

Does global environmental change cause vulnerability to disaster?

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1 Contested global environmental change

We have experienced natural hazards since the beginning of history. To those who experience them the world has appeared to cave in when a natural catastrophe occurs. It is only with the advent of economic, social and environmental globalisation that we have, in effect, created the ability to actually make our world cave in and to change it irrevocably. At the same time globalisation makes us more aware of the impacts of natural hazards, and our perceptions of risk from them cannot be divorced from its social setting. The physical basis of many natural hazards is assumed to be periodic but essentially in equilibrium. Some elements of the natural world that wreak havoc when they occur do so with unpredictable timing, but are in themselves predictable after a fashion and at other time scales. But some hazards are changing in nature due to global environmental change. In this Chapter we seek to elucidate what global environmental change might mean in the context of globalisation, to outline some examples of global environmental change and the implications for exposure to natural hazards, and to examine some evidence of whether there has been a change in the scale and scope of environmentally ‘triggered’ natural hazards in the past century.

The term global environmental change is contested and problematic. First, all forms of environmental change are in some sense global or, more accurately, universal. This issue is not merely semantic, but rather frames the way in which risk and response to environmental change are perceived, particularly at the level of public policy. Second, and related, the term global environmental change has become synonymous with a mindset that sees the transnational nature, or global public-good nature, of environmental change as the justification for exclusively global and market-oriented solutions to solve them. This is common across the range of so-called global environmental problems, from biodiversity loss to desertification and climate change (Adger et al., 2001).

In the 1990s the discourses of global environmental change have moved to the center ground of environmental debates, leading to global scale solutions for what are perceived to be significant environmental problems. At the heart of this realization of the global significance of environmental change are the two major environmental problems of depletion of the stratospheric ozone layer and the issue of global climate change. The nature of these two phenomena spurred the framing of international environmental agreements on a scale unprecedented before then, and unprecedented scientific networking and political consensus-building within the scientific

community (see Clark et al., 2001 for example). These two issues, perhaps climate change in particular, have had remarkable political and economic ramifications. But added to these came a myriad of so-called global environmental phenomena for which global science and global policy-making, and the implications for environmental risk and hazard are hugely different. In Table 1 a range of global environmental problems are classified in a two-way typology of systemic and cumulative change, proposed by Turner et al. (1990) and discussed and updated by Kasperson et al. (2001). Systemic risks are those which impact on an environmental system operating at the planetary scale. Cumulative global environmental change is that which becomes important because it occurs everywhere.

Type	Characteristic	Example
Systemic	Direct impact on globally functioning system	(a) Industrial and land-use emissions of greenhouse gases
		(b) Industrial and consumer emissions of ozone-depleting gases
		(c) Land-cover changes in albedo
Cumulative	Impact through worldwide distribution of change	(a) Groundwater pollution and depletion
		(b) Species depletion/genetic alteration (biodiversity)
	Impact through magnitude of change (share of global resources)	(a) Deforestation (b) Industrial toxic pollutants (c) Soil depletion on prime agricultural lands

Table 1 Types of global environmental change

Source: (Kasperson et al., 2001, p. 3).

Environmental threats come in many guises. Although much work on the consequences of global change for natural hazards has been undertaken in the context of global climate change, it is clear that the state of vulnerability to external stress is often determined by the coincidence of external environmental threats with social and economic changes in the political economy context. Local extinction of key species associated with natural ecosystem change, health impacts of changing patterns of disease, degradation of groundwater resources, forest cover change and a variety of other environmental changes in many ways eclipse systemic global change, at least in the short run, in terms of their contribution to the onset of natural disasters.

These other environmental threats are more localised but no less complex in terms of causes, thresholds and dynamic impacts. Kasperson and colleagues (2001) argue that both systemic and cumulative environmental changes pose significant challenges in understanding of both the drivers and processes of change, but also in the predictability of change and the risks involved, given a trajectory of change. At the same time, however, it needs to be recognised that global environmental change is not a given environmental phenomenon – in the case of climate change, upward trends in emissions of greenhouse gases and inexorable rises in temperature and sea level are not pre-determined. These are socially constructed futures over which there is a

degree of space for action. Hence social vulnerability to these global environmental risks is a construct of the physical and the social worlds.

The second problem with global environmental change is the domination of discussion and action in the field by a unshakeable belief in the necessity of global-scale action to the exclusion of locally determined sustainable development priorities. It has been argued that this is, in part, a result of scientific advance in detecting global environmental change phenomena such as climate change, and the rise of global scale scientific endeavors (Shackley and Wynne, 1995). Other motivations may simply be associated with economic and cultural globalisation. Goldman (1998) and others question this hegemony of global environmental change. Goldman argues that the science contributing to this debate is simply another facet of a new dominant paradigm where commons management is a panacea and antidote to all threats. Further he argues that the emerging global commons paradigm is driven by interests that seek to colonise and extract from global commons that were previously only locally controlled.

In summary the term global environmental change is intuitively appealing as it captures some depressing trends in the state of the world's environment. Some of these phenomena may be more accurately described as universal rather than global. We further recognise that the term has particular purchase in some areas of public policy where perceptions of global action have become institutionalised. Nevertheless, we believe that long term environmental change, particularly climate change, can add stress to resource and human systems and can in addition become a major driving force in the changing nature, intensity and frequency of natural disasters.

2 Environmental triggers for natural disasters?

A society experiences a natural disaster when it is subject to an environmental perturbation of such a magnitude that its ability to cope is exceeded. Internal changes within a society may be such that this coping ability is reduced, rendering it more vulnerable to events that are relatively common. Such changes may be social, economic or institutional in nature, or may be the result of a society's interaction with its local physical environment. For example, the impact of extreme rainfall events may be heightened by deforestation that increases runoff and leads to flooding. Alternatively, an individual event may be of such a magnitude that it overwhelms an otherwise functioning and healthy society that has not experienced a reduction in its coping capacity. By definition, such events are unusual, either representing long return-period extremes of natural variability, or resulting from environmental change. Examples of long return-period extremes are particularly severe storms, earthquakes and volcanic eruptions, which may recur on multi-century or millennial timescales. Many examples of such discrete events may be found in twentieth century records, although such events do not fall into any of the categories in Table 1.1 as they are not the result of continuous changes in the ambient physical environment, but rather are manifestations of natural variability.

Examples of natural disasters arising from continuous large-scale environmental change are most likely to be found in the study of climate change. Humans have

adapted to long term changes in climate and other environmental parameters. Indeed the history of agriculture can be seen in terms of adaptation of cropping and livestock systems to an ever-changing set of circumstances (e.g. Bray, 1986; Diamond, 1999). Nevertheless there are examples where climate change may take place so rapidly that societies are unable to adapt to it. Such disasters may be viewed as examples of systemic changes as described in Table 1. With hindsight it is possible to identify past natural disasters as consequences of global climate change. For example, the desiccation of the present arid belt stretching from West Africa to China, some five thousand years ago, was associated with large-scale societal disruption and the rise and fall of civilisations as people either adapted or failed to adapt to arid conditions (Roberts, 1998). While climatic determinism has remained unpopular in many quarters, largely due to its association with nineteenth and early twentieth century pseudo-science concerning differences between races (see, for example, Huntingdon, 1924), there is increasing evidence that large-scale, systematic changes in global climate have had profoundly negative consequences for many societies in the past (Keys, 1999; Cullen *et al.*, 2000; de Menocal, 2001). We can expect current and future systemic change to have similarly dramatic consequences for societies throughout the world, mediated a process of economic globalisation that may magnify or mitigate disruption for any given population group depending on its relationship with the rest of the globalised world. However, without the benefit of hindsight it is extremely difficult to attribute any particular climatic event to systematic climate change.

Climate and weather variability are significant constraining factors in human interventions with the biotic world for agricultural purposes. Agriculture is a major sector through which climate plays a role in economic development, and there is a long history of analysis of the adaptation of human societies to different climates and to changes in climates in terms of food production (Lamb, 1995, for example). At the global scale, a further analogy of global warming as a coevolutionary process has been set out by Schneider and Londer (1984). Human societies have always altered their own environments. The scale of alterations in recent times, through land use change in the past few centuries (Richards, 1990), and through industrialisation since the 19th century, has altered the composition of the atmosphere and hence the global climate (Houghton and Skole, 1990). No part of the world is immune to these changes in the global climate system (the climate is a pure public good in the economic sense). Many parts of the world are affected by feedbacks in the climate system to which human society is forced to adapt. Adaptation may further alter the ambient environment in order to maintain 'equilibrium' in resource use. This global coevolution of the climate system with the economic system therefore involves inanimate parts of nature as well as not just the biotic world.

The most important aspects of the causal relationships between climate and social systems are the scale of analysis and the directness or remoteness of the links between climate and human activities. Thus, for example, social upheaval and ultimately peasant rebellion against colonial French rule during early 20th Century Vietnam occurred concurrently with severe floods and droughts throughout the region (Scott, 1976; Adger, 1999). The link between typhoon flooding and agricultural output is clear, while the impact of reduced harvest with high taxes as a trigger for rebellion is obviously more speculative. Ingram *et al.* (1981) point out that regarding scale, the inevitable concentration on acute periods of crisis may be misleading. Short-term

influences of climate, at the annual or intra-annual scale, do not necessarily imply any long-term causal relationship between climate and human history. Thus the key issues in analysing the role of climate in shaping human society and the evolution of economies and institutions, are the attribution of causality and definition of appropriate scale in the analysis. Technologies, land use and institutions themselves evolve. The driving forces of this evolution are demand for the goods and services provided by land; induced innovation of technologies; and social, political and cultural factors (see Norgaard, 1994). Allied to these, climate makes some contribution to, or acts as a constraint to, particular activities and technologies in many resource-dependent societies.

Cumulative environmental change as described in Table 1 may be the direct result of human manipulation of the local surface environment or of climate change, a systemic process which may in turn be caused by anthropogenic modification of the global atmospheric environment. Cumulative and systemic changes may interact to exacerbate environmental problems, as in the deforestation/flooding example given above. Deforestation may also interact with drought to cause soil degradation and desertification, and the removal or die-back of vegetation due to human activity or climate change may produce new sources of carbon, thus further exacerbating global climate change (Williams and Balling, 1996). Norberg-Bohm *et al.* (2001) summarise the causal structure of environmental hazards in terms of changes in material fluxes, caused by natural processes or human activity, which in turn cause changes in *valued environmental components* (VECs). Changes in VECs modulate the exposure of human populations and systems on which they depend, and therefore have consequences for these populations and systems. Changes in material fluxes may involve processes such as the redistribution of carbon between the ocean or land surface and the atmosphere, the release of pollutants into groundwater, the removal of soil via wind or water erosion, or changes in plant and animal stocks. VECs are simply those systems that humans value for practical or aesthetic purposes, and exposure represents the pathways via which changes in VECs impact on human health, economic well-being, physical infrastructure and ecosystems.

Systemic and cumulative environmental change are intimately linked via complex feedback processes, the most obvious of which are land-atmosphere interactions that involve changes in quantities such as heat and moisture fluxes, rainfall, vegetation cover, soil erosion, atmospheric circulation and global atmospheric greenhouse gas and aerosol content. Rainfall, vegetation, soils and local and regional climate regimes are all examples of VECs, and changes in them affect valued systems by altering exposure to droughts, floods, famines (via reduced agricultural productivity) and other disasters.

Below we explore the relationship between systemic and cumulative environmental change in the African Sahel, and examine their impacts on human populations within the context of vulnerability to famine. The Sahel is chosen as it has experienced marked changes in rainfall amounts and variability over the course of the twentieth century, and consequently has been widely studied. Changes in rainfall have been associated with widespread suffering related to drought and famine, which has been exacerbated by local and global socio-economic trends. However, in recent years there is evidence of effective adaptation to a changed environment.

Environmental change in the Sahel

The Sahel, situated at the southern fringe of the Sahara desert and stretching from the West African coast to the East African highlands (Figure 1), is particularly prone to drought. The region achieved international prominence during the catastrophic drought of the early 1970s, during which hundreds of thousands of people and millions of animals died (de Waal, 1997; Mortimore, 1998). Dry conditions began in the late 1960s, and have persisted until the present day, with some amelioration during the 1990s (Figure 2).

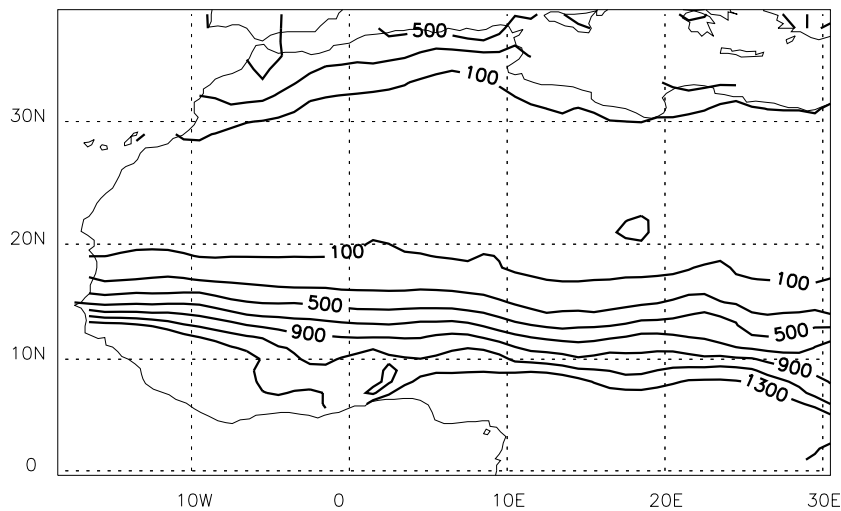


Figure 1: Isohyets representing mean annual rainfall in mm over northern Africa for the period 1901-1996. The Sahel corresponds approximately to the zone of high south-north rainfall gradients where annual rainfall amounts average 100 mm to 700 mm. The data were obtained from the Climatic Research Unit and are described in New (1999).

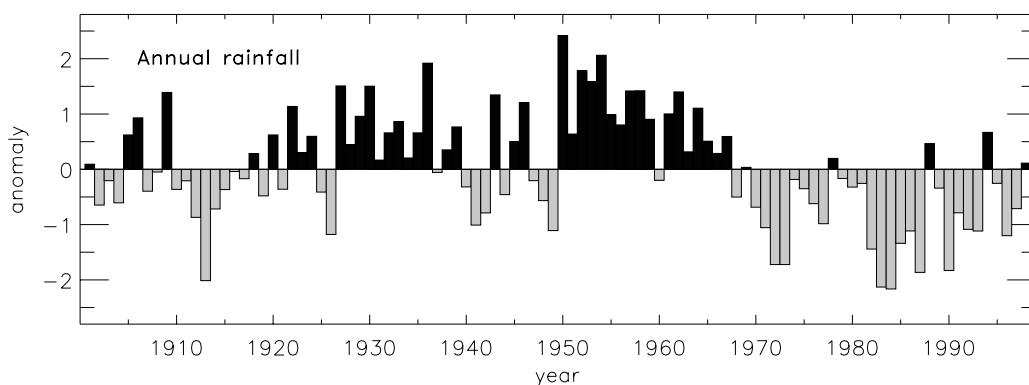


Figure 2: Spatially aggregated annual rainfall anomalies (in standard deviations) representing the region 10° - 20° N; 25° W - 30° E, roughly corresponding to the Sahelian zone. Anomalies are calculated with respect to the mean for the entire series (1901-1998).

The increased frequency of dry years after the late 1960s represents a significant desiccation of the Sahelian region (Hulme, 1996). This desiccation has been associated with a shift from interannual rainfall variability to quasi-decadal scale variability, and an increase in rainfall persistence, or the degree to which one year's rainfall resembles that of the previous year (Brooks, 2000). An important control on rainfall in the Sahel appears to be the contrast in temperature between the northern and southern hemispheres as reflected in patterns of sea-surface temperature (SST) anomalies: when the northern hemisphere oceans are cold relative to the southern hemisphere oceans and northern Indian Ocean, drought is more common in the Sahel (Folland *et al.*, 1986; Street-Perrott and Perrott, 1990; Ward *et al.*, 1993). While the world as a whole has warmed over the twentieth century (IPCC, 2001a), from the late 1950s until the mid 1970s northern hemisphere SSTs cooled. Southern hemisphere SST anomalies (relative to the 1961-1990 average) exceeded those of the northern hemisphere from the early 1970s until around 1990 (IPCC, 2001a). This pattern may have been caused by a number of factors. While such fluctuations may be manifestations of internal oceanic or atmospheric variability, they may also be caused by the following phenomena: (i) reduced solar heating of the northern hemisphere oceans due to atmospheric pollution caused by human activity and increased dust emission from deserts, particularly the Sahara (Charlson *et al.*, 1992; N'Tchayi *et al.*, 1994, Schollaert and Merrill, 1998), (ii) a reduction in the strength of the thermohaline circulation (THC) that drives the Gulf Stream, bringing warm tropical surface waters to the North Atlantic (Hansen *et al.*, 2001), or (iii) injections of cold fresh water resulting from the melting of sea ice or permafrost, which may in turn also suppress the deep-water formation that drives the THC (Hecht, 1997; Cavalieri *et al.*, 1997). It should be noted that the northern Indian ocean, cut off from northern high latitude influences, behaves in the same way as the southern hemisphere oceans. Warming of the northern Indian ocean intensifies local large-scale convection, and may consequently intensify large-scale subsidence over West Africa via the Walker circulation, suppressing convection and therefore rainfall over the Sahel (Shinoda and Kawamura, 1994). Dry years in the Sahel are also associated with a weakening of the south-north circulation over northern Africa, which has been synchronous with tropospheric warming (Shinoda, 1990).

All of the above are observed climatic changes, and all are consistent with scenarios of human-induced climate change as described in modelling studies (e.g. IPCC, 1996). It is therefore highly plausible that they represent manifestations of systemic change driven by emissions of greenhouse gases from twentieth century industrialisation. Global economic activity may well have contributed significantly to the recent environmental changes that have occurred in the Sahel, and which have been associated with widespread human suffering and societal disruption via drought and famine.

It is interesting to note that, despite decades of controversy over locally-driven environmental change in the Sahel, there is little or no evidence that cumulative change in the form of overgrazing, deforestation or other "inappropriate land use practices" has played a role in bringing drought to the Sahel. However, prolonged drought episodes may increase the likelihood that resource exploitation becomes unsustainable, increasing vulnerability, as the land surface is denied the opportunity to recover from dry periods in inter-drought years. Dry conditions appear to be predominantly driven by exogenous processes, and even changes in dust storm

activity, usually explained in terms of land degradation and desertification, may be at least partly due to changes in atmospheric circulation (Brooks, 2000; Brooks and Legrand, 2000).

Environmental change as a factor in the 1972/73 Sahelian famine

The Sahel drought of 1972/3 was the culmination of a downward trend in rainfall that commenced in the 1950s, when rainfall throughout the region was high. By 1972, a large number of Sahelians had already suffered from several years of drought. The only previous year during the period of meteorological records in which aggregated rainfall for the whole Sahel region was similarly deficient was 1913 (Figure 2.2). The cumulative effect of drought in the late 1960s and early 1970s was to increase people's vulnerability in the short term by depleting their stocks of capital, grain and animals, and undermining their health, as well as reducing the amount of available rural labour by encouraging migration (Rau, 1991; Cross and Barker, 1992).

Although the famine of the early 1970s was precipitated by several consecutive years of drought, a number of non-climatic factors had conspired to make societies particularly vulnerable to drought. As in most famines, it was the rural poor who suffered most. The following factors all contributed to the vulnerability of rural communities through political marginalisation and decreased food security: (i) isolation due to poor communications and transport links, (ii) an urban bias in policymaking resulting from poor rural representation, (iii) a focus on short-term economic stabilisation rather than long-term development, (iv) an emphasis on industrial investment and the conversion of agriculture to cash crops at the expense of the production of food for local consumption (Baker, 1987; Shaw, 1987; Rau, 1991). Lack of democracy and the prioritisation of economic growth through industrialisation and agricultural exports, partly as a result of pressure from foreign creditors, contributed to the above (Rau, 1991; Sen, 1999).

Sahelian governments also encouraged nomadic populations to settle in highly marginal areas that, although cultivable in the wet decade of the 1950s, quickly reverted to aridity in the subsequent drought. Populations in such regions were nomadic in order to cope with marginal conditions and highly variable rainfall. Where they were not settled, nomads were pushed into even more marginal areas by the expansion of agriculture, reducing their coping options in times of drought (Horowitz and Little, 1987).

It appears that a combination of sustained drought, altered demographics, social engineering and external political and economic factors had increased vulnerability to drought in the Sahel during the early 1970s.

Adaptation

The Sahel has not experienced a repeat of the massive, systematic, regional-scale famine that occurred in the 1970s, despite continued rainfall scarcity (Mortimore, 2000), although food scarcity has continued to affect populations in some locations (Cross and Barker, 1992). Regional rainfall deficits were greater than or comparable

to those of the early 1970s in 1983, 1984, 1987 and 1990 (Figure 2), and some locations continued to experience severe rainfall deficits throughout the 1990s (Mortimore, 2000). Evidently it was not drought alone that led to the widespread human suffering of the early 1970s: the socio-economic factors that led from drought to famine via increased vulnerability have been briefly summarised above.

As well as disrupting societies on a large scale, drought and famine can also act as a trigger for adaptation. Because of its location in the transition zone between humid equatorial Africa and the hyper-arid Sahara, the Sahel is highly sensitive to variations in global and regional climate which modulate the West African Monsoon. As a consequence of the resulting high climatic variability, its inhabitants have been developing highly effective strategies to cope with drought since the region became semi-arid some four or five thousands of years ago (Andah, 1993; Casey, 1998). These strategies, including agricultural diversification, labour export and migration (e.g. Rain, 1999) have survived despite centuries of foreign interference and decades of state neglect and/or mismanagement (e.g. de Waal, 1997). While the factors listed earlier in this chapter mitigated against successful short-term adaptation to persistent drought conditions in the early 1970s, the massive societal disruption caused by the famine paradoxically appears to have both stimulated and facilitated local autonomous adaptation. The changed socio-economic landscape of the region provided opportunities, and change was also encouraged by other external factors.

For example, the removal of state subsidies on artificial fertilisers encouraged people to turn to integrated crop and livestock management, increasing animal numbers in order to provide manure, which is used instead of artificial fertiliser (Mortimore, 2001). In many locations cash crops have been replaced by food crops, and more resilient crop varieties have been introduced (DFID, 2000). Soil conservation and well-managed tree plantations are also emphasised (Mortimore, 2001). These local-level adaptation strategies have enabled farmers to increase soil fertility and maintain or even increase food production despite reduced rainfall and a shortening of the growing season (Rain, 1999; Mortimore, 1998, 2001). Indeed, even for cash crops, which are traditionally viewed as environmentally damaging, evidence from Mali and elsewhere suggests that cotton and other cropping systems are adaptable. Cash crop farmers act to minimise livelihoods risks from their exposure to economic as well as environmental shocks (Benjaminsen, 2001).

Adaptation has not been restricted to farm management. Income diversification has also played a part in reducing vulnerability to drought (Mortimore, 2001). Although the growth of cities is associated with a host of problems, urban centres provide a market for locally produced foodstuffs and surplus farm labour. Migration and labour export have always been coping strategies in the Sahel, with migration peaking in drought years (Rain, 1999). However, they are not simply measures of last resort, but represent an important source of income for rural communities wishing to diversify their resources and reduce their vulnerability to drought (DFID, 2000).

Globalisation and vulnerability - lessons from the Sahel

We explore in this chapter the contribution of environmental change to vulnerability to natural disasters. The Sahelian famine of the early 1970s certainly qualifies as a

natural disaster, given that it was precipitated by drought and killed large numbers of people and animals. Furthermore, the drought was a manifestation of regional, and possibly global climate change. The increased frequency of dry years after the onset of desiccation and the shift to quasi-decadal rainfall variability undoubtedly increased people's vulnerability in the short term, as repeated consecutive dry years meant that there was little opportunity to recover from one drought and prepare for the next.

Referring to rainfall changes and agriculture in the Kano-Maradi region which straddles the borders of Nigeria and Niger, Mortimore (2001) states that "Climate change has not undermined the basis of economic life. Positive trends in soil fertility and tree management, in a context of intensifying drought stress, are remarkable in such circumstances." Whereas unusually persistent drought may increase people's vulnerability in the short term, in the medium to long term it may encourage adaptation. Rather than causing vulnerability, environmental change in the Sahel has increased the *exposure* of the population to one particular type of natural disaster: drought, and by extension, drought-associated famine. Vulnerability is not simply a function of exposure, but also of people's capacity to adapt to change. If the latter remains unchanged, increased exposure will lead to increased vulnerability.

The lessons of the Sahel are common throughout history and throughout the world. Vulnerability is caused by inequality, inappropriate governance structures, and maladaptive economic and agricultural development. In the Sahelian case, an emphasis on urban industrialisation in countries with predominantly rural economies, and an emphasis on cash crops and export earnings in countries where much of the population cannot afford or access imported foodstuffs, is a recipe for increased national vulnerability. Paradoxically, it may require the shock of a catastrophic natural disaster, or a shift away from policies originally designed to encourage national economic growth, before national populations can begin to adapt by developing a sustainable rural economy. Most often though this opportunity comes from political reform rather than from natural disaster. The rebuilding of Honduras after Hurricane Mitch is a prime example where an apparent clean slate does not necessarily lead to reform – the status quo in uneven development is simply replicated (Jamieson and Glantz, 2000).

The Sahelian example also demonstrates the importance of local-level adaptation, and illustrates how people may adapt effectively outside of a global commons management framework. The maladaptive nature of policies ostensibly designed to increase national prosperity demonstrates the danger inherent in a "top-down" approach to development, particularly when it is dictated by the global economic paradigms of the day, paradigms that often exist in a vacuum as far as considerations of the physical world and rural communities are concerned. But all countries are subject to the vagaries of globalisation. Market liberalisation and decentralisation of governance structures in Vietnam during the 1990s have exacerbated vulnerability to typhoon hazard in that country because the basis for co-ordinated local level collective action has been undermined (Adger, 2000).

The determination of developing countries' national economic and social policies by remote institutions driven by a particular ideology, such as the current free-market ideology promulgated by the rich nations and the global economic institutions, therefore holds dangers for developing countries with large populations of rural poor

who are largely excluded from the global economic system. However, globalisation may also provide opportunities for income diversification and access to markets, decreasing vulnerability to famine. There is evidence that urban markets created by oil revenues, and derivative incomes, acted to mitigate vulnerability to famine in northern Nigeria in the 1970s (Mortimore 1998, but see Watts, 1981). These findings suggest that globalisation may benefit the poor of the developing world in some instances as long as it allows them sufficient space for autonomous adaptation, and does not encourage states to undertake maladaptive social and economic engineering projects. Nonetheless, globalisation in any form is likely to produce winners and losers as long as it is associated with changes in existing orders.

3 Trends in 20th century climate related disasters

It is in the analysis of trends in natural disasters and their economic and human costs that the consequences of combinations of external environmental and internal socio-economic factors become most apparent. For example, data from the insurance industry indicate that global economic losses (in 1999 US\$) from catastrophic weather events increased by a factor of ten between the 1950s and the 1990s; the number of events associated with these losses increased by more than a factor of five (IPCC, 2001b). However, these increases are not necessarily due to changes in climatic regimes or the frequency of extreme events, and may be explained at least partially by changes in recording practices or the extent of insurance cover.

The Emergency Events Database (EM-DAT) of international disasters provides a further means of analysing frequencies and impacts of disasters related to extremes in climate. This dataset is widely used in the field of disaster studies, and is available from the Centre for Research on the Epidemiology of Disasters (CRED) at the Université Catholique de Louvain in Brussels (<http://www.cred.be/emdat>). While EM-DAT nominally represents the entire twentieth century, data coverage is poor for much of this period, as apparent from the number of events without associated data for economic damage or numbers of people killed and otherwise affected. Data coverage improves markedly from around 1970; data prior to this date should be treated with caution, a conclusion also drawn by other authors (e.g. Charvériat, 2000).

Figure 3 shows global annual incidences of floods, windstorms, epidemics and landslides (including avalanches), the four disaster types that exhibit the most striking trends in the EM-DAT database over the final decades of the twentieth century. Other types of disaster exhibit considerable variability. Droughts and wildfires exhibit a peak in the early-mid 1980s and another around the turn of the century (Figure 4); a large component of the 1980s drought maximum is likely to be a result of the drought in the Sahel, which affected a number of countries. Recorded heat waves and cold waves increase in frequency after 1980, and insect infestations exhibit a large peak in the late 1980s. All categories except insect infestations exhibit a large frequency maximum for the year 2000, and of these the year 2000 is associated with the largest number of occurrences except in the case of droughts and windstorms, for which it is exceeded only by 1983 and 1990 respectively.

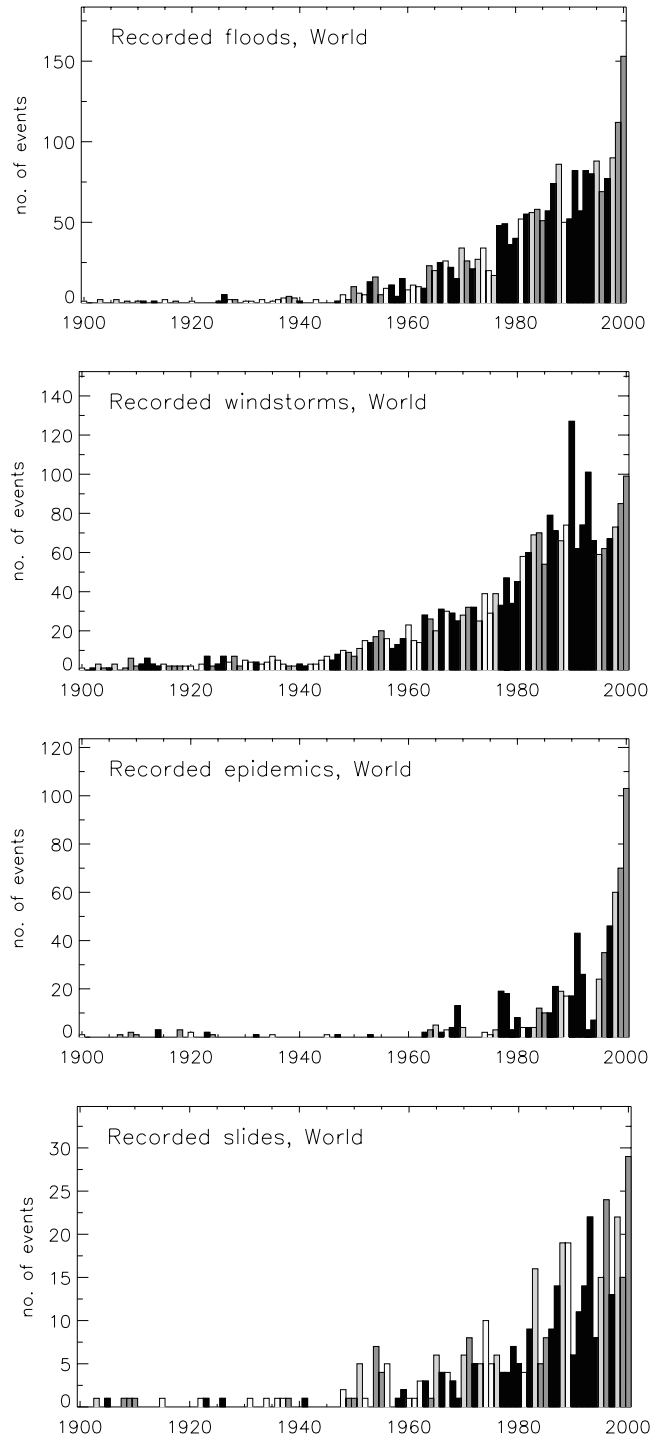


Figure 3 Annual global occurrences of four disaster types. Dark bars represent El Niño years; La Niña years, years representing a transition from El Niño to La Niña or vice versa, and non-ENSO years are represented by progressively lighter shading. Note the different scales on the vertical axes.

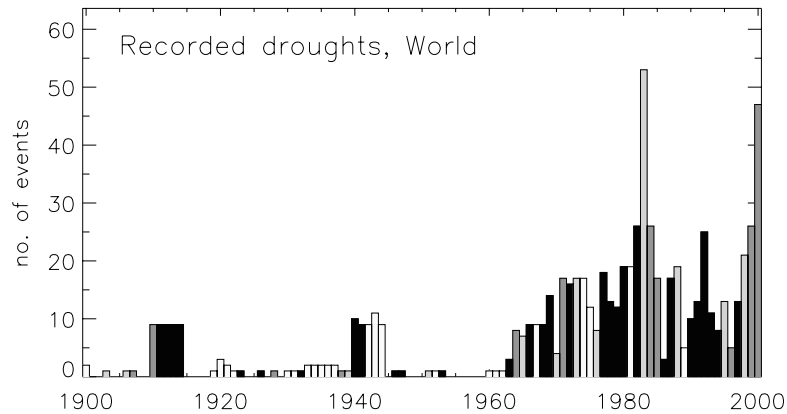


Figure 4. Global drought occurrence, showing a maximum at the time of the driest period in the Sahel.

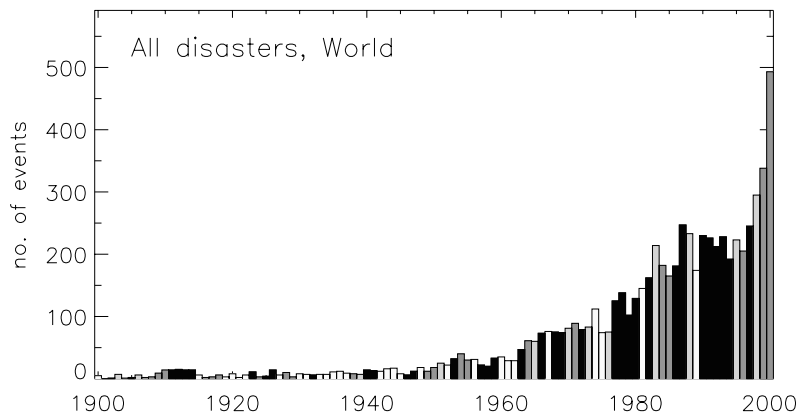


Figure 5. Global frequencies of all disaster types.

All disaster types except drought and insect infestations exhibit upward trends in frequency of occurrence. Aggregated disasters show an upward trend interrupted by a slight decline from the late 1980s until the late 1990s (Figure 5). This feature is encouraging, as it suggests that the frequency of recorded disasters is not merely rising in parallel with constantly improving recording practices. Similarly, the peak in drought frequency at the height of the Sahelian dry period indicates that the data do indeed reflect variability in extreme event frequency

It is difficult to ascertain whether the above trends in recorded disaster frequencies are the result of changes in the return periods of weather extremes, better reporting practices, or other factors. An event is much more likely to be recorded if it affects large numbers of people, or the physical infrastructure or economy of a country. As populations grow and expand into areas that are more climatically marginal or more exposed to weather extremes, climatic variability is more likely to adversely affect human beings or the systems on which they depend. Numbers of people killed and otherwise affected (injured, displaced or requiring immediate assistance) by climate-related disasters exhibit a trend similar to those in Figure 3. However, it is interesting to note that four years are associated with greater numbers of killed and otherwise affected than the year 2000, and the largest entry is for 1987.

It is probable that the increased frequency of recorded disasters results from a combination of climatic change and socio-economic and demographic changes. While the evidence for climatically-driven changes in disaster frequency is limited, the IPCC (2001a) reports changes in some extreme climate phenomena. The Third Assessment Report (TAR) states that “it is likely that there has been a widespread increase in heavy and extreme precipitation events in regions where total precipitation has increased, e.g. the mid- and high-latitudes of the northern hemisphere.” However, it reports that there is little evidence for increases in tropical storm intensity and frequency, and uncertainty as to whether mid-latitude cyclones have exhibited any such trends. Observed increases in areas classified as severely wet and severely dry are “closely related to the shift in El Niño – Southern Oscillation (ENSO) towards more warm events since the late 1970s” and coincide with record high global mean temperatures. However, Figure 3 and other series (not shown) indicate that there is no systematic relationship between ENSO events and the annual global frequency of climate-related disasters.

Changes in climate phenomenon	Confidence in observed changes (latter half of 20 th century)	Confidence in projected changes (during 21 st century)
Higher maximum temperatures and more hot days over nearly all land areas	Likely	Very likely
Higher minimum temperatures, fewer cold days and frost days over nearly all land areas	Very likely	Very likely
Reduced diurnal temperature range over most land areas	Very likely	Very likely
Increase of heat index over land areas ¹	Likely over many areas	Very likely over most areas
More intense precipitation events	Likely over many northern hemisphere mid to high latitude land areas	Very likely over many areas
Increased summer continental drying and associated risk of drought	Likely in a few areas	Likely over most mid-latitude continental interiors.
Increase in tropical cyclone peak wind intensities	Not observed in few analyses available	Likely over some areas
Increase in tropical cyclone mean and peak precipitation intensities	Insufficient data for assessment	Likely over some areas

Table 2 Estimates of confidence in observed and projected change in extreme weather and climate events.

Source:(IPCC (2001).

Note: Heat index is a combination of temperature and humidity that measures effects on human comfort.

The IPCC (2001a) report that there is no evidence for widespread systematic changes in severe local weather events such as tornadoes, thunder days, lightning or hail, although changes have occurred in some regions. Trends represented by increases in minimum temperatures, maximum temperatures, number of hot days, and heat index (a combined measure of heat and humidity related to human comfort) are reported as “likely” or “very likely”, and an increase in continental drying and drought risk is reported as “likely in some areas” (see Table 2). Records of hazards such as floods, slides, wildfires, epidemics and insect infestations are not addressed directly in the TAR, but such events are likely to be associated with increases in precipitation and continental drying as described above.

Nonetheless, the relative importance for disaster frequencies of twentieth century climate change when compared with changes in human vulnerability is still unclear. The period of maximum global warming, i.e. since 1970 (IPCC, 2001a), has also been a time of accelerating globalisation during which humanity has become collectively more aware of global environmental problems and human vulnerability. The discovery of the ozone “hole” alerted national governments and the public in the developed world to the existence of global environmental problems, and interest in climatic and environmental change has been sustained by bodies such as the Intergovernmental Panel on Climate Change (IPCC) and events such as the “Earth Summit” in 1992. Events such as the Sahelian famine of the early 1970s and the Ethiopian famine of the mid 1980s have led to a greater awareness of natural disasters and humanitarian crises. Factors as disparate as the formulation of the Kyoto Protocol on Climate Change and the attacks on the United States in September 2001 have raised levels of concern about poverty and social and political exclusion. At the same time, economic growth and global economic integration have increased the value of capital assets at risk from natural disasters, just as population growth has increased numbers of people at risk. All of these factors have led to greater efforts to monitor environmental variability and change and their impacts.

4 Future Directions

There is no reason to believe that recent positive trends in natural disaster frequency and associated economic damage will reverse in the near future. The expansion of economic activity and settlement, as populations grow and economic globalisation continues, will result in the exposure of greater numbers of people and greater quantities of capital assets to natural disasters. Where natural resources are not managed sustainably, cumulative environmental change in the form of processes such as soil loss and degradation, groundwater pollution, use of fossil water reserves, increased runoff potential due to deforestation, and overfishing will increase exposure of vulnerable communities to hazards such as food and water scarcity and flooding,

and their vulnerability to drought, famine and disease. Climate change is very likely to exacerbate such anthropogenic cumulative change by increasing exposure to risk.

Although there is no conclusive evidence that recent disaster trends are the result of climate change, the global temperature record suggests that large-scale rapid anthropogenic warming has only commenced within the past several decades. We are therefore working with relatively short timeseries of data relating to the new “artificial climate” in which “all of our weather is influenced to a greater or lesser extent by the human alterations to the global atmosphere” (Hulme, 2002) that might be altering exposure to natural disasters. These series may be too short for the identification of disaster trends, and they are made ambiguous by the factors discussed in the previous section. It is therefore instructive to turn to modelling studies and theoretical considerations in order to illuminate our understanding of possible future relationships between climate change and natural disasters. The most comprehensive assessment of potential future climate change is the series of reports of the Intergovernmental Panel on Climate Change, and the following discussion of projected changes in climate and their impact on exposure is based on the findings of Working Group I of the IPCC (2001a), unless otherwise indicated.

Although there is much uncertainty concerning future climate change, we can be almost certain that temperatures and sea-levels will continue to rise in the near-future. Higher baselines of temperature and sea-level will increase exposure via higher frequencies of extreme events that are temperature and sea-level dependent (Figure 6). Increased temperatures over land will lead to more hot spells, which will increase heat-stress on living organisms and also lead to enhanced evapo-transpiration, thus increasing agricultural demand for water while reducing surface water availability, increasing the risk of drought. These factors may be offset by increases in precipitation, although increases in mean precipitation are most likely in middle and high latitudes. Increases in precipitation extremes are likely to be widespread; in the tropics and sub-tropics a higher frequency of extreme rainfall events is more likely to increase the number of floods and epidemics than mitigate drought, the incidence of which is likely to increase due to projected continental drying. Regions such as the Sahel are particularly vulnerable to increases in rainfall variability and extremes; the timing of rainfall is as important as the amount of rainfall for agriculture in the Sahel. Extreme rainfall events in semi-arid regions are also likely to lead to increased soil erosion; analysis of interannual variability in rainfall and atmospheric dust content in the Sahel indicates that episodic rainfall events play an important role in generating the erodible material that is necessary for the development of dust storms (Brooks and Legrand, 2001). Atmospheric dust is a major cause of respiratory problems in regions such as the Sahel (Shinn, 2001), and a shift towards higher rainfall variability and intensity might therefore have a negative impact on health.

Elevated temperatures over the ocean are likely to affect the development of tropical storms. Although there is little evidence that tropical storm frequency has increased in recent decades or will increase in the near future, the IPCC (2001a) suggests that tropical storm intensities may increase, and that “mean and peak precipitation intensities are likely to increase appreciably”. This would have important implications for human mortality resulting from storm-related flooding and landslides (Cockburn *et al.*, 1999). Elevated sea-levels will increase the risk of flooding from storm surges for coastal communities, as well as exacerbating coastal erosion and groundwater

contamination. With the number of people living below the 1,000 year flood level estimated to rise to 600 million by 2100 (Nicholls and Mimura, 1998) increased exposure of coastal populations to climatic risk is likely to enhance nations' vulnerability to natural disasters by a significant amount.

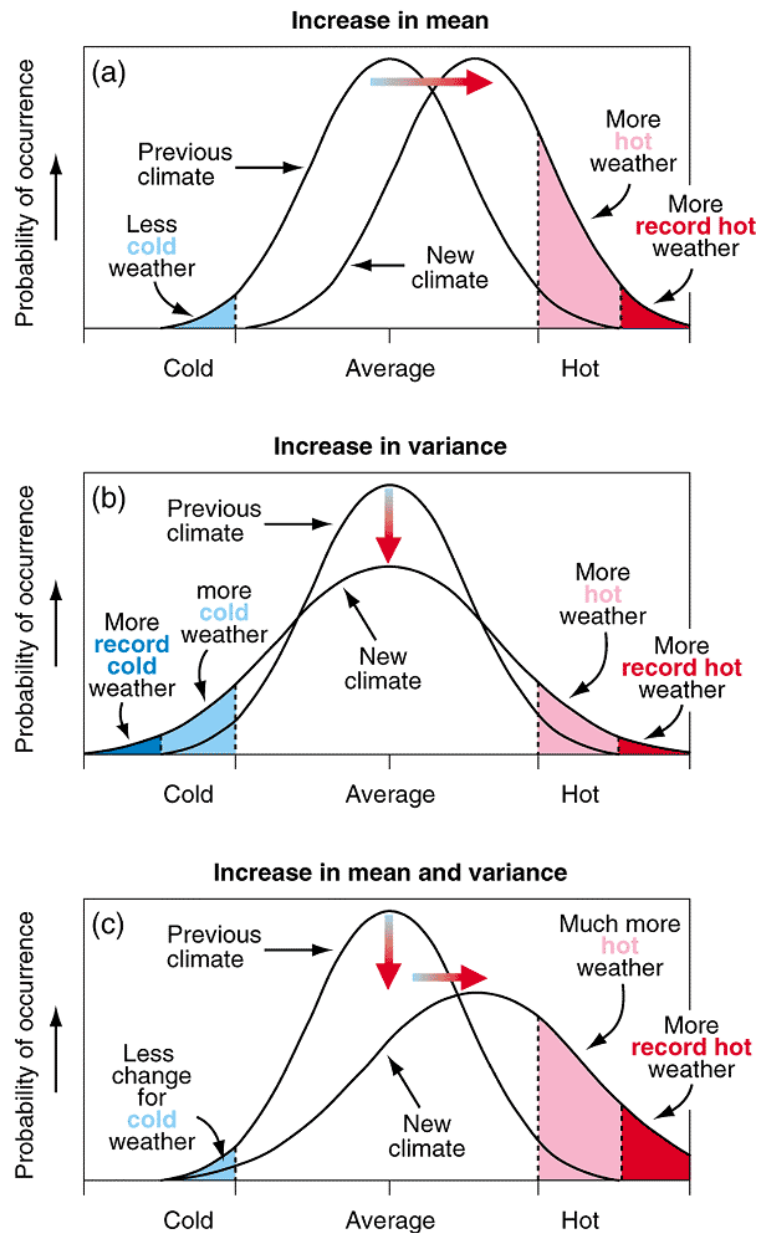


Figure 6. Changes in the probability of extreme events with increases in mean and variance for temperature. Reproduced from IPCC (2001a).

The above argument concerns the consequences of rises in global mean temperature and sea-level, to which we are committed because of past emissions of greenhouse gases and future emissions that will certainly continue well into the twenty first century, increasing the greenhouse gas content of the atmosphere for years, and probably decades, to come. We can be certain that climate change will occur, and we can also be certain that population growth will increase population densities in areas exposed to climatic risk. What is highly uncertain is the magnitude, rapidity, and even

nature of climate change over the coming decades and centuries. However, this uncertainty is not simply a result of our lack of understanding of the climate system, but is also a function of our lack of knowledge as to how human societies will develop. The IPCC Special Report on Emissions Scenarios (SRES) uses a number of modelling studies to demonstrate that the extent and rapidity of climate change over the twenty first century will depend strongly on the nature of the process of globalisation. Important factors include the degree and rapidity of global economic integration; the rate at which alternative energy sources are developed; the amount of emphasis on environmental protection, sustainable development and social equity; the extent to which solutions to environmental problems and poverty are local as opposed to global; and the rate of population growth. These and other factors will interact in a complex manner to determine the evolution of greenhouse gas emissions, and hence of the coupled system comprising human society, the surface environment and the global climate.

Choices made by individuals, institutions and governments over the next few decades will determine the degree and nature of future climatic and environmental change for millennia to come (Burgess *et al.*, 2001). Twenty first century choices regarding energy technologies, economic models, intellectual property and technology transfer, equity and sustainable development, and patterns of consumption will determine the exposure and vulnerability of future generations. While the process of globalisation may not be inexorable, further economic integration, technological development, cultural exchange and human migration will continue in the short to medium term. The future nature of our world, globalised or otherwise, will depend on how these processes are managed. Global environmental change will be a fact of life for future generations, and it will alter their exposure to environmental risk and hence partially determine their vulnerability to natural disasters. The extent of the change with which they have to cope, and the options available for minimising their vulnerability, will be decided by the politics of today.

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