Global Change and Southern Africa

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Abstract
The developing nations of southern Africa have previously been identified as vulnerable to the vagaries of global change, particularly in terms of future climate change. This paper explores recent climate change scenarios for the region in terms of some representative sectors of the environment-society interface, namely biodiversity, agriculture and related land uses, water resources and health issues. It is concluded that the impacts of predicted climate changes over the next century are likely to be very marked indeed. Biome distribution, agriculture, rangelands and water resources are highlighted as being negatively impacted in ways that will increase the vulnerability of the great majority of the region’s population to natural hazards. The potential impact of these changes on the prolific biodiversity of southern Africa is clear. Holistic policy responses, incorporating both environmental and human development concerns, are required in the near future if a crisis is to be averted.

KEY WORDS Climate change; impacts; biodiversity; agriculture; water resources; health

Introduction
It is clear from previous studies that southern Africa faces significant environmental and economic challenges as a consequence of global climate change (Magadza, 1994; Hulme, 1996). In the decade since the publication of Hulme’s 1996 review, new – more highly resolved – climate change scenarios have emerged (for example, IPCC, 2001) that suggest these and, indeed, other African countries remain vulnerable to the vagaries of a rapidly changing environment, more especially against the background of a global economy that continues to marginalise developing nations (Halsnaes et al., 2002). As Adger et al. (2005) note, there have been key developments during recent years in respect of the interaction between global changes and human societal responses. These include a more sophisticated (although admittedly still limited) understanding of the dynamics of the earth system coupled with a greatly expanded available data set. The emergence of a greater diversity of social science perspectives on global change is also important, in particular the recognition of complexity in terms of vulnerability, resilience, resistance and the diversity of the human response (Adger et al., 2005). In part due to their level of vulnerability and in part due to the high proportion of the global population that they house, developing countries as a whole have been an important focus of global change impact studies (Ravindranath and Sathaye, 2002; Markandy and Halsnaes, 2004) although, with the notable exception of South Africa, those in southern Africa have enjoyed relatively little attention in this regard.

Global climate change is a critical issue, both in Africa in general and in southern Africa (Desanker and Justice, 2001). It is timely, then, that the situation in the region be reviewed in light of the latest available climate change scenarios. This paper aims briefly to review the scenarios and then goes on to explore the responses of some key elements of the environmental and economic systems in southern Africa. In particular, the paper focuses on the first-order implications of recent and predicted future climate change...
for four important sectors: ecosystems and biodiversity; forestry, agriculture and rangelands; water resources, and health issues. This is not a comprehensive list for it does not include all elements of the environment-society interface, for example possible impacts on marine ecosystems and fisheries; but it is representative of the range of sectors and likely impacts in the region. ‘Global change’ here is interpreted mainly as predicted climate change over the next 50 years or so, together with its associated environmental variables, rather than economic changes such as globalisation, although issues related to such processes are highlighted where relevant.

For the purposes of this paper, southern Africa is defined as the geographical area encompassed by the countries of Namibia, Botswana, Zimbabwe, Mozambique, South Africa, Lesotho and Swaziland (Figure 1). Examples are drawn from across the region where possible, although relevant studies from outside South Africa are still few in number. Nevertheless, South Africa itself has examples of all the regional ecosystem types and, despite its relative wealth and unusual juxtaposition of developed and developing economies within one country, is sufficiently representative of the region to suggest that the responses to change are relevant beyond its borders. Moreover, South Africa has completed a recent ‘country study’ on the potential effects of climate change (DEAT, 2000), although this was not referred to in Smith and Lazo’s (2001) global review of such studies.

Climate change scenarios
Globally, climate change scenarios rely on the application of General Circulation Models (GCMs), principally to a so-called ‘doubled CO$_2$’ situation. Initially, such models were at a very coarse scale of spatial resolution and failed to couple the ocean and atmosphere systems. More recently, however, there have been significant developments in the number and complexity of global climate parameters handled by the models, and there is now greater confidence that they can produce valid scenarios for conditions under perturbed atmospheric chemistry and land cover situations (Houghton, 2004). Due to restrictions in computer power, outputs even of these more skilful GCMs remain only at a grid size of around 300 km $\times$ 300 km, and as such they have limited application to predictions of impacts at a scale that allows for meaningful policy response. All such models reveal positive mean annual temperature anomalies in the future, in the range of two to three degrees Celsius for southern Africa.

![Figure 1](image-url) Map of southern Africa showing localities mentioned in the text.
Precipitation, in terms of mean annual amounts, seasonality and length and intensity of wet/dry seasons is, however, a more cryptic parameter. Hulme’s (1996) assessment was based on models with a grid size of 0.5° latitude by longitude and suggested generally drier climates with increased rainfall variability across southern Africa. The third assessment report of the International Panel for Climate Change (IPCC, 2001) based its predictions on models with a similar spatial resolution, although the outputs were more sophisticated in their use of several different emission scenarios. Again there is consensus on significant climate warming as an outcome, increases in the severity of flood events and, for southeastern Africa at least, reduction in mean annual precipitation (Hulme et al., 2001).

The advent of regional climate models (RCMs) employing statistical downscaling (Cavazos and Hewitson, 2005) to produce outputs with a grid size of 50 km × 50 km or less has facilitated application of model predictions at a geographical scale more useful at the policy-response level. The most recent scenarios (Hewitson and Crane, 2005) are derived from three GCMs: HadCM3, ECHAM4.5 and CSIRO Mk2. Given that temperature warming per se (of the order of two to three degrees Celsius) is widely predicted and uncontroversial, the models instead employ statistical downscaling to focus on scenarios of rainfall in particular. The outputs are for South Africa only, but are certainly relevant to and indicative of the nature and scale of precipitation changes in the region in general. The GCMs produce a spatially cohesive set of predicted changes and converge on a downscaled solution that suggests a) increased summer rainfall in the eastern part of South Africa and the interior, and b) reductions in winter rainfall in the Western Cape.

Typical model outputs (Hewitson and Crane, 2005) suggest increases in mean annual rainfall (in places anomalies exceed 100 mm) over the convective regions of the eastern and central plateau and the Drakensberg Mountains, while a reduction in rainfall is predicted for those parts of the sub-continent under the influence of winter frontal systems (Hewitson and Crane, 2005). The scenarios go beyond simple predictions of mean annual precipitation anomalies and also suggest an increase in the frequency of heavy (greater than 20 mm per day) rainfall events. According to one of the models explored (ECHAM), some areas in the eastern part of the region would experience an additional two days per month of heavy rain (Figure 2); tangible evidence that most GCMs forecast an increase in the frequency and magnitude of extreme events under elevated greenhouse gas concentrations. That such changes are already underway is a contention supported by the work of Mason et al. (1999), who analysed historical rainfall data for southern Africa and noted an increase in the intensity of extreme rainfall events for 1931–1960 and a further increase from 1961–1990 over 70% of South Africa. Regionally downscaled models further indicate variations in the number of raindays per month and in some instances a decrease in this parameter coinciding with an increase in mean annual rainfall and the frequency of heavy rain days, all of which point to climate scenarios that are significantly more dynamic and variable than those of the present day.

Further advances in the ability of such models to skilfully predict future climates are anticipated, although the dynamics and influence of changes in the El Niño Southern Oscillation (ENSO) are a key challenge (Hulme et al., 2001; Mason, 2001). Indeed, there remain significant limitations in the predictive ability of downscaled circulation models. For example, changes in the frequency and magnitude of important synoptic events such as tropical or extra-tropical cyclones are difficult to predict (Hudson and Hewitson, 1997; Sinclair et al., 1997; Henderson-Sellers et al., 1998; Jury et al., 1999). Recent advances (see Landman et al., 2005) show that regional models can produce cyclone-like vortices and further iterations may soon provide more realistic simulations of tropical storm genesis. Such analyses may in time show how global climate change may influence the genesis of these systems in the southwestern Indian Ocean (Landman et al., 2005) but, for now, the general conclusion reached by Henderson-Sellers et al. (1998), that tropical cyclones are not expected to change significantly with global warming, needs to be accepted for southern Africa.

**Impacts of climate change on ecosystems and biodiversity**

Given that southern Africa contains two of the world’s top 25 so-called ‘hotspots’ (Myers et al., 2000), it is hardly surprising that considerable research effort has been expended in assessing the possible impacts of global climate change on biodiversity in the region. The *South African Country Report on Climate Change* commissioned by the Department of Environment Affairs and Tourism (DEAT, 2000) has three chapters devoted
to the issue of impacts of change on plant, animal and marine diversity respectively. Rutherford et al. (in DEAT, 2000) suggest that projected climate changes on the basis of the HADCM2 model are sufficient to reduce the area suitable to South African biomes to perhaps only one half of their current spatial distribution (Figure 3). Significant reductions in such areas are modelled to occur in the western, central and northern parts and include the almost total displacement of the existing Succulent Karoo Biome and a marked eastward relocation of the Nama-Karoo Biome (Rutherford et al. in DEAT, 2000; Hannah et al., 2002). They go on to suggest the constriction of the Savanna Biome on the Botswana and Zimbabwe borders. The prolific plant species richness of the Fynbos Biome in the southwest is markedly threatened (Midgely et al., 2002), an indication being the loss of around 10% of all members of the Proteaceae family. Associated reductions in the ranges of individual species are likely to alter community composition and produce major vegetation structural changes in the Grassland Biome where there are significant threats from invading savanna tree species (Rutherford et al., in DEAT, 2000). Further iterations of the climate envelope models used in developing these scenarios reveal a power-law relationship with geographical range size and the resultant ‘doomsday’ scenario that up to 37% of taxa in a selection of species-rich areas (including southern Africa) are ‘committed to extinction’ (Thomas et al., 2004, 145). In nearly all biomes of southern Africa, invasive alien species are likely to be advantaged by changed climates and increased atmospheric carbon dioxide concentrations (Dukes and Mooney, 1999) in a region that is already strongly impacted by such species and which stands to be further transformed by agriculture and urbanisation in the future (Rouget et al., 2003).

This rather depressing tale is repeated and even amplified when animal taxa are considered (van Jaarsveld et al., in DEAT, 2000). Applying a similar climate envelope technique to that employed in the plant diversity impact analysis, Erasmus et al. (2002) demonstrate significant range contraction in almost 80% of the 179 species included in the study (including 34 bird, 19 mammal, 50 reptile, 15 butterfly and 57 ‘other invertebrate’ species), with the majority of these contractions being towards the east. Most chillingly, perhaps, the authors suggest that the flagship conservation area in the region, South Africa’s Kruger National Park, may lose up to 66% of those animal species included in the analysis. Clearly this kind of analysis points to the imperative of understanding the role of climate change in relation to the network of conservation areas in southern Africa and prompts the need for considering the further development of so-called trans-frontier parks and corridors linking such areas.

Impacts of climate change on agriculture, rangelands and forestry

Agriculture

In most countries in southern Africa, agriculture (mostly, but not exclusively, of the subsistence form) is the dominant mode of individual economic activity and is a leading component of the national economies in all cases. The staple food in many instances is maize, and this prompted du Toit et al. (in DEAT, 2000) to explore the predicted impacts of climate change on the productivity of this crop in particular. Depending on which particular scenario is employed, maize production will either be only marginally affected by the year 2050 in southern Africa or show negative anomalies of up to 20%, the uncertainty being a product of the extent to which the crop will benefit from the carbon dioxide fertilisation effect (not yet quantified

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Figure 3  Hannah et al.’s (2002) models of distribution of South African biomes under contemporary climates (a), and the HadCM2 model applied to an atmosphere with 550 ppm carbon dioxide (b). Unshaded areas in (b) represent areas with climatic conditions not currently encountered so that it is not possible to predict the composition of the communities in these places.
under southern African conditions (Turpie et al., 2002). At a broader spatial scale, Jones and Thornton (2003) predict a 10% reduction in maize productivity in Africa, although this average figure hides very marked spatial variability. In any case, maize production in the region oscillates strongly on an annual basis with varying weather conditions and the more marginal western production areas in the region may well become unsuitable for maize in the future (Turpie et al., 2002). The South African Country Study (DEAT, 2000) concludes that, overall, despite increases in carbon dioxide and possible increased precipitation in some of the summer rainfall areas, reduced maize productivity could result in economic losses of hundreds of millions of Rands.

For the major commercial crops in the region, for example, wheat and sugar cane, Turpie et al.’s so-called ‘back-of-the-envelope’ calculations suggest losses of 10 to 20% by 2050. Furthermore, changes in soil moisture, which are often inadequately parameterised in GCMs, both as an output of and as an influence on climate change (see New et al., 2003), due to the anticipated increased regional temperatures are a potential additional challenge for agriculture. Overall, the threats to the agricultural sector of the southern African economy are very marked and, as noted by Leichenko and O’Brien (2002), there are further constraints that arise from economic globalisation, particularly for marginalised subsistence farmers in the region.

**Rangelands**

Of the total land area of South Africa, almost 70% is classified as grazing land (NDA, 2000) and this figure may be taken as representative of the region as a whole. Livestock production within such areas is clearly dependent on the productivity of the associated vegetation of these rangelands. Turpie et al. (2002) explore the impacts of climate change on animal production in South Africa and conclude strong spatial variability in the scale and direction of the effect. For example, productivity in the savanna grasslands in the eastern parts of the country may well improve, especially if the carbon dioxide fertilisation effect is taken into account, although it may well manifest itself as bush encroachment. In general the impact of change is likely to be strongly negative in the sheep-rearing areas of the arid and semi-arid west, and marginally to quite strongly positive in the larger, livestock-rearing areas of the better watered east (Turpie et al., 2002). Problems identified in the more arid parts of the region are consistent with the global analysis of drylands performed by Puigdefabregas (1998), who notes the sensitivity of such systems to disturbance and the likelihood of enhanced land degradation as a consequence. Oba et al. (2001) have demonstrated the significance of external climate forcing ENSO, in the case of sub-Saharan Africa, in promoting desertification, and Meadows and Hoffman (2003) concur that degradation of rangelands is likely to accelerate under scenarios of global climate change in the subsistence grazing areas of the former so-called homelands of South Africa. Using an established model of dune mobility, Thomas et al. (2005) explore the impact of climate change scenarios on the extensive, vegetated, linear dune systems of the Kalahari. Although no account is taken of the possible carbon dioxide fertilisation effect, the modelling results suggest future widespread remobilisation of these dune systems throughout the year with consequent very severe implications for rangeland productivity in the region (Figure 4). Previous considerations of the impact of climate change on southern African drylands may, therefore, have underestimated the extent of future pastoral and agricultural disruption due to global change.

**Forestry**

Although plantation forests, much of them State-owned, only account for just over 1% of the land area of South Africa (regionally, the value is likely to be somewhat lower), these make a significant contribution to the national economy and are an important focus in the Country Study (DEAT, 2000) and subsequent commentaries (Turpie et al., 2002). Although carbon dioxide fertilisation is difficult to quantify for individual commercial tree species, it appears that any beneficial effect will be strongly outweighed by enforced range changes and the reduction in areas classified as ‘highly suitable’ (Turpie et al., 2002), especially in the case of eucalypts. Nevertheless, this conclusion is based on earlier climate change scenarios and on the general premise that southern African climates will generally aridify by 2050, whereas the latest regionally downscaled scenarios (Hewitson and Crane, 2005) suggest that this may not necessarily be the case in the eastern parts where many of the plantations are located. Coupled with a fertilisation effect due to changes in atmospheric chemistry, the response of forestry may be somewhat more positive than previously thought.
Impacts of climate change on water resources

Southern Africa is fundamentally an arid subcontinent, more especially in the interior and western parts, so that most ecological – and, for that matter, economic – processes are, to a greater or lesser extent, limited by water availability. Schulze (2000) documents the challenges of predicting the hydrological response to climate change in situations, such as those which prevail across much of the region, where the coefficient of variation of runoff is already very high. In other words, the hydrological regime is so variable in space and time, that trends imposed by climate change are very difficult to detect. Nevertheless, Schulze (2000) goes on to estimate anomalies in mean annual runoff employing the UKMO model and a so-called IS92a emission scenario for the year 2050, and demonstrates marked runoff reductions in the already xeric western parts of southern Africa. Arnell (1999) employs Hadley Centre models HadCM2 and HadCM3 to predict changes in runoff in the major river basins of southern Africa by 2050. The models suggest substantial runoff reduction.
in the Zambezi (−40%), Limpopo (−30%) and Orange (−5%) basins as well as decreases in the volumes of low flows in all three rivers (Arnell, 1999). Such impacts are likely to be exacerbated by change in land use, which is an important component of the hydrological system.

Further stresses on the hydrological system arise from increased demand. Across the region there is a political and practical imperative to improve access to potable water for both the rural and urban poor in particular, placing great strain on a resource that is already stretched due to high agricultural and industrial requirements (Schulze et al., 2001). Meigh et al. (1999) conclusively demonstrate the likelihood of increases in water scarcity in large parts of eastern and southern Africa as a result of the combined effects of reduced groundwater recharge and elevated demand. For the winter rainfall zone of the south-western Cape, a region characterised by strong population growth and accelerated economic development in the recent past, New (2002) shows how reduced streamflow response in the future, together with elevated water demand against a limited supply capacity, will soon result in the permanent inability to meet supply yields in the area’s largest city (Cape Town). The South African Country Study report (DEAT, 2000) bases its hydrological predictions of climate change on two GCMs (HADCM2 and CSM), which both point to a greater intensity of rainfall events in the eastern part of southern Africa (consistent with Hewitson and Crane’s (2005) regionally downscaled model outputs) and accentuated flooding in the associated rivers. This positive effect on runoff, however, is offset by longer dry spells and, in short, a significantly more variable hydrological response. Geomorphic implications may include increased soil erosion, and Meadows and Hoffman (2003) have indicated as much for parts of the summer rainfall region. All of this points to a potentially increased hydrological hazard in the future, both in terms of drought and flood frequency and intensity. Coupled with possible negative changes in water quality due to increased temperatures, the scenario is especially gloomy unless there are significant shifts in policy vision (Mukheiber and Sparks, 2003).

Impacts of climate change on health

A large proportion of the population of the developing countries in southern Africa is vulnerable to the diseases of poverty, for example malaria, tuberculosis and, increasingly, HIV/AIDS.

Despite the intuitively logical view that rapid climate change should negatively influence human health, especially in the developing world, the first conclusively documented evidence of such effects was published only recently when Rodó et al. (2002) demonstrated the relationship between the incidence of cholera and varying ENSO-related weather phenomena in Bangladesh. Nevertheless, epidemiologists have been aware for some time of the potential impact of such changes on diseases and disease vectors, especially in the case of malaria. Van Lieshout et al. (2004) model the potential impact of changed climate (using four of the emission scenarios from IPCC, 2001) and show that much of sub-Saharan Africa is likely to experience conditions more conducive to the transmission of malaria in the future, with up to 60 million more people at greater risk. However, most of these people live in East Africa, and parts of southern Africa may become too warm and dry to sustain the vector organisms (mosquitoes). Certainly, regional warming is associated with a resurgence in the disease (Patz, 2002). According to the World Health Organisation, malaria-related deaths in children doubled in many parts of Africa between the 1980s and 1990s and already account for 20% of childhood mortality on the continent (Hales and Woodward, 2003).

Potential changes in the prevalence of HIV/AIDS have not thus far been assessed, although the virus is opportunistic and is likely to increase in the event of the intensification of other climate-related stressors, such as reduced food security, on vulnerable populations. Health policies in countries of southern Africa therefore need to be based on the recognition of possible increased risk of HIV/AIDS prevalence in a region which already has the highest incidence in the world (Plot et al., 2001).

Conclusions

It is pertinent to compare the predicted responses of the natural and associated economic systems reviewed here with those identified by Hulme in 1996. There are many similarities in the picture that emerges, but some key differences. Hulme’s original review noted a marked concern for future losses of biodiversity in response to range shifts under both climate scenarios considered. By comparison, the regional analysis documented in Hannah et al. (2002), based mainly on the IPCC (2001) scenarios, suggests much greater impact, with very substantial areas of southern Africa developing climatic conditions for which
there is no meaningful modern analogue. Accordingly, while it is difficult to be precise as to what particular mix of species will prevail in such areas if these scenarios come about, it is clear that biodiversity losses could be very severe indeed. Reduction in diversity of grazing mammals was identified in the Hulme study, but Erasmus and co-workers (2002) make a compelling case for accentuated impacts across a wide range of animal taxa, with consequent increased levels of conflict between conservation and other land uses. Hulme’s report highlighted agricultural impacts but suggested that not all the changes would have negative consequences. Maize yields, for example, were expected to increase, although Jones and Thornton’s (2003) considerations predict substantial reductions. Hulme’s review also appears to underestimate the regional impacts of climate change in rangelands, more particularly in light of Thomas et al.’s (2005) suggestion of widespread remobilisation of sand across large areas of southern Africa.

The most recent, regionally-downscaled, climate change scenarios provide improved spatial resolution and open the door for more precise estimates of the impact of such change on run-off. These scenarios are consistent with those developed by Hulme in predicting reduced rainfall-runoff ratios in the western and western-central parts of the region and in suggesting increased variability elsewhere. This hydrological response will, of course, be an important driver of changes in other sectors too, not least in agriculture and for the management of industrial and urban water supplies. Finally, with respect to health issues, subsequent reviews of the implications of climate change for diseases such as malaria concur with Hulme’s analysis of the situation in anticipating an increase in prevalence. For other prominent diseases of southern Africa, such as HIV/AIDS, scientists have yet to assess the second-order impacts of future climate change, and this must become an important consideration of health and welfare planning for governments.

By comparison with the scenarios developed and modelled by Hulme (1996), more recently available, downscaled scenarios point to accentuated, and probably accelerated, problems in relation to all sectors explored in this paper. Fundamentally, this means that the vast majority of the southern African population, the rural and urban poor, have an increased level of vulnerability to impacts. As Misselhorn (2004) notes, enhanced levels of vulnerability are already deeply embedded and manifest themselves as widespread food insecurity across the region, especially in the less developed countries of Mozambique, Lesotho, Swaziland, Namibia and Zimbabwe, although it is difficult to develop policy given the uncertainties about the nature and direction of change (Schneider and Kuntz-Duriseti, 2002). Without doubt, however, global change, with all its complex manifestations, will only serve to further marginalise those most at risk to natural hazards such as floods and droughts. What is clearly needed is recognition of the potential problems, and development and implementation of holistic mitigatory policies that address both biodiversity conservation and livelihood concerns. For southern Africa, global change is a major threat to the survival of its communities, human and otherwise.

REFERENCES
Arnell, N.W., 1999: Climate change and global water resources. Global Environmental Change 9, 31–49.


Hulme, M. (ed.), 1996: Climatic Change and Southern Africa. Climate Research Unit, University of East Anglia, Norwich, U.K.


