. It also concentrates on engaging the relevant observation and modelling communities within Northern Eurasia and China into PEEX work. http://www.atm.helsinki.fi/peex/

2nd PEEX workshop
12-14 February 2013
Moscow, Russia

GEO Secretariat meeting
3 June 2013
Switzerland
PEEX accepted as a GEOSS artic region project

3rd PEEX workshop
26-28 August 2013
Hyytiälä, Finland

Launch of joint CRAICC-PEEX research and educational activity
19 November 2013

PEEX-China Kick-off meeting
20 November 2013
Beijing, China

4th PEEX workshop
4-6 March 2014
St. Petersburg, Russia

iLEAPS-China

In 2013, the iLEAPS community in China proceeded to a new level by launching the iLEAPS-China national committee based on the iLEAPS-China working group initiated in 2006. Co-chaired by Prof. Aijun Ding at Nanjing University, a Scientific Steering Committee member of iLEAPS, and Prof. Xiaodong Zeng at Institute for Atmospheric Physics in Chinese Academy of Science, the iLEAPS-China committee was organised with more than 30 members from about 20 universities, institutes and funding agencies.

Opening ceremony and 1st workshop of iLEAPS-China
24-25 April 2013
Nanjing University, Nanjing, China

4th iLEAPS Science Conference
12-16 May 2014
iLEAPS Early-Career Scientist Workshop
10-12 May 2014
Nanjing University, Nanjing, China

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iLEAPS-ENDORSED PROJECTS AND RESEARCH INITIATIVES

ACPC
Aerosols, Clouds, Precipitation and Climate Research Program

AMMA
African Monsoon Multidisciplinary Analyses

BRIDGING THE GAP BETWEEN ILEAPS AND GEWEX LAND-SURFACE MODELLING

EEE
Extreme Events and Environments

EMISSION, EXCHANGE, AND PROCESSES OF REACTIVE COMPOUNDS

FLUXNET
International Network Measuring Terrestrial Carbon, Water and Energy Fluxes

HENVI Forests and Climate Change

GEIA
Global Emissions InitiAtive

GLACE -CMIP5
Global Land-Atmosphere Coupling Experiment

IBBI
Interdisciplinary Biomass Burning Initiative

IMECS
Interactions among Managed Ecosystems, Climate, and Societies

LUCID
Land-Use and Climate, Identification of robust impacts
Methane Loss From The Arctic

NEESPI
Northern Eurasia Earth Science Partnership Initiative

PEEX
Pan-Eurasian Experiment

TAITA
Multidisciplinary Research Station in Kenya

WELGEGUND
Observation Platform in South Africa