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The science of climate change in Africa: impacts and adaptation

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Executive summary

ALTHOUGH MUCH HAS BEEN LEARNED IN RECENT YEARS, there is still a great deal about climate change in Africa that we do not know.

The African climate is determined at the macro-level by three major processes or drivers: tropical convection, the alternation of the monsoons, and the El Niño-Southern Oscillation of the Pacific Ocean. The first two are local processes that determine the regional and seasonal patterns of temperature and rainfall. The last is more remote in its origin, but strongly influences the year to year rainfall and temperature patterns in Africa. Despite the importance of all three processes, we poorly understand how they interact and how they are affected by climate change.

What we can be sure of is that global warming—expressed, for example, through higher sea and land surface temperatures—is affecting the outcomes, increasing the incidence and severity of the droughts, floods and other extreme weather events that these drivers produce.

We also know that over the next 100 years (assuming rapid economic growth but with a balance of energy sources):

- The drier subtropical regions will warm more than the moister tropics.
- Northern and southern Africa will become much hotter (as much as 4 °C or more) and drier (precipitation falling by 15% or more).
- Wheat production in the north and maize production in the south are likely to be adversely affected.
- In eastern Africa, including the Horn of Africa, and parts of central Africa average rainfall is likely to increase.
- Vector borne diseases such as malaria and dengue may spread and become more severe.
- Sea levels will rise, perhaps by half a metre, in the next fifty years, with serious consequences in the Nile Delta and certain parts of West Africa.

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But there is much that we do not know, for example:

- Will the Sahel Belt get wetter or remain dry?
- Will the flow of the Nile increase or decrease?
- By how much will the flows of the Zambezi and Limpopo decrease?
- Will the overall fall in agricultural production be very large or relatively small?

Part of our ignorance comes from a growing but, nevertheless, poor understanding of the drivers of the African climate and their complex interactions. Part is due to a severe lack of local weather data, particularly for central Africa. This lack of knowledge makes it difficult to validate climate models and hence predict with any degree of accuracy what will happen as a result of climate change at a country, or even sub-regional level in Africa.

This relatively poor state of knowledge has two implications:

- We urgently need more research into the dynamics of the global drivers on the one hand, and into the detailed consequences at local levels on the other.
- We need to design adaptation measures to cope with high levels of uncertainty.

In general the best assumption is that many regions of Africa will suffer from droughts and floods with greater frequency and intensity.

Adaptation thus depends on developing resilience in the face of uncertainty. The application of the concept of resilience is similar in many respects to the approach that has been long used in the face of natural disasters such as earthquakes and tsunamis:

- It begins with anticipation, surveying and forecasting of the likely stresses or shocks.
- It moves to developing preventative measures and increasing tolerance.
- After the occurrence of the event or events, it focuses on recovery and restoration.
- It is embedded, where possible, in 'everyday' risk management and is thus more proactive than reactive.
- The various options at each stage are appraised in terms of cost-benefit and other criteria.

Throughout the process learning remains important. In general the more time and resources put into the earlier and sustainable stages of this process, the better.

Most of the population of Africa already experiences a variety of stresses and shocks on a regular basis. In this sense, the impacts of climate change are nothing new. But the scale and, in some situations, the nature of the impacts will change dramatically as the pace of climate change increases. Greater investment in adaptation is needed now to respond to the changes that are already occurring.

To deliver such a package there needs to be more research and support for hazard mapping (including physical and biological mapping and the mapping of human vulnerability) and long-range forecasts, and more funding for research into drought, flood resistance and flood tolerance.

Resilience is important at national, regional and local levels, and involves not only technologies, but also appropriate economic policies and institutional arrangements. It is the poor who will be most vulnerable to the effects of climate change. To some extent the process of development itself may help them to adapt. If people are better fed, in better health, and have better access to education, jobs and markets, they may have the capacity to be more resilient.

> We urgently need more research into the global drivers of African climate and into the detailed consequences at local levels.

Traditionally, poor people have developed various forms of resilient livelihood to cope with a range of natural and manmade stresses and shocks. But these may be inadequate in the future, because they may have been lost in the development process, or the rate of change may have outstripped the levels of resilience that have been developed. There is an urgent need for governments, NGOs, universities (which house the majority of climate change researchers in Africa), and the private sector to work with local communities to build up the resilience of Africa and its people.

Introduction

Attempting to understand the effects of climate change on Africa is fraught with difficulties. While some things are known and relatively well understood, there is still great uncertainty about the key climatic processes and their consequences. There is also much that is simply unknown. In this report I try to explain what the science tells us and what the implications for policy and action are.

First, it is important to recognise that Africa's climate is naturally both highly diverse and highly variable. It encompasses the extreme aridity of the Saharan deserts at one end of the range and the extreme humidity of the Congo rainforest at the other. Interacting with these natural patterns are the combined effects of anthropogenic global warming and human interference more generally. In most instances it is difficult or impossible to disentangle one cause of change from another.
For example, the countries of the Sahel have experienced many multidecadal periods of drought since end of the last glaciation

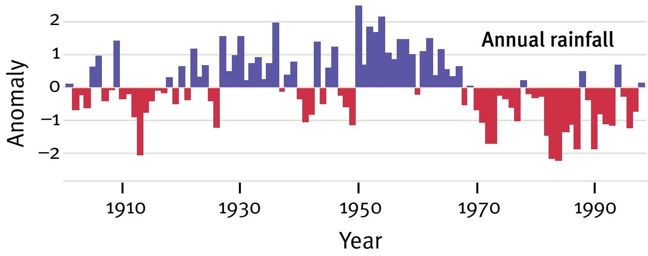


Figure 1. Annual rainfall anomalies representing the region 10° - 20° N; 25° W – 30° E, roughly corresponding to the Sahelian zone.[2]

12,000 years ago[1], and are in one such period now (Figure 1). Whether this current period is another natural episode or the result of environmental degradation or global warming we do not know. Probably it is a combination of these factors. What we do know is that global warming is likely to exacerbate droughts such as these, increasing their frequency and intensity.

Droughts or floods that last a few months can be highly destructive. When they last decades the effects can be devastating and sometimes irreversible, at least in the short term. The current Sahelian drought has resulted in the Sahelian, Sudanese and Guinean ecological zones shifting 25-35 km further south, with loss of valuable grassland, savanna and other resources that the indigenous people rely upon.[3] One of the most severe consequences has been the Darfur conflict in the Sudan, which originated from clashes between pastoralists and sedentary farmers over depleted water and other resources (Box 4, page 14).

Global drivers

Driving the African climate are several processes that are interrelated in complex and still not yet fully understood ways.[4] Two of these—tropical convection and the alternation of the monsoons—are local processes that determine the regional and seasonal patterns of temperature and rainfall. A third—the El Niño-Southern Oscillation of the Pacific Ocean—is more remote in its origin but strongly influences the year to year rainfall and temperature patterns in Africa.

Although these drivers are powerful global and regional forces, it is not yet clear whether their patterns are significantly altered by global warming. What we can be sure of is that global warming—expressed, for example, through higher sea and land surface temperatures—is affecting their outcomes, increasing the incidence and severity of the droughts, floods and other extreme weather events that they produce.[5]

Tropical convection

Intense solar heating near the equator leads to rising warm, moist air and heavy rainfall. As the air rises it creates an area of low pressure at the surface, known for centuries by sailors as the Doldrums, and also referred to as the Intertropical Convergence Zone (ITCZ). The rising air moves north and south towards the tropics and eventually falls in the subtropics (between 20° and 30° N&S of the equator) as warm, dry air. From there it is carried back towards the equator by the trade winds.

Each year, the ITCZ moves north and south following the seasonal tilting of the globe towards the sun (Figure 2), leading to four distinct climatic zones:[4]

- Tropical moist climates with ~2000 mm of rain that support the equatorial rainforest
- Tropical climates that alternate between wet summers (brought by the ITCZ) and short dry winters, giving a total rainfall of 1000-2000 mm
- Tropical semi-arid climates, with long dry seasons, at the northernmost limits of the ITCZ and rainfall of 300-800 mm
- Arid climates located 30°-40° north and south, with less than 250 mm year rainfall.

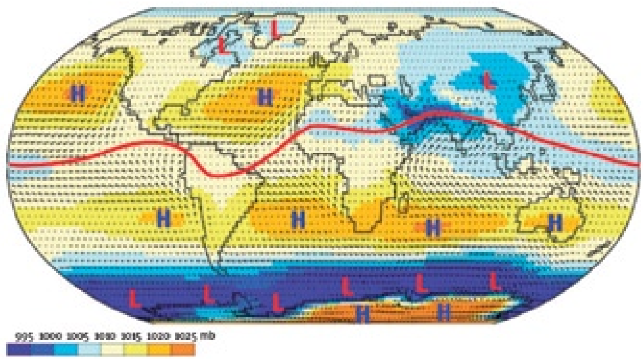


Figure 2. The position of the ITCZ and monsoons in July (red line). Other colours indicate sea-level pressure; arrows indicate direction and intensity of surface winds. [6]

These are not distinct zones; their boundaries overlap and vary from year to year with the latitudinal and longitudinal movement of the ITCZ. For example, when it migrates further north than usual it brings heavy rain and floods to the Sahel (as happened in 2007); when it lies quite far south over the SW Indian Ocean it will be very dry over South Africa.

Monsoons

Another phenomenon linked to tropical convection is the marked seasonal change of direction of the monsoonal winds, which affect West and East Africa.[4] In simple terms, monsoon winds occur because land heats up and cools down more quickly than the sea. Their change in direction involves several processes including the movement of the ITCZ and relative surface temperatures, which interact in ways that are still not well understood.[7]

The Indian monsoon is the most extreme form of monsoon with a 180° reversal of the wind. The south-west monsoon arises in spring and summer. As the air over north-west India and Pakistan becomes much warmer than over the Indian Ocean, it creates a low pressure drawing in warm, moist air from over the Ocean. The air first moves northward, and then because of the effects of the Earth's rotation is diverted north-eastward. It begins to rise and cool, shedding its moisture as rain.

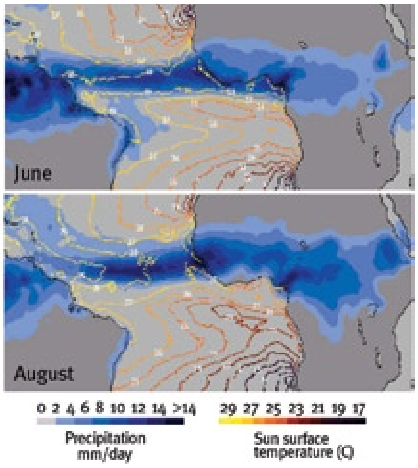


Figure 3. The two phases of the West African Monsoon[8]

In winter the reverse occurs, with the land cooling more than the oceans do, creating the north-east monsoon. These changes affect lands far from south Asia, for example along the eastern margins of Africa.

West Africa is affected by a south-west monsoon that arises in a similar fashion. In the summer, as the land becomes hotter than the ocean and the air starts to rise over the Sahara, cooler, more humid air from the Atlantic Ocean is drawn in, 1000 km to the south. It brings rainfall from May to September in two phases (Figure 3). The first phase (April - June) centres on the Gulf of Guinea (about 4°N), and appears to be influenced by sea surface temperatures. Then in a sudden event known as the monsoon jump, usually in early to mid-July, the rainfall maximum follows the ITCZ northwards into the southern Sahel (about 10°N) over a period of just a few days. The second phase is influenced by easterly atmospheric waves, which are also associated with the ITCZ.

El Niño-Southern Oscillation

The third driver of African climate, the El Niño-Southern Oscillation (ENSO) is far distant, in the Pacific Ocean. It is characterised by a close coupling of the ocean and the atmosphere, and is

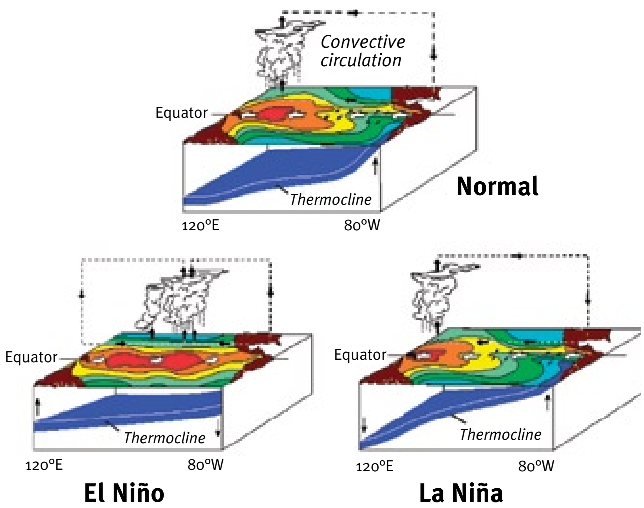


Figure 4. Comparison of atmospheric and oceanic flows in the Pacific during normal, El Niño and La Niña years.[11]

referred to as an oscillation because of its characteristic switch in the Pacific between a cold phase, La Niña, and a warm phase, El Niño (Figure 4). Under 'normal' conditions, the Peru current brings cool water to the Central Pacific. From there trade winds move increasingly warm water westwards from the high pressure of the Central Pacific to the low pressure located over Indonesia. This raises sea level by about half a metre on the Indonesian coast compared with the Ecuadorian coast, and the water is 8-10°C warmer. Very heavy and extensive rainfall, partly fed by trade winds, occurs over the warm water of the western Pacific, while the eastern Pacific experiences relatively dry weather.[9]

Sometimes however, the pattern is reversed, with wide-ranging consequences.[10] Every 3-7 years El Niño sets in and there is a change in the prevailing pattern of ocean surface temperatures and pressures. Air pressure strengthens over Indonesia and the trade winds slacken. Sometimes they reverse, being replaced by westerly winds that move the surface waters towards the central Pacific. Rain falls in the east and droughts occur in Southeast Asia and Australia.

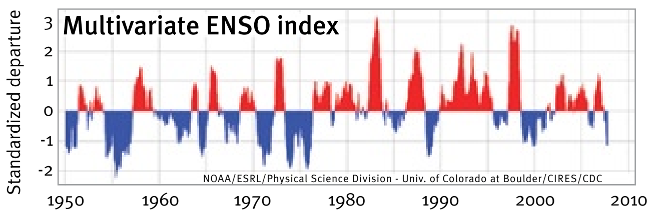


Figure 5. The alternation of La Niña (blue) and El Niño (red) events. (The Multivariate ENSO Index is based on six variables measured across the Pacific).[13]

La Niña is an extreme version of the 'normal' condition with very cold water, strong high pressure and very dry conditions in the eastern Pacific and the opposite in the western Pacific.

The phenomenon is called El Niño, the Spanish for 'the boy child', because the warm waters have tended to arrive off the South American coast at Christmas time. The extreme westward flow phenomenon is referred to as La Niña, 'the girl child.'

There are many theories as to whether it is a true oscillation, and different views on the nature of the dominant mechanisms involved, but a complete theory is still lacking. It is possible to provide fairly good short-term predictions of the change between La Niña and El Niño, but these rely on complex, coupled atmospheric/oceanic models.

There has been a tendency towards more prolonged and more frequent El Niños since the early 1990s (Figure 5). This has caused speculation that it may be a consequence of global warming but, so far, there is no evidence to substantiate the connection.[12]

Although ENSO is primarily a Pacific Ocean process, the effects are felt as far away as Africa and, indeed, in most regions of the world. ENSO events involve large exchanges of heat between

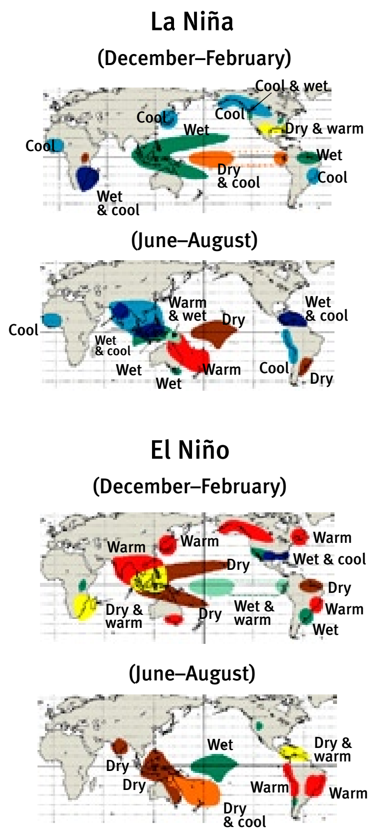


Figure 6. Global correlates of the El Niño – La Niña phenomenon[17]

the ocean and atmosphere and affect global mean temperatures. Thus, six months after an El Niño phase the global mean surface air temperature increases. In the tropics and sub-tropics this seems to be a consequence of the heat given up to the atmosphere as the water cools down during La Niña. After the severe El Niño of 1997-98 the global temperature went up by nearly 0.2°C[14]. Relatively simple statistical models predict that during an El Niño year, weather in December to February is usually wetter in eastern Africa but drier to the south, while La Niña produces the reverse. El Niño is also associated with a drier Sahel, while La Niña is correlated with a wetter Sahel and a cooler West Africa (Figure 6).

The 1997/98 El Niño was one of the strongest of the 20th century. It was associated with droughts and forest fires in Indonesia and north-east Brazil, and catastrophic floods in east Africa. Among its many other consequences was the extensive coral bleaching that occurred in the Indian Ocean and Red Sea and a massive outbreak of a *Paederus* rove beetle in Nairobi that caused severe dermatitis in a third of the human population[15]. The following La Niña of 1998-2000 was associated with devastating floods further north in the Sudan and Sahel, and in the south in Mozambique. The floods in the south were then followed by two major cyclones.[16]

Sahelian drought

One of the most significant consequences of these interacting drivers is the phenomenon of the Sahelian drought (Figure 1 and Box 1).

Africa's impact

Africa's climate is also a driver at a global level. The heat released in the ITCZ is a major source of the planet's atmospheric warming. Africa is also a source of the Atlantic hurricanes that often develop from easterly atmospheric waves passing over Africa at the time of the monsoon.

Africa is a not insignificant producer of greenhouse gases. Virtually all of the carbon released to the atmosphere from land use changes now comes from the tropics. Tropical deforestation, including logging and the permanent and temporary conversion of forests to croplands and pastures, releases about 1-2 PgC/yr. This is 15-35% of annual fossil fuel emissions during the 1990s (adding in all the other gases that result from land use change e.g. methane, nitrous oxide etc., tropical deforestation

Box 1. A hypothesis to account for the Sahelian drought[18]

In the 1970s the suggested cause of Sahelian drought was the systematic and irreversible degradation and desertification of the land by farmers and pastoralists in the region. But subsequent studies using remote sensing have convincingly dismissed this hypothesis. Desertification has been mostly transient and land degradation plays a smaller, although somewhat more complicated, role.

The most convincing hypothesis today argues that during the second half of the 20th century, the warming of the south Atlantic and the Indian Ocean in contrast to the cooling of the north Atlantic reduced the land–ocean temperature differential. This in turn caused the monsoon to weaken. The ITCZ and its associated deep convection migrated southwards so depriving the Sahel of rainfall.

There may also have been an influence of El Niño and a positive feedback loop involving the vegetation (Figure 7). As the monsoon weakens, so less vegetation grows, the surface albedo (reflectivity) increases, reflecting back solar radiation and further weakening the monsoon.

This may well explain the recent Sahelian drought, but it leaves open what will happen in the future. Some argue that the south Atlantic has begun to cool since the 1990s while the north is relatively warmer. This may reverse the cycle of events producing more rainfall and vegetation in the Sahel, but this is still a very tentative conclusion.

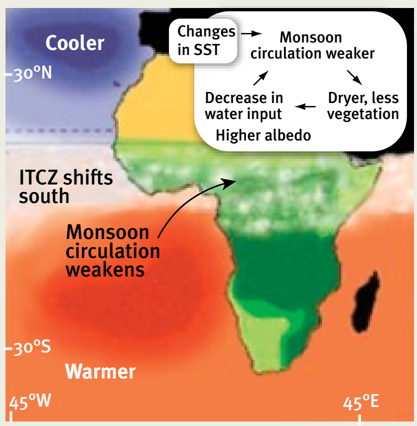


Figure 7. Illustration of a hypothesis to account for the Sahelian drought of the second half of the 20th century.[19]

accounts for about 25% of the total anthropogenic emissions of greenhouse gases). Africa contributes about 0.12-0.35 PgC/year (Figure 8).

More significant than the carbon released by deforestation, large quantities of carbon are produced by the open burning of the savannas of Africa. It is estimated that over 50% of the annual carbon released from burning (both of forests and savannas) comes from Africa (Figure 9).

Both biomass burning and wind-borne dust also produce large quantities of aerosols. The effects of aerosols (including those produced by burning fossil fuels and as a result of industrial processes) on climate are highly complex. In certain circumstances, some aerosols reflect incoming radiation, so cooling the planet, but others trap the heat and add to the greenhouse effect. Dust can either reduce or stimulate rainfall. In low clouds, water attaches to dust particles and prevents droplets from becoming heavy enough to fall. But in high clouds dust particles over wetter regions may provide surfaces for ice crystals to form around them, resulting in greater rainfall.[22]

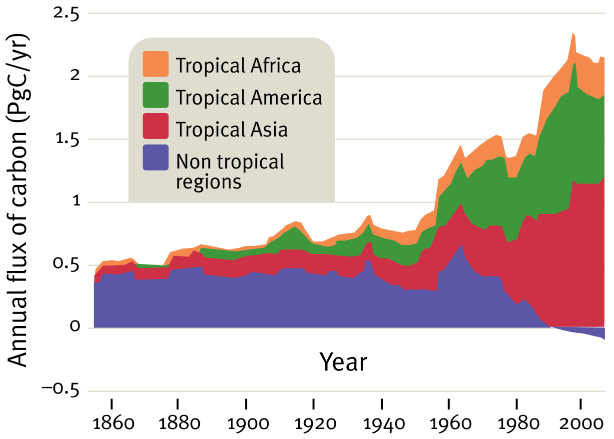


Figure 8. Annual emissions of carbon from changes in land use (Note P = 10^{15}).[20]

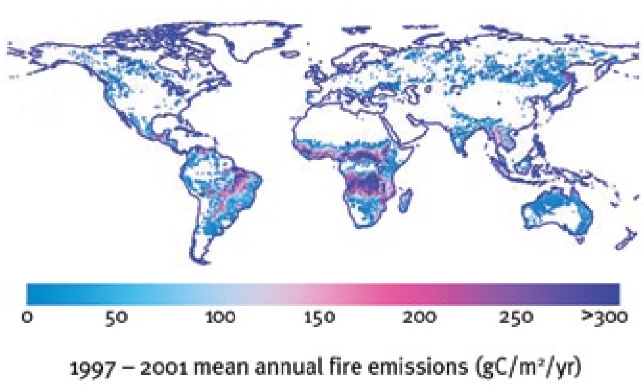


Figure 9. Mean annual carbon emissions from fires 1997-2001.[21]

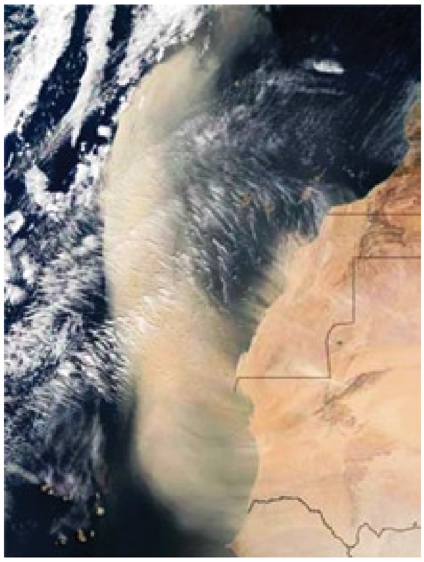


Figure 10. Massive dust storm reaching from the Sahara across the Atlantic.[23]

The great Saharan dust storms are by far the largest source of dust on the planet (Figure 10). They can be blown long distances, influencing weather on the far side of the Atlantic.

The need for information

As discussed above, there is still much to understand about the African climate, its drivers and the links to global warming. Despite considerable progress in African meteorological science, we are still not confident about the major climate trends at either the continental level or for individual countries. For example, is the Sahel going to become drier or wetter? Will the high frequency of El Niño events continue with consequent effects on the African climate?

Part of the problem is that the Global Climate Models (GCMs) used to simulate the regional patterns of climate change are relatively crude: they work to a horizontal spatial resolution of several hundred kilometers. Thus they do not take full account of the topographic, vegetation and land use diversity of the landscape. Nevertheless, their potential is still underexploited, partly because of the lack of trained climatologists in Africa.

A major challenge is to downscale these models in some way, so as to produce a finer scale of prediction.

One approach to downscaling is to adapt the GCM to a specific region using a smaller resolution regional climate model, e.g. 50 km, by feeding in the boundary climate conditions created at the surrounding, more widely spaced, grid points. One example of such a model is PRECIS (Providing Regional Climates for Impacts Studies), a portable regional climate model, developed by the Hadley Centre of the UK Met Office, that can be run on a personal computer.[24]

Such models are valuable tools for understanding local climate dynamics. They are more sensitive to the effects of local topographies and other phenomena. It must be stressed, however, that they act by applying the coarse-resolution GCM dynamics to a regional level. As a result, GCM uncertainties are likely to be magnified, so reducing their usefulness. Only in a few locations is the local data sufficient in quality and quantity to provide a basis for the accuracy required at a fine scale.

An alternative approach, known as empirical downscaling, works by looking for a statistical relationship between the observed weather (temperature or rainfall) at finer resolution grid points and the weather simulated by the GCM at the nearest large-scale grid point.[25] The GCM is then run to simulate future climate and the results are 'downscaled' to finer resolutions, assuming that these relationships continue to hold.

The production of regional and local models is further limited by the paucity of regular, detailed information on the African weather. The global network of World Watch Weather Stations, which provides real-time weather data, is very sparsely represented in Africa. There are only 1152 stations in Africa, a density of about 1 per 26,000 km2, and eight times lower than the level recommended by the World Meteorological Organisation. Moreover, the location of the stations is very uneven. Vast areas are unmonitored, including Central Africa and the Horn of Africa (Figure 11).[26]

It is this lack of knowledge that makes it difficult to predict with any degree of accuracy what will happen as a result of climate change at a country, or even sub-regional level in Africa.

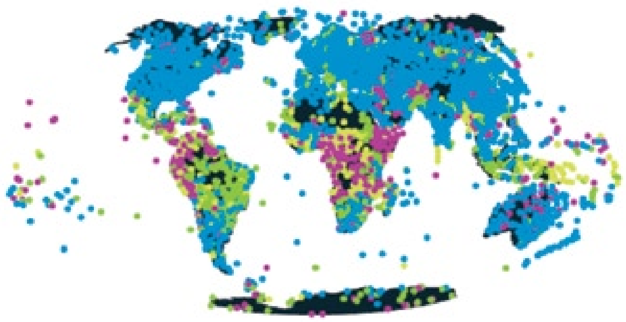


Figure 11. The paucity of reports received by the World Meteorological Office from African World Weather Watch Stations 1998 – 2002.[27]

What we do know

Despite these various uncertainties about the mid – far future, we do know, at least in general terms, what is likely to happen in the near future. [28 29]

Africa is very likely to get:

- warmer (colder in a small number of places)
- drier (but with more floods in some regions).

There will probably be:

- more intense tropical cyclones
- higher sea levels
- more storm surges
- and, in general, more climatic variation and extreme weather events.

Temperature and rainfall

There is already evidence that Africa is warming faster than the global average, and this is likely to continue (Figure 12). The warming occurs for all seasons of the year. Although the overall trend is geographically widespread, there are varia-

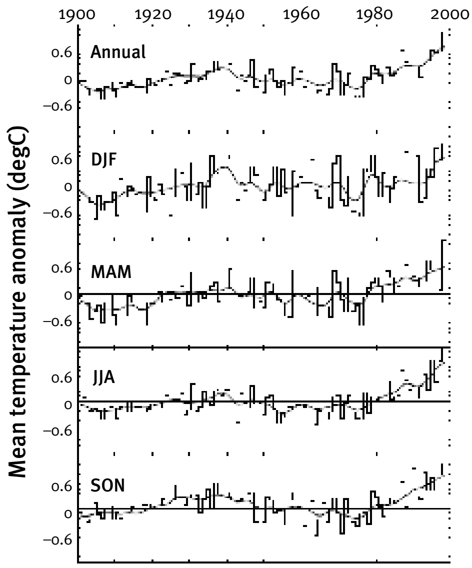


Figure 12. African mean temperature anomalies for the past 100 years.[34]

tions. For example, the tropical forests have warmed by 0.29°C per decade. In southern and western Africa there have been more warm spells and fewer extremely cold days. In eastern Africa temperatures have fallen close to the coasts and major inland lakes. [30–33]

In general, the tendency is for the drier subtropical regions to warm more than the moister tropics.[29] The 21 Atmosphere-Ocean General Circulation Models analysed by the Intergovernmental Panel on Climate Change (IPCC) mostly agree that northern and southern Africa are likely to become much hotter (as much as 4°C or more) over the next 100 years (This is based on scenario A1B – rapid economic growth but with a balance of energy sources). The warming is greater than the global annual mean warming for the continent as a whole. Northern and southern Africa will also become much drier (precipitation falling by 15% or more) over the next century. The exceptions are in East Africa, including the Horn of Africa, where average rainfall will increase (Figure 13). Over much of the rest of Africa (including the Sahel) there is considerable uncertainty as to how the rainfall will evolve.

These are, it should be stressed, large-scale predictions and provide a poor guide to local climates. As an illustration, an

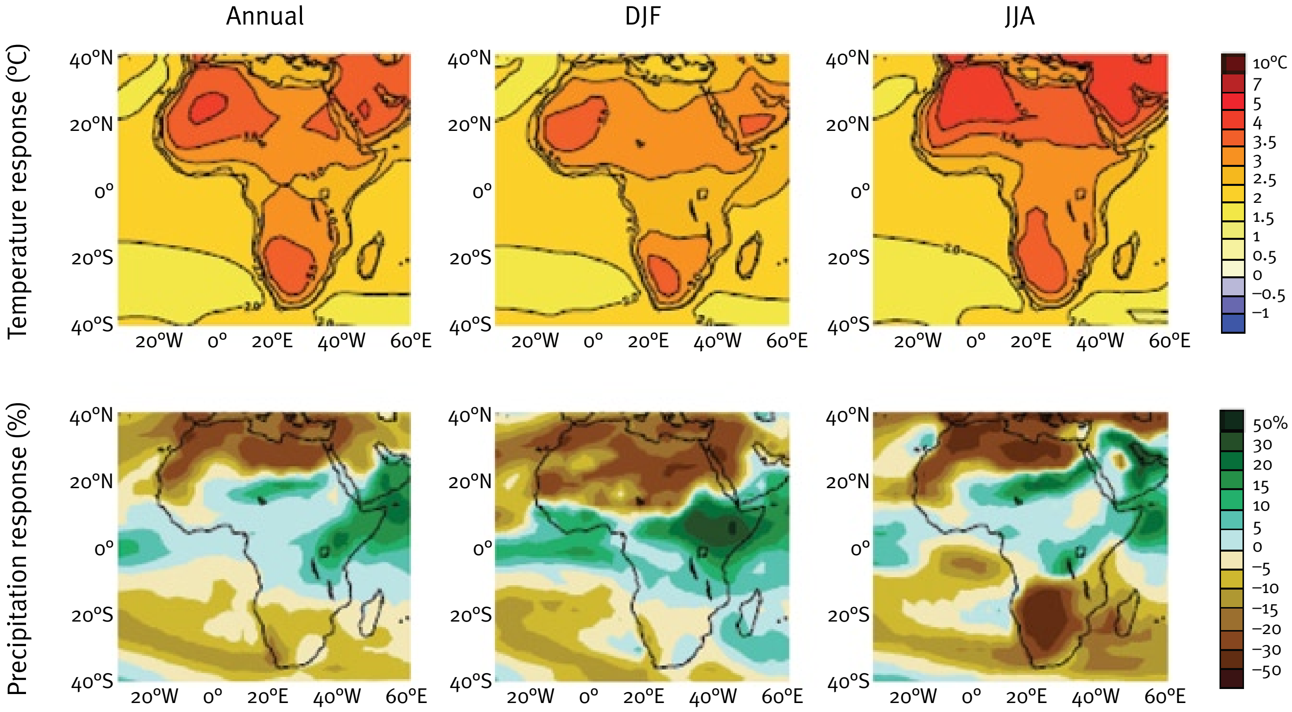


Figure 13. Change in temperature (top row) and rainfall (bottom row) for Africa, between 1980-1999 and 2080-2099 for scenario A1B, averaged over 21 Atmosphere-Ocean General Circulation Models. DJF – Dec, Jan, Feb; JJA – June, July, Aug. (The A1B scenario assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies, with a balance of fossil and non-fossil energy resources).[35]

empirical downscaled model for South Africa indicates increasing summer rainfall (Dec, Jan, Feb) over the central and eastern plateau and the Drakensberg Mountains, while the Western Cape will see little change, with some slight drying in summer and a slight decrease in wintertime rainfall (Figure 14).

Increased variability. Increasing rainfall variability is already apparent.[37] Inter-annual rainfall variability is large over most of Africa and, for some regions, multi-decadal variability is also substantial.[29] Many African regions are going to suffer from droughts and floods with greater frequency and intensity.

In Zimbabwe, for example, there are more cooler and hotter days, and the length and severity of the drier periods is increasing.[38] In the future, the frequency of extremely dry winters and springs in southern Africa is likely to increase alongside the frequency of extremely wet summers. As in other parts of the world, we can expect a general increase in the intensity of high-rainfall events associated, in part, with increased atmospheric water vapour.[39] It is not only changes in the total amount of rainfall that is important, but also changes in the pattern of rainfall. For example, in regions of mean drying, there is likely to be a proportionally larger decrease in the number of rain days, but with greater intensity of rainfall.[40]

We are also likely to experience greater cyclonic activity. The south east coast of Africa is subject to periodic tropical cyclones that originate over the Seychelles from October to June due to the southward displacement of the ITCZ. Rising sea surface temperatures are likely to increase cyclone intensity and there are some estimates of greater cyclone frequency, but cyclones are affected by many factors.[41]

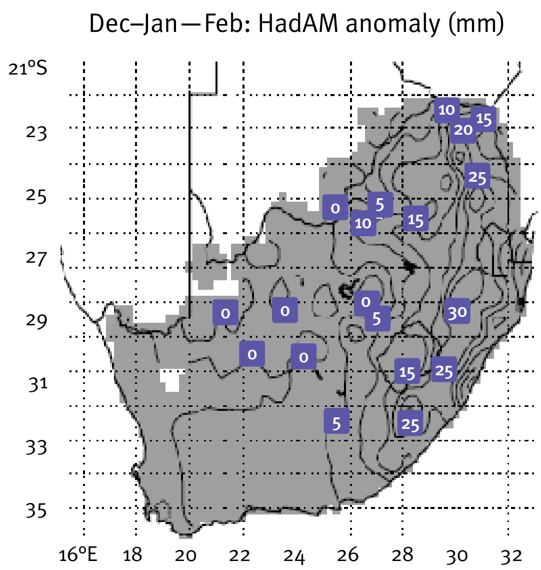


Figure 14. Projected mean monthly rainfall anomalies for the summer period in South Africa from the downscaled Hadley model HadAM3.[36]

Fortunately we know more about climate variability than we do about the medium- to long-term climate projections. Connected to this we have increasingly confident means of making seasonal predictions (Figure 31). This knowledge is a crucial component of the adaptation process.

The impacts

The actual and potential impacts of these climatic changes are large and wide ranging, affecting many aspects of people's everyday lives.

Sea-level rise

Sea levels will rise around the globe as a result of global warming. The primary cause, at least in the near term, is the thermal expansion of the oceans resulting from rising oceanic temperatures. This will deliver a rise of about half a metre by the end of this century.[42]

This prediction is subject to many uncertainties, including the speed at which the Greenland ice sheet melts.[43] Some predictions are that it will take many hundreds of years before it is all gone. But some models suggest that as local temperatures move 3-4.5°C (equivalent to a global increase of around 2-3°C) above pre-industrial temperatures, the surface temperature of the ice sheet will become too warm to allow recovery from summertime melting and the ice sheet will start to melt faster and perhaps irreversibly.[44]

Signs are that the ice is already melting faster than expected,[45 46] partly due to the seeping of melt water through crevices in melting ice, so lubricating glaciers and accelerating their movement to the sea.[47 48] A full melting would result in sea levels some 7 metres above present levels. There is a similar risk posed by accelerated melting of parts of the Antarctic ice sheet, but this is less acute.

Africa is less likely to be as damaged by rising sea levels than many small islands or delta regions such as the Ganges-Brahmaputra and the Mekong Rivers. The most extensive inundation is likely to be in the Nile Delta. A one metre rise would affect some 6 million people (Box 2).

There are also likely to be severe consequences along the West African coast (Figure 15). Banjul, the capital city of Gambia could be completely submerged in the next 50 years or so.[50 51]

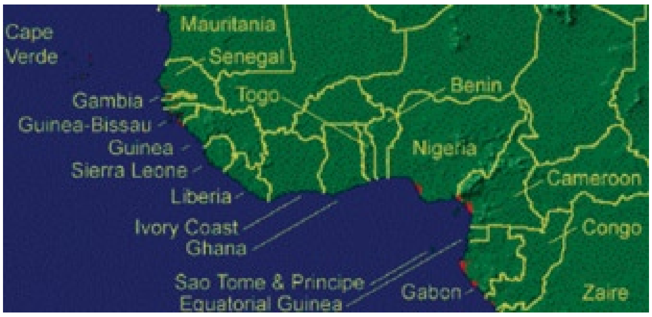


Figure 15. Effects of 1 metre sea level rise in West Africa. Inundated areas are in red.[52]

In Ghana, the coastal zone occupies less than 7% of the land area but contains 25% of the population and so even relatively small rises could have damaging physical consequences on the economy. These could include:

- Permanent connection of lagoons to sea
- Penetration of salt water inland
- Increased coastal erosion
- Salinisation of freshwater lagoons and aquifers
- Increased depth of water table in coastal areas
- Destruction of wetlands and associated industries
- Accelerated loss of the capital, Accra

A further, say, 6 metre rise, occasioned by a more rapid than expected acceleration in the melting of the Greenland and/or Antarctic ice caps, could have even more serious consequences.

Glacier melting

The glaciers on Mount Kilimanjaro in Tanzania are melting fast and are expected to have disappeared by 2020 (Figure 16).[53] However, the major change in hydrology on the mountain and

Box 2. The inundation of the Nile Delta[49]

The Nile Delta is a highly fertile flood plain that supports a very large population with densities as high as 1600 people/km^2. Deserts surround the low-lying, fertile floodplains. Most of a 50 km wide land strip along the coast is less than 2 m above sea level and is only protected from flooding by a 1 - 10 km wide coastal sand belt, shaped by the discharge of the Rosetta and Damietta branches of the Nile. Erosion of the protective sand belt is a serious problem and has accelerated since the construction of the Aswan Dam.

Rising sea levels would destroy weak parts of the sand belt, which is essential for protecting the lagoons and low-lying reclaimed lands. The impact would be very serious. One third of Egypt's fish catches are made in the lagoons. Sea level rise would change the water quality and affect most fresh water fish. Valuable agricultural land would be inundated. Vital, low-lying installations in Alexandria and Port Said would be threatened. Recreational tourism beach facilities would be endangered and essential groundwater would become salinated.

Dykes and protective measurements would probably prevent the worst flooding up to a 50 cm sea level rise. However, this would still cause considerable groundwater salination and the impact of increasing wave action would be very damaging.

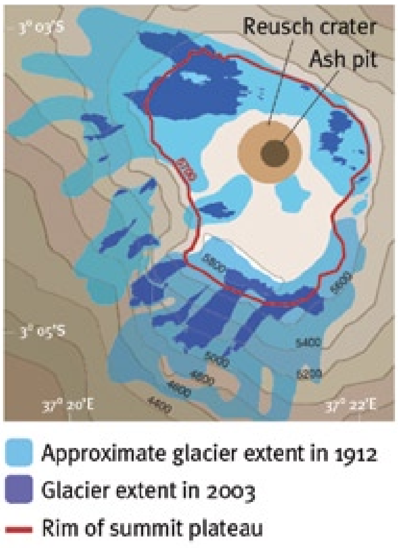


Figure 16. Melting of the glaciers on Mount Kilimanjaro, Tanzania[54]

its environs is not due to the glacier melt but to the dramatic shift, as a result of climate change, in the vegetation zones on the mountain.

Floods and droughts

Floods could become more common in Africa, in part because some regions will experience higher rainfalls, but even in drier regions there is likely to be a higher frequency of more intense downpours, which may create flooding. 2007 saw heavy flooding in both eastern and western Africa (Box 3).

There are many direct and indirect consequences of floods:

- Immediate deaths and injuries from drowning
- Non-specific increases in mortality
- Infectious diseases e.g. increased malaria
- Exposure to toxic substances
- Damage to infrastructure e.g. roads, dams, power generation
- Damage to crops and livestock
- Community breakdowns
- Increased psychological stress
- Increased demands on health systems and social security

Perhaps of even greater importance for Africa will be the rising incidence of droughts, both short- and long-term. The worldwide percentage of land in drought has risen dramatically in the last 25 years (Figure 19). One-third of the people in Africa live in drought-prone areas and the IPCC estimates that, by the 2080s, the proportion of arid and semi-arid lands in Africa is likely to increase by 5-8%.[57]

Many of the consequences are similar to those for floods, but the most significant impact in Africa is likely to be on agricultural production.

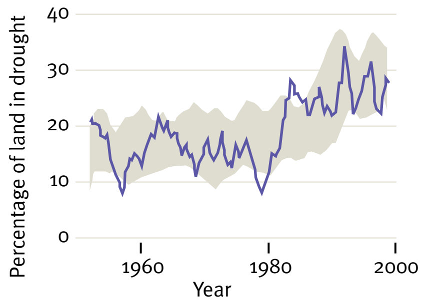


Figure 19. Global area of land in drought since 1950.[58]

Water resources

There are a dozen major river basins in Africa. The impact of climate change is likely to vary depending on the rainfall regime within each basin (Figure 20).

In river basins with low rainfall (<400mm a year) there is virtually no perennial drainage; those that receive 400 - 1000 mm of rain, experience an unstable drainage regime that varies greatly

Box 3. The 2007 African floods

The floods that occurred across the African Sahel in summer 2007 were caused by the heavy rainfall and thunderstorms within the rain belt of the ITCZ, which was further north than usual (Figure 17). Much of the land was dry from the years of previous drought and the record rainfalls resulted in high levels of run-off (Figure 18).

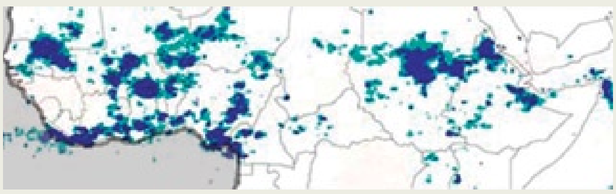


Figure 17. Regions across Africa where rainfall was a 1 in 20 year event or rarer (shown in blue) for July and August 2007.[55]

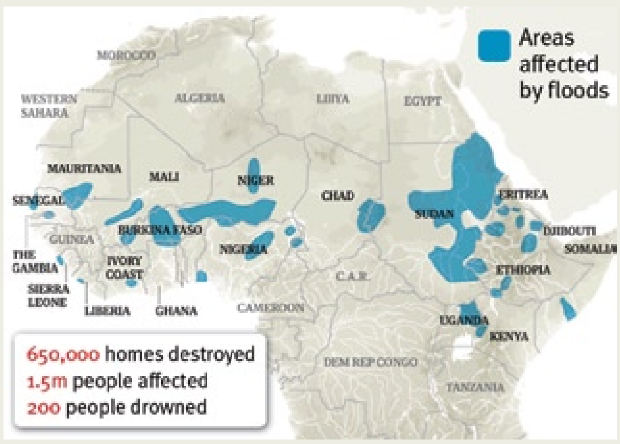


Figure 18. Map of the 2007 African floods.[56]

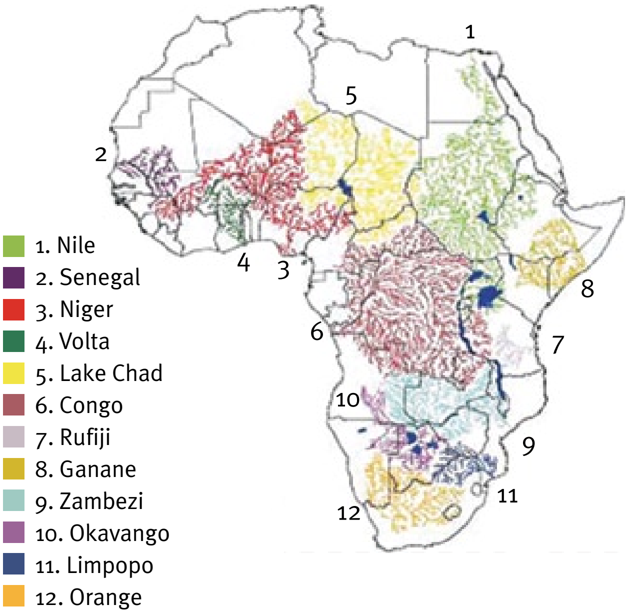


Figure 20. The twelve major river basins of Africa.[59]

with rainfall; basins with more than 1000 mm have a slight increase in drainage with increasing rainfall (Figure 21).

The intermediate unstable zone is likely to experience the greatest impacts from climate change. For example, if in a region receiving 600 mm / year the precipitation decreases to 550 mm / year the drainage will be cut by 25%, whereas a change from 500 mm year to 450 mm would cut the drainage by half. River flows will fall accordingly.

Most of southern Africa lies in either the unstable or the dry regime. The Orange River, the fifth largest river in Africa and one of the 50 largest ones in the world, is likely to be severely affected. The river has run dry in the past and has experienced very low flows in recent years.

On the other hand, rivers in eastern Africa may experience increased drainage density because of the higher predicted rainfall. The flow of the Nile is difficult to assess and current models vary considerably in their predictions, but some of the headwaters may experience greater rainfall.[60]

Water scarcity thresholds are based on estimates of the water requirements for domestic, agricultural, industrial and energy sectors and the needs of the environment.[61] A country is assumed to experience water scarcity when the level available is $<1000m^3$ per capita per year and absolute scarcity is defined as $<500m^3$. On this basis it will be North Africa that suffers most, with the situation improving in northeast Africa (Figure 22).

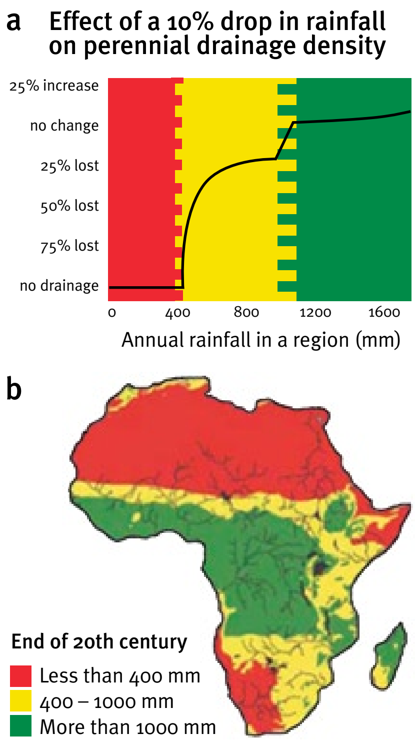


Figure 21. Rainfall and drainage regimes in Africa.[59]

Agriculture

Agricultural production and food security in many parts of Africa are affected by natural climate variability and are likely to be severely compromised by climate change, in particular by damaging high temperatures and the greater incidence of drought. We can expect a decrease in the area suitable for agriculture and in the length of growing seasons and yield potential, particularly along the margins of semi-arid and arid areas. This is likely to further adversely affect food security and exacerbate malnutrition in Africa.[46]

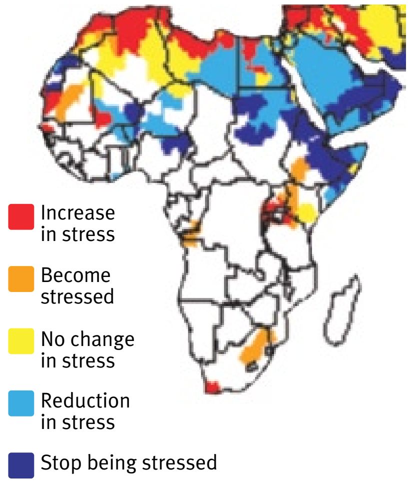


Figure 22. Change in water stress by 2085 using a Hadley Circulation model (HadCM3 A2a).[61]

Many crops in Africa are grown close to their limits of thermal tolerance. We already know that just a few days of high temperature near flowering can seriously affect yields of crops such as wheat, fruit trees, groundnut and soybean.[62] Such extreme weather is likely to become more frequent with global warming, creating high annual variability in crop production. But more prolonged high temperatures and periods of drought will force large regions of marginal agriculture out of production.[29]

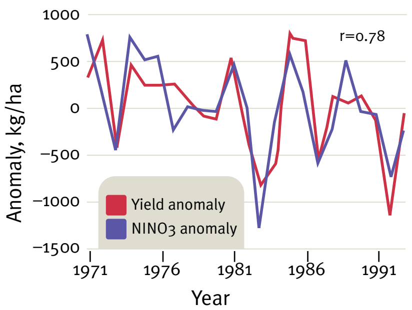
The maize crop over most of southern Africa already experiences drought stress on an annual basis. This is likely to get worse with climate change and extend further southwards, perhaps making maize production in many parts of Zimbabwe and South Africa very difficult if not impossible. Wheat yields in northern Africa are likely to be threatened. Drought will also severely affect livestock production. In the 1980s, protracted drought killed 20-62% of cattle in countries as widespread as Botswana, Niger and Ethiopia.[29]

Drought in southern Africa may be particularly severe in El Niño years. Maize yields in Zimbabwe have long been highly correlated with the ENSO cycle as measured by sea surface temperatures off the Peruvian coast. During El Niño years, droughts tend to occur at the most susceptible time for the maize grain to develop (February). This correlation is so strong that it is possible to predict the Zimbabwean crop in March with 70% probability, using sea surface temperatures in the eastern Pacific from the previous September (Figure 23).

In southern Africa and across western and north-central Africa lower rainfall may also shorten the growing period, reducing the chances of a second crop in some areas, and even the viability of a single one in others (Figure 24).

Just how severe these impacts will be on agriculture will depend on the so-called 'carbon fertilisation' effect. Carbon dioxide is a basic building block for plant growth and hence we would assume that rising levels will increase crop yields. Greenhouse and field chamber experiments show this to be the case, but the latest analyses of more realistic field trials suggest the benefits of carbon dioxide may be significantly less than initially thought – an 8 - 15% increase in yield for a doubling of carbon dioxide for responsive species (wheat, rice, soybean) and no significant increase for non-responsive species (maize and sorghum) that are widely grown in Africa.[65 66] This offsetting factor may therefore be less than previously assumed.[61] Its benefits are only likely to be realised where improved water efficiency is combined with increased fertiliser use. IPCC estimates of yield losses (with CO_2 fertilisation) for wheat are 18% in northern Africa, and for maize are 22% in southern Africa.[67]

Figure 23. Correlation between sea surface temperatures and Zimbabwean maize yields.[63]



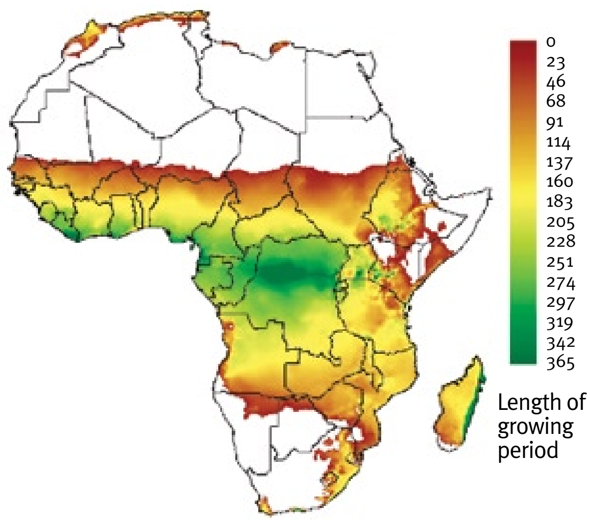


Figure 24. Length of growing period (no of days) in Sub-Saharan Africa, 2000.[64]

	Negative impact	Positive impact
Very high confidence		
» Malaria: contraction and expansion, changes in transmission season	←	→
High confidence		
» Increase in malnutrition	←	
» Increase in the number of people suffering from deaths, disease and injuries from extreme weather events	←	
» Increase in the frequency of cardio-respiratory diseases from the changes in air quality	←	
» Change in the range of infectious disease vectors	←	→
» Reduction of cold-related deaths		→
Medium confidence		
» Increase in the burden of diarrhoeal diseases	←	

Table 1. Global estimates of impacts of climate change on human health.[61]

Health

Climate change has a wide range of actual and potential impacts on health (Table 1).[68]

High temperatures can have a direct effect on human health. In all urban areas. temperature rises above 30°C result in significant loss of life. Although the relationship described in Figure 25 is for New Delhi, major African cities may be similarly affected.

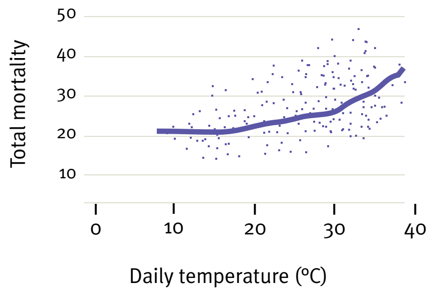


Figure 25. Effect of high temperatures on human mortality in New Delhi.[69]

Most other health effects are likely to be indirect. Diseases carried by insects and other vectors are especially susceptible to the effects of climate change. For example, the geographical distribution and rate of development of mosquitoes are highly influenced by temperature, rainfall and humidity. One mosquito species that carries malaria—*Anopheles arabiensis*—has been found for the first time in the central highlands of Kenya.[70] Increased temperatures and prolonged rainy seasons may extend the transmission period of the disease.

In general, we may expect the range of malaria carrying mosquitoes and malaria to extend into higher elevations, particularly above 1000m.[71 72] There have been resurgences of malaria in the highlands of East Africa in recent years. While some of this may be due to factors such as poor drug treatment implementation, drug resistance, land-use change, and socio-demographic factors including poverty, there is also a strong correlation with climate change. [73–78] Figure 26 reveals that the temperature in the East Africa highlands has risen by 0.5°C since 1980—much faster than the global average—and that this has been accompanied by a sharp increase in mosquito populations. The increased rainfall September – November combined with increased warmth may accelerate mosquito larval development.[79]

The incidence of Dengue, another mosquito-borne disease (carried principally by *Aedes aegypti*) is also likely to increase. Recent models based on predicted rises in relative humidity show a considerable expansion of the geographical range of the disease, particularly through Central and Eastern Africa (Figure 27).

Other infectious diseases that may also increase in range and intensity include water-borne diseases such as cholera and other diarrhoeal diseases, rodent-borne diseases, meningococcal meningitis,[82] Ross River virus and Rift Valley fever.[83]

Biodiversity and ecosystems

Africa comprises a wide variety of ecosystems, including savannas and tropical forests, montane ecosystems (in highland areas below the subalpine zone), coral reefs and great inland lakes and rivers. These contain about one-fifth of all known species of plants, mammals and birds, and one-sixth of amphibians and reptiles.

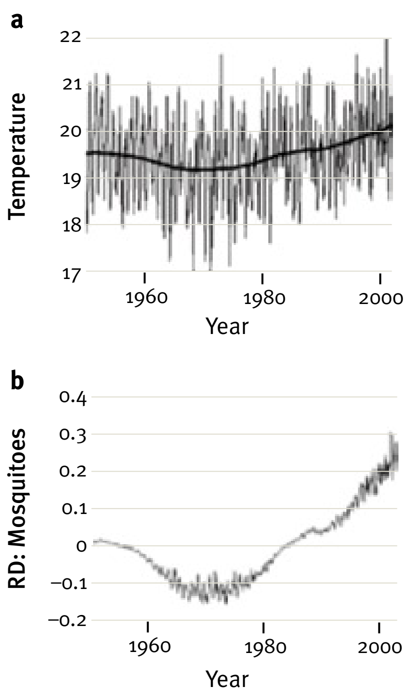


Figure 26. a) Temperature and b) mosquito population increases at Kericho in Western Kenya.[80]

One estimate suggests that, globally, approximately 15-40% of land plant and animal species will become extinct by 2050 as a result of climate change.[84] In Africa, the ecosystems of dry and sub-humid lands are particularly at risk because quite small changes in temperature and rainfall patterns can have deleterious impacts on the viability of plants and animals. Most drylands are already under stress from cultivation, livestock grazing and other human activities.

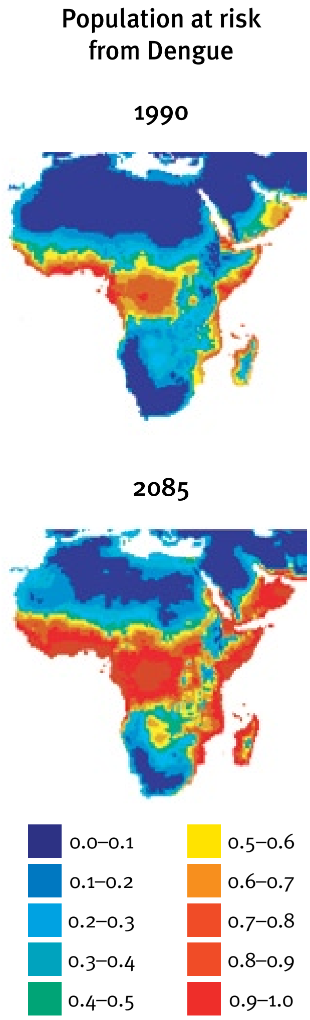


Figure 27. Predicted expansion of Dengue in Africa. (This projection uses the IPCC IS92a scenario that delivers a three fold increase in CO_2 by 2100).[81]

For example, the succulent semi-desert region of the west coast of South Africa and Namibia known as the Karoo is home to about 3,000 species of plants that occur nowhere else. A large fraction of the world's succulent flora lives in the Karoo thriving on its unique dry, winter-rainfall climate. The region is likely to shrink or completely disappear as a result of climate change.[85]

Many animal species would also be affected, including some of the mammals of the African National Parks. Overall between 25-40% of animals in sub-Saharan African national parks are endangered.

Marine ecosystems are particularly vulnerable. Coral reefs off the African coasts are at risk. More generally, such ecosystems are likely to suffer damage from increasing acidification as a direct consequence of increased CO_2 concentrations.

On land perhaps one of the biggest losses, with most widespread consequences, will be of forests, particularly along the edge of the Congo Basin, driven by logging, both legal and illegal, and by increasing aridity. We have few detailed assessments of land-use and land-cover changes in such areas. Nonetheless deforestation is likely to lead to:

- less biodiversity
- less rainfall

- more soil erosion
- more floods
- emergence of zoonotic diseases
- more greenhouse gases

The last of these may be the most important, as deforestation globally contributes to 20% of greenhouse gas formation. This in turn produces more droughts and hence creates a vicious circle.

The processes of adaptation

It is the poorest countries and the poor especially who are amongst the most vulnerable to climate change. African countries are particularly at risk for a variety of reasons (Box 4).

Most of the population of Africa already experiences a variety of stresses and shocks on a regular basis.[87 88] Globally the number of disasters has increased rapidly over the past three decades, with Africa accounting for 20% of the total[89] About half of the natural disasters are due to extreme weather conditions. In the decade 1993-2002 some 16,000 people died, with a further 137 million also affected by losing their homes, land and livelihoods (Table 2).

Disasters caused by extreme weather are nothing new. But the scale and, in some situations, the nature of the impacts may change dramatically as the pace of climate change increases. More and more people could experience:

- Less secure sources of water and food
- Adverse impacts on health and delivery of social and economic services
- More outbreaks of vector borne diseases
- Damaged and degraded infrastructure
- Threatened human settlements and human life
- Destroyed biodiversity and damaged ecosystems

The challenge faced by governments, communities and households is how to become more resilient to these increasing stresses and shocks. In part, the answer is the process of development itself.

Type	Killed	Affected
Flood	9,642	19,939,000
Drought/famine	4,453	110,956,000
Windstorms	1,335	5,687,000
Extreme temperatures	147	8,000
Total	**15, 713**	**136, 590, 000**

Table 2. Numbers of people affected by extreme weatherrelated disasters in Africa 1993-2003. [89]

If people are better fed and in better health, and have better access to education, jobs and markets, then they will be more resilient to climate change. Development in the era of climate change thus goes beyond the Millennium Development Goals to include:

- Reducing inequity
- Promoting fair growth and diversification of economic activity
- Enhancing resilience to disasters and improving disaster risk reduction
- Promoting the sharing of risk, including social safety nets for the poorest.

Adapting to climate change is, inevitably, as complex a process as the phenomenon of climate change itself. Each of the various impacts needs to be assessed and the most appropriate countermeasures designed, taking account of effectiveness, costs and socio-political acceptability.

Challenges for adaptation

About 70% of people in sub-Saharan Africa live in rural areas, and it is their livelihoods that will be most at risk from climate change. About a third of the African population already experiences chronic hunger. In addition, there are periodic famines in further

Box 4. The vulnerability of African countries to climate change[86]

- Most African countries are highly dependent on natural resources and their agricultural sector for food, employment, incomes, tax revenue and exports. Changes in weather conditions that damage the agricultural sector will thus have a major impact on incomes and livelihoods.

- Poor countries and poor communities tend to have a higher share of their assets and wealth tied up in natural resource and environmental assets, so anything that damages the natural resource base will clearly damage these countries more.

- There is little irrigation in Africa and most subsidence farmers rely on natural rainfall, making them highly vulnerable to even quite small changes in rainfall patterns

- One third of Africa's productive area is already classified as dryland, and climate change may bring less rainfall and a shorter growing season, extending such drylands over a larger area.

- Many parts of Africa are already short of water – a shortage that may further increase.

- Government and institutions are weak and poorly resourced, so many people will have to cope on their own. The brain drain of well-qualified people further limits their capacity.

- Most people operate at low levels of income with limited reserves, and lack formal insurance cover.

Box 5. Causes of famine and conflict in Darfur [90 91]

The Darfur region lies in the west of Sudan, along the borders of Libya, Chad and the Central African Republic. It has long been inhabited by two groups of people: 60% subsistence farmers and 40% nomadic or semi-nomadic herders of livestock. Traditionally they have lived together in relative harmony, with the herders crossing the land of the subsistence farmers and using their wells.

The Sahel drought (Figure 1) also severely affected the Darfur region, culminating in the subsequent famine in 1984/5, when 95,000 people died out from a total of some 3 million. (Whether or not the drought is a product of climate change is debatable).

The consequent shortages of food and water and the ensuing land degradation forced the herders to migrate southward, which increased competition for land and water between them and the subsistence farmers. This was made worse by population growth.

The conflicts escalated when the Janjaweed militia, with government support, began to force the farmers from their homes and take possession of the wells. The UN estimates that to date 450,000 people have died through violence or disease and as many as 2.5 million have been displaced.

regions, caused by civil unrest, poor governance or failure of the rainfall. Famine is often a combination of all three (Box 5).

Drought can have other catastrophic effects on rural communities. For example, in northeastern Ethiopia, drought-induced losses in crop and livestock were estimated at $266 per household 1998-2000 – greater than the annual average cash income for more than 75% of the households.[92]

Chronic hunger is likely to be made worse by climate change. This is partly because the proportion of arid and semi-arid lands is expected to increase (5-8% more by the 2080s), and partly because of depleted water resources. Projected reductions in yield in some countries could be as much as 50% by 2020, and crop net revenues could fall by as much as 90% by 2100, with small-scale farmers most vulnerable.[46]

Deaths from malaria in Africa currently amount to nearly 1 million people per year, to which must be added deaths from other infectious diseases such as measles and dengue.[93] In addition, mortality from diarrhoeal diseases is nearly 700,000 per year, partly as a result of poor quality drinking water and poor sanitation, in turn affected by the availability of adequate water resources. In 2000, only ~60% of the African population had access to improved water supplies.[94 95] Scarcer water resources will challenge this figure further.

The impact of increased disease could be costly. One estimate puts the population at risk from malaria in Africa at 1.15 billion in 2030 (compared with 0.63 billion in 2005).[96] The current economic burden of malaria already reduces average annual economic growth by 1.3% for those African countries with the highest burden.[97]

Sea level rise will only affect a small proportion of Africa's land mass, but the impact will be considerable. Forty percent of the population of West Africa lives in coastal cities, and it is estimated that the 500 km of coastline between Accra and the Niger delta will become a continuous urban megalopolis of more than 50 million inhabitants by 2020.[46] By 2015, Africa will have three coastal megacities of at least 8 million inhabitants with many of the poorest populations located in the most flood-prone districts.

Other costly impacts will be on infrastructure with roads, rail tracks, bridges and power installations all vulnerable to damage from flooding. Degradation of ecosystem services and loss of biodiversity will also have an economic impact, reducing the capacity of the land to recover from floods and droughts.

Building resilience

At the core of adaptation is the concept of resilience, which encompasses the abilities of countries, communities, households and individuals to cope with climate change.

Resilience focuses on a desired pathway of development, usually measured as yield, agricultural production, household income or GDP per capita. This pathway is then subject to a stress or shock. A stress may arise from increasing maximum or minimum temperatures or the effects of a progressively drier climate or of rising sea levels. A shock, by contrast, is a less predictable and sudden event such as a major flood or drought or a storm surge or cyclone.

Figure 28 illustrates development as a trend. Along comes a stress or shock, which in some circumstances can be fully resisted: for example, a dam or barrage may prevent a flood. More commonly, development is adversely affected and growth falls,

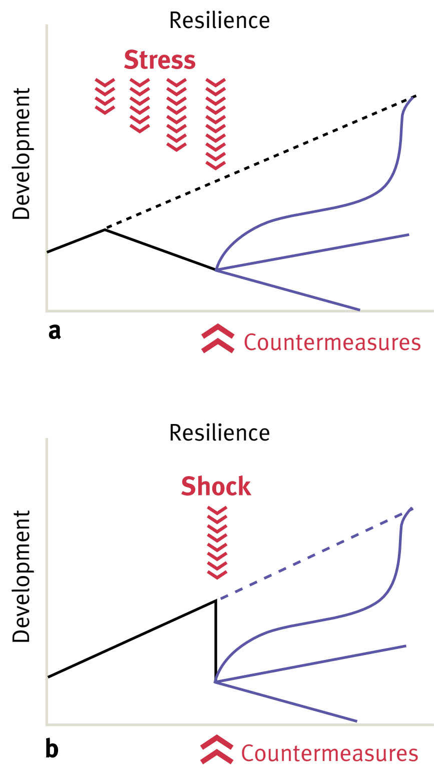


Figure 28. Patterns of resilience (a) to stress, (b) to shock.

recovering fast or perhaps slowly. In some cases, the disturbance is too great, recovery does not occur and development collapses. For each stress or shock there is an appropriate countermeasure. In general, developed countries are likely to resist or recover more rapidly than developing countries, which may experience a greater impact, and recovery will be slow or non-existent.

Resilience has the advantage of being a qualitative and quantitative concept. In theory, the strength of stress and shock can be measured, as can the path of resistance, recovery or sometimes collapse. Costs can be assigned to the impact of shock and stress, and to the countermeasures. The benefits to the subsequent development pathway can also be assessed and hence the different countermeasures can be assessed in terms of both costs and benefits.

Countermeasures contributing to greater resilience can take many different forms, including social, economic and technological:

- Institutional—land-use zoning, integrated warning systems
- Economic—weather insurance, micro-credit schemes
- Physical—cyclone shelters, embankments
- Medical—vaccines
- Environmental—mangrove shelterbelts
- Agricultural—drought- and flood-resistant crop varieties, increased nutrients
- Livelihood—income diversity, rural-urban linkages, ability to migrate
- Education—information and development of skills

It is useful to categorise the countermeasures on a time scale relevant to the incidence of the stress or shock (Figure 29).

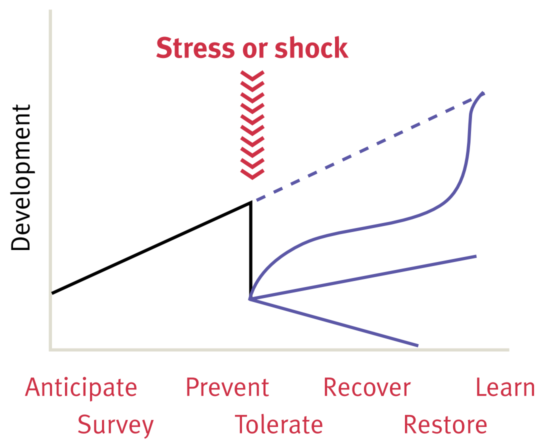


Figure 29. The timescale of countermeasure interventions.

This conceptualization follows in some respects the steps taken in modern disaster risk reduction to cope with hazards such as earthquakes and cyclones. Developing resilience to climate change thus builds on the various approaches to disaster risk reduction that have been successfully practised over the years.[98]

Forecasting and surveys

Anticipating stress and shock involves a survey process to determine the likely location and probability of potential disturbances. Such inventories can be depicted as hazard maps, some on a large scale, often produced by government agencies. Such maps need to take into account:

- Physical hazards e.g. sites prone to floods and droughts (Figure 30), infrastructure vulnerabilities particularly in relation to sea level rises and storm surges
- Biological vulnerabilities e.g. crops and livestock at risk, ecosystem vulnerabilities
- Human vulnerabilities e.g. from flooding or drought, health hazards, vulnerable livelihoods.

Local communities can produce smaller scale surveys for their own planning, to help them respond rapidly to local floods and other hazards.

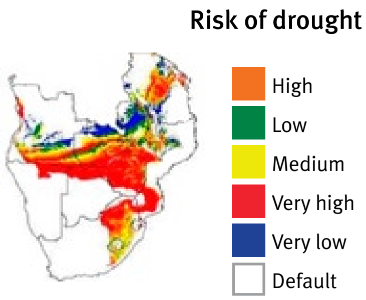


Figure 30. Risk of drought during the grain-filling stage of maize in southern Africa[99]

Anticipation also includes producing long-range weather forecasts, which are then used to put adaptive measures in place. Some such forecasts are possible for Africa, because of the relationship between sea surface temperature (SST) and large-scale weather patterns. Slow changes in SST and associated weather patterns can be predicted with some degree of accuracy up to six months in advance (Figure 31).

Prevention and tolerance

The subsequent steps of prevention, tolerance, recovery and restoration involve defining the objectives, identifying the various options and appraising them in terms of their outcomes and the relevant costs and benefits (Figure 32). To be effective, the option appraisal needs to be fairly sophisticated (Table 3).

Countermeasures against stresses are highly targeted. For example, the impact of increasing drought can be prevented by a variety of specific water harvesting and water saving systems - devices, ranging from large-scale reservoirs to village tanks with accompanying systems of delivery. The design and construction of such systems are relatively well known; often the challenge is to ensure they are sustainable and easily accessed by the poor as well as the rich.

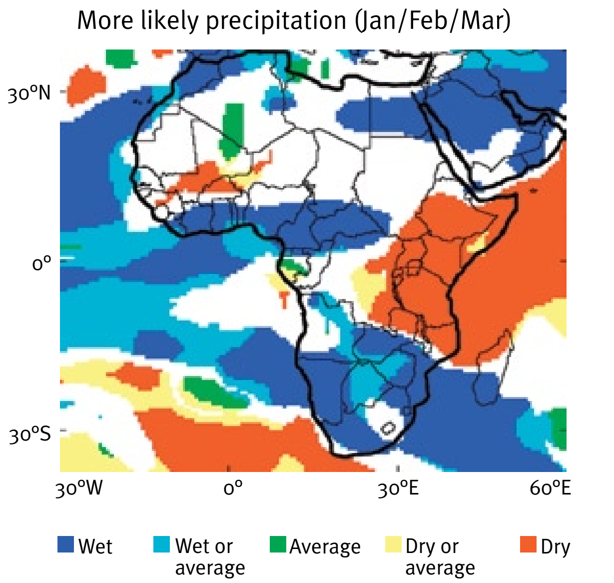


Figure 31. Long-range forecast for Africa made by the UK Meteorological Office in December 2005 for the following three months.

Drought tolerance can be achieved by crop breeding, such as the collaboration between the International Maize and Wheat Improvement Center (CIMMYT) with national agricultural research systems, the private sector and farmers to breed over 50 new varieties of maize, which are typically tolerant of drought, low soil fertility, parasitic weeds and other stresses. Appropriate cropping systems can also improve drought tolerance (Box 6).

Resilient livelihoods

Countermeasures to prevent or reduce the impact of shocks such as sudden floods or droughts, cyclones or storm surges tend to be more general when aimed at reducing the vulnerabilities of people.

One of the best defences against shock is to diversify the livelihood, either by increasing the diversity of crops and livestock on a farm or by establishing more varied income sources for the household. This could mean having another crop that will grow and survive if a drought or flood has knocked out the first one, or by establishing off-farm sources of income to complement the farm income should the latter be destroyed.

Local communities have often built resilience to disasters into their social networks and systems. For example, strategies for coping with drought may involve a diverse range of subsistence and income-generating activities (Box 7).

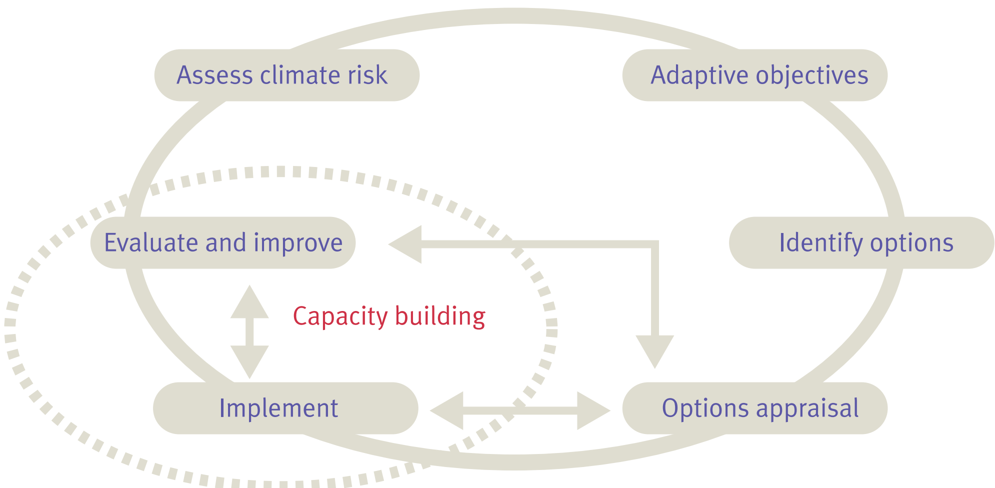


Figure 32. An adaptation option appraisal process developed in China.[100]

Table 3. Multiple criteria used in appraising options in Chinese adaptation model, using methods developed for DFID Climate Screening Process ORCHID.[100 101]

Criteria	Indicator
Win-win options	Does option address current climate variability *and* future climate change?
Existing risk management	Is the option consistent with existing risk management activities?
Cost effectiveness	Can costs and benefits of option be easily determined?
Adaptive flexibility	Does the option focus on narrow range of future scenarios, or allow flexibility of response?
Unintended impacts	Potential negative spin-off impacts beyond targeted activity?
Practical considerations	Is the option practical and feasible for implementer?
Knowledge level	How certain are we in predicting a particular change in hazard and its impact?
Policy coherence	Does option reflect local and national DRR/adaptation plans or studies?

Figure 33. Conservation farming in Zimbabwe.

Figure 34. Conservation plots in Zimbabwe after 3 years with a) conventional tillage, and b) minimum tillage

Box 6. Conservation farming in Zimbabwe

It has become common, if not standard practice, since colonial times, to till the soil with a moleboard plough before maize is sown. On the poorer soils this destroys the soil structure and increases water loss. Many argue that the practice is responsible for the long-term decline in Zimbabwe's soil fertility.

The alternative is to till the soil minimally and leave the crop residues in place as mulch for the next crop (Figure 33). Prior to seeding, farmers use hoes to prepare small basins in which fertiliser (inorganic and/or manure) is placed, followed by one or two maize seeds. One or two selective weedings may be needed, but that is all.

The benefits begin in the first year. After three years they are dramatic. In one pair of plots in southern Zimbabwe the soils remain dry and sandy under conventional production but are moist and structured in the conservation plots (Figure 34). Yields are doubled – in some cases the conventional approach will fail altogether.

There are clearly lessons to be learnt from people who have had to cope with regular stresses. But often such resilience has been steadily eroded under the impact of migration, family breakdown, famine relief, poverty and disease in recent decades, with the result that people have become more dependent on outside aid. A major challenge for governments, donors and particularly for NGOs is to help communities rebuild their resilience mechanisms. For example, many of the activities in Box 7 rely on the informal sector and governments can help by creating links to the formal sector and by providing skills, knowledge and access to markets.

Often, women play a key role in creating resilient livelihoods. They may be primarily responsible for home gardens and for higher value vegetable and fruit crops that help diversify the agricultural production. Skills such as weaving and handcraft manufacture can provide a source of income when agriculture fails. This stresses the importance of seeing livelihoods as a whole family affair involving both men and women and, as they grow older, the children. Any programme of enhancing livelihoods needs to take this wider holistic and more long-term view into account.

In summary, it is useful to envisage a pyramid of adaptation (Figure 35). At the base is the process of development itself; in the centre, reducing the vulnerability of people to major shocks; and at the top, the specific adaptations required for individual stresses. The greater the knowledge of the likely impact, the more refined the response. At the same time, we do not have to wait until we know everything about likely impacts: much will be achieved by increasing the general resilience of households, communities and institutions.

Learning

Finally, building resilience is about learning. Small-scale stresses and shocks experienced by a country or community will help them assess how they coped, and how well their planned adaptations perform in practice. This means putting learning processes into place at all levels, of household and community, and of district and national government. This will require effective monitoring and development systems, accessible archives and ways of sharing experiences between communities. Most importantly, it requires a sense of collective responsibility. In the longer run, this will help build a development process that is both resilient and self-learning, and hence sustainable.

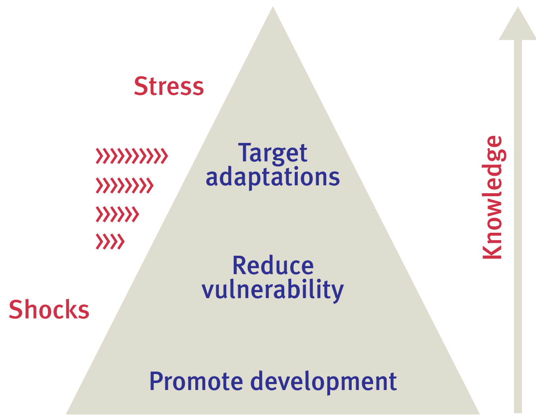


Figure 35. The pyramid of adaptation

Box 7. Drought coping mechanisms in Kenya [102]

The Kitui District of eastern Kenya suffered from poor rainfall in 1995 and 1996 and ran out of food between the harvest in July 1996 and that in February 1997. Only two out of a random sample of 52 households had a maize crop that lasted them through this period.

The farmers listed a large number of coping activities:

- Skilled work
- Selling land
- Collecting honey for consumption and sale
- Making bricks for sale
- Engaging in food producing or money making group activities
- Business, such as selling snacks
- Burning charcoal for sale
- Salaries of householder or remittances
- Handicrafts for sale
- Selling or consuming exotic fruits from the farm
- Receiving credit
- Borrowing food or money from relatives
- Borrowing food or money from neighbours
- Engaging in casual labour
- Selling livestock
- Collecting indigenous fruit for consumption or sale
- Receiving food aid from government or other organisations

Each household averaged about six activities during the drought. After the drought this dropped to three. Diversity remains a common feature of livelihoods.

Conclusions

There are some things we know about the impact of climate change on Africa. We know that northern and southern Africa will become much hotter (as much as 4 °C or more) and drier (precipitation falling by 15% or more). Wheat production in the north and maize production in the south would then be adversely affected. In eastern Africa, including the Horn of Africa, average rainfall is likely to increase. Vector-borne diseases such as malaria and dengue may spread and become more severe. We also know that sea levels are very likely to rise, perhaps by half a metre, in the next fifty years with serious consequences in the Nile Delta and certain parts of West Africa.

But there is much that we do not know. The Sahel may get wetter or remain dry. The flow of the Nile may be greater or less. We do not know whether overall the fall in agricultural production will be very large or relatively small. Part of our ignorance comes from a still poor understanding of the drivers of the African climate, their interactions and the effects upon them of global warming. Part also is due to a severe lack of local weather data, particularly for central Africa.

There are many other known unknowns. Will climate change experience tipping points, for example an accelerating and irreversible ice loss from the Greenland ice cap and the Antarctic shelf, resulting in much greater rises in sea levels? Will El Niño become a more permanent phenomenon with consequences for Africa's rainfall patterns?

There are also, probably, many unknown unknowns – potential tipping points that we are unaware of: for example diseases that can be transmitted from animals to humans, which may emerge as a result of climate change.

This relatively poor state of knowledge has two implications. First, we urgently need more research, into the dynamics of the global drivers and the detailed consequences at regional and local levels. Second, we need to design and build on existing adaptation measures to cope with high levels of uncertainty.

In general the best assumption is that many regions of Africa will suffer from droughts *and* floods with greater frequency and intensity. The implication is that we have to plan for the certainty that more extreme events will occur in the future but with uncertain regularity.

Adaptation thus depends on developing resilience in the face of uncertainty. The conceptualisation of resilience presented above is similar in many respects to the approach that has been long used in the face of natural disasters such as earthquakes and tsunamis. It begins with anticipation, surveying and forecasting, moves to developing preventative measures and increasing tolerance, and subsequently after the event or events focuses on recovery and restoration. At the end is the importance of learning. In general, the more time and resources put into the earlier stages of this sequence, the better.

Resilience is important at the national, regional and local levels, involving not only technologies, but also appropriate economic policies and institutional arrangements. It is the poor who will be most vulnerable to the effects of climate change. To some extent the process of development itself will help them to adapt. If people are better fed and in better health, and have access to education, jobs and markets they will have the capacity to be more resilient. Traditionally, poor people have developed various forms of resilient livelihood to cope with a range of natural and man made stresses and shocks. But these may be inadequate in the future or may have been lost in the development process. The urgent need is for governments, NGOs and the private sector to work together with local communities to enhance the resilience of the poor of Africa

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