Discussion Forum

There is increasing recognition amongst many in the scientific community that the components of the Earth System are intimately connected, and that interactions extend from local to global scales. This is clearly articulated in the recent Executive Summary of the IGBP Synthesis Book [1] which emphasises the complex, nonlinear behaviour of the Earth System, and which is based on scientific contributions from each of the IGBP projects. The recognition of the multiple interactions across space and time scales has led to a new interdisciplinary direction for IGBP, which promises to be an effective means to advance our understanding of the Earth System, and its human-caused and natural dynamics.

A Broader Perspective on Climate Change is Needed

There are significant consequences of this complexity however, which need to be more widely recognised. One consequence is that prediction (also referred to as projection), cannot by itself be the primary basis on which to plan for the future. This is discussed in another IGBP sponsored paper [2] that presents examples demonstrating that the Earth's climate system is highly nonlinear, that inputs and outputs are not proportional (change is often episodic and abrupt, rather then slow and gradual), and that multiple equilibria are the norm. One example, is the transformation of above average snow pack in the Colorado Rocky Mountains in the mid 1990s to well below average later in the decade and early 2000s (Figure 1a). This abrupt change had a very substantial effect on the reservoir water storage in this region (Figure 1b), where the available water supplies were rapidly depleted and not adequately replenished by the melting of the deficient snowpack. Such transitions in winter precipitation have not been adequately explained using climate models.

Indeed, with respect to climate projections, as we increasingly recognise the diverse, multiple types of global and regional radiative and non-radiative climate forcings, skilful forecasts of future global and regional climate become increasingly more challenging [4]. No climate change model even includes all of the important forcings and feedbacks. To accommodate this uncertainty, an approach of first assessing key societal and environmental vulnerabilities, and then seeking to determine if skilful predictions are possible has been proposed [5].

This new direction to Earth sciences has not been clearly recognised by many, particularly, in the atmospheric science and science policy communities. For example, many, if not most climate change policy studies still focus on global mean surface temperature change as the metric to link to economic impact due to anthropogenic changes in atmospheric composition [6]. Yet climate impacts extend far beyond a global mean temperature and include other anthropogenic climate forcings, such as land use change [e.g.7,8], the multiple forcings associated with aerosols [e.g.9,10] as well as complex feedbacks [11]. The perspective adopted by many in the atmospheric modelling and climate policy communities is that the global models provide skilful projections of the future, and we are just seeking to confirm them with selected observations. However, there are issues with the robustness of climate change models, as has been documented in the peer-reviewed literature [e.g.12,13]. The resistance within the atmospheric modelling community to more rigorous model testing and the general lack of effective dialog within and between disciplines, has constrained advances in our understanding. Rial and colleagues conclude that "it is imperative

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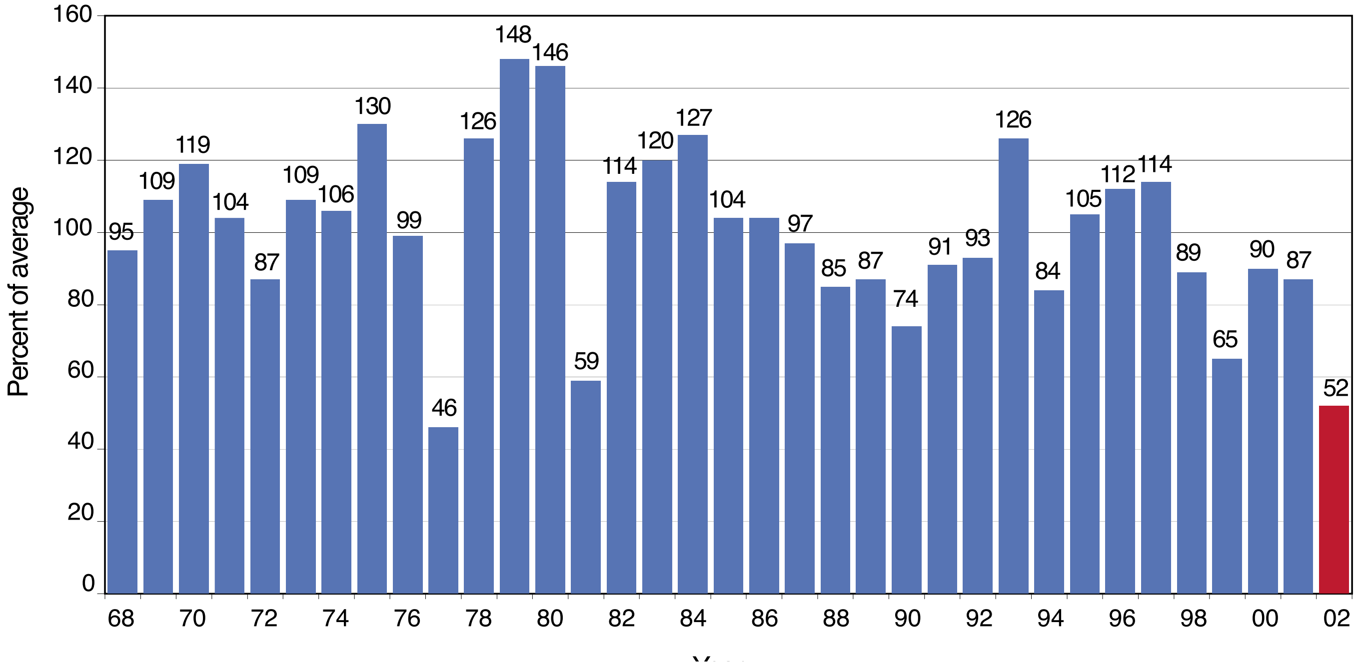

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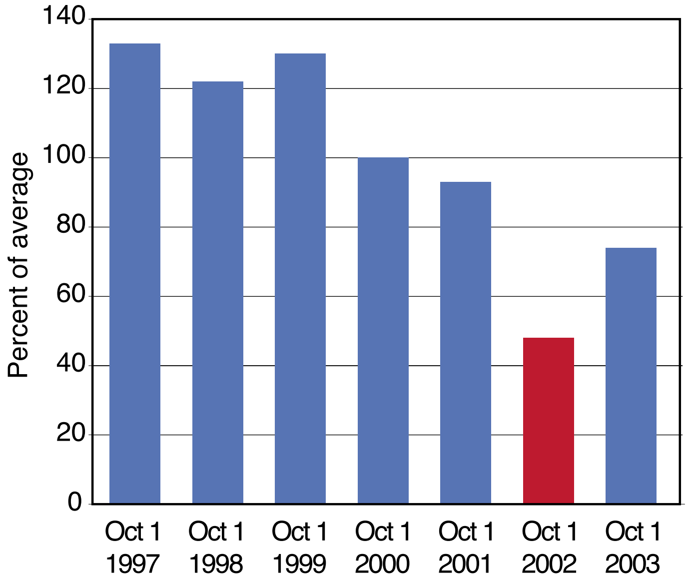

Figure 1. (a) April 1 snowpack percent of average for state of Colorado for years 1968 through 2002 [from 3]. (b) Colorado statewide reservoir storage levels as a percent of average for the end of the growing season (data provided by the Natural Resource Conservation Service, USDA).

that the Earth's climate system research community embraces this nonlinear paradigm if we are to move forward in the assessment of the human influence on climate" [2].

A new vulnerability paradigm is proposed in the BAHC Synthesis Book [14] to address the shortcoming of emphasising global model projections as the primary basis for determining the likely impacts for us of future climate. The vulnerability paradigm, as applied to the Earth System, is a more inclusive approach than prediction. Key vulnerabilities include risks, for example, to regional and global food, water and energy supplies. The environmental and human-caused threats extend well beyond climate.

An example of the application of the vulnerability paradigm is the question of whether population growth, or the climate change predicted by the atmospheric-ocean general circulation models (GCMs), poses the greater threat to potable water [15]. Figure 2 illustrates that the risk, as represented by the model forecasts, is very much dominated by population growth. Another example is the comparison of the risk from damage due to tropical cyclones based on GCM predictions, to the risk from coastal population and infrastructure growth [16]. As with the potable water situation, the larger risk is associated with human population (in this case, their migration to coastal areas) (Figure 3). With respect to the risk from tropical cyclones, the relative sensitivity of societal change to GCM-predicted climate change ranges from 22 to 1, to 60 to 1, depending on the scenarios used. The conclusion from both of these studies is that steps to modulate the future climate via greenhouse emission reductions, based on the GCM predictions, would only address a very small portion of the future risk to potable water and tropical cyclone damage. These comparisons, of course, do not mean that human-caused climate change is not a risk, but if we accept GCM simulations as skilful projections, we actually diminish the importance of threats from climate change, which can be abrupt, but cannot be predicted.

The framework for vulnerability assessments (Figure 4) is place-based and has a bottom-up perspective, in contrast to the GCM-focus which is a top-down approach from a global perspective The vulnerability focus is on the resource of interest – water resources in the case of Figure 4. The challenge is to use resource specific models and observations to determine thresholds at which negative effects occur associated with the resource. Changes in the climate (represented therein by weather and land surface dynamics) represent only one threat to the resource; the climate itself may also be significantly altered by changes in the resource, and there are multiple, nonlinear interactions between the forcings (indicated by the dashed

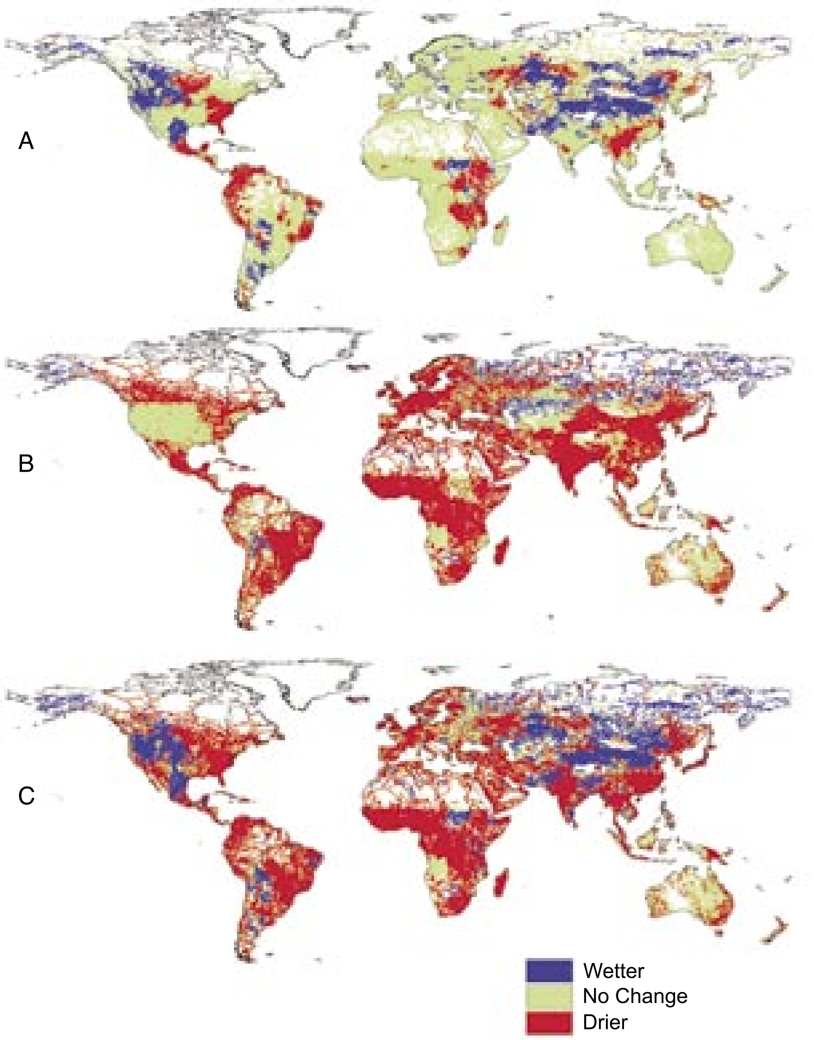

Figure 2. Maps of relative change in water reuse under (A) GCM-simulated climate change, (B) population and economic development, and (C) GCM-simulated climate change and population and economic development [from 15]. Reprinted with permission from Vörösmarty et al., SCIENCE 289:284-88 (2000). Copyright 2000 AAAS.

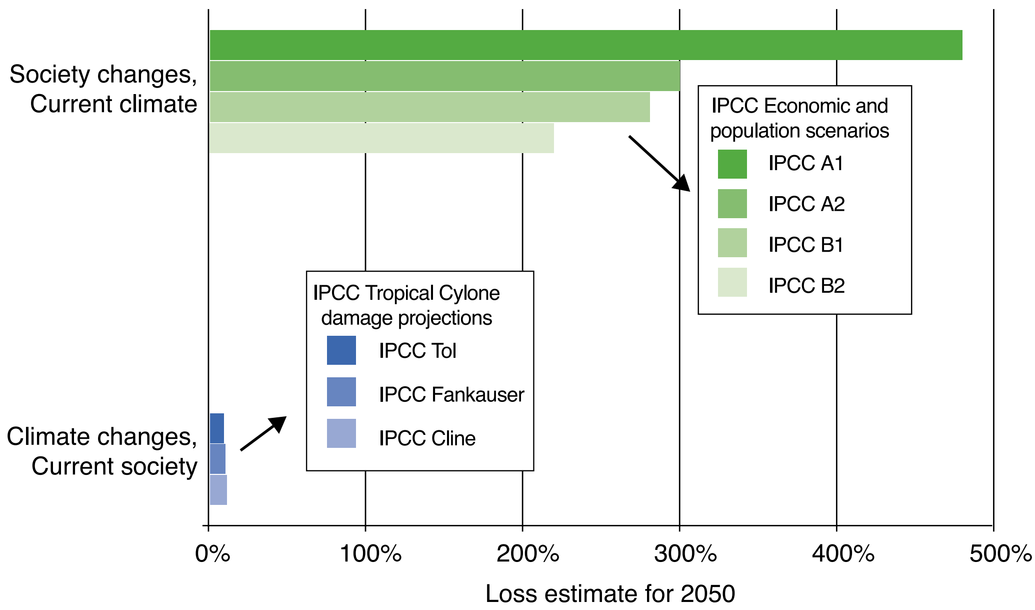

Figure 3. 2050 global tropical cyclone loss sensitivities based on IPCC scenarios and analyses [from 16].

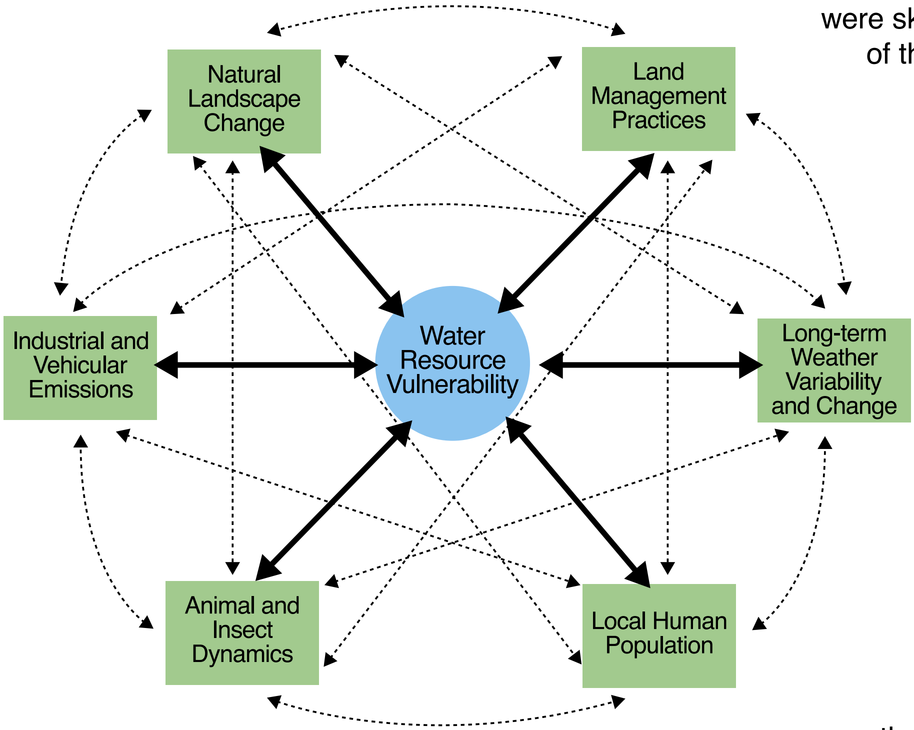

Figure 4. Schematic of the relation of water resource vulnerability to the spectrum of the environmental forcings and feedbacks [adapted from 14]. The arrows denote nonlinear interactions between and within natural and human forcings.

lines on Figure 4). The GCM models, even if they were skilful predictions, still only capture a portion of the threat to the resource.

To accommodate the perspective that the Earth System, including the climate, involves complex forcings and interactions across space and time scales, requires us to be more inclusive in the involvement of the diverse communities performing climate and environmental change research and to elevate interdisciplinary scientists to leadership roles in these communities. IGBP has been extremely successful in developing such an approach, and will continue to promote interdisciplinary and cross-project integration in the coming decade of research. Within IGBP, the emerging AIMES project (Analysis and Integrated Modelling of the Earth System) will provide one focus for investigating complex forcings and interactions within the Earth System.

Roger A. Pielke Sr
Professor, Department of Atmospheric Science
Colorado State University
Colorado, USA
E-mail: pielke@atmos.colostate.edu

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