08

The Science of Climate Change

The receding glaciers on Mt. Kilimanjaro, Tanzania which may be caused by climate change
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In part two we examined the role of science and innovation in addressing the challenges of the MDGs as though they constituted a set of discrete goals with their own distinct trajectories. In some cases they are on track to meet their targets; in others the prospects are gloomier. There is a justification for such a 'siloed' approach. As we have seen, the scientific issues and the technologies that are needed are themselves complicated and require the undivided attention of those who have the skills and experience to tackle them. Nevertheless, as has become increasingly apparent, the MDGs exist in a global context that is itself challenging and transforming. Globalisation, demographic changes, financial crises and a range of major global threats, including climate change, will determine whether or not we can achieve the MDGs.

In part three we begin by looking in some detail at the threat of climate change, its science, the expected impacts and then in the next chapter, we discuss how we can adapt to them. The fundamental message is that we have to become more resilient.

Global climate change has been largely driven by the activities of the industrialised countries. Yet its most severe consequences are going to be felt, and indeed are already being felt, by the developing countries. Moreover, it is the poor of those countries who, in part, because of their poverty, are most vulnerable. If left unchecked, climate change will increase hunger and mortality from infectious diseases and will cause the further deterioration of the environmental resources on which, as we have seen, the poor so often depend.

In this chapter we explore the role of science and technology in answering the following questions:

- What do we know and not know about climate change?
- What will be the most serious consequences, especially in Africa and Asia?

1. What do we know about the global impacts?

There is convincing evidence that global climate change is occurring and is the result of man-made emissions of greenhouse gases (GHG) – primarily carbon dioxide (CO_2), methane and nitrous oxide. The mechanism is relatively simple and increasingly understood: these gases form a layer over the earth's surface which traps an increasing proportion of the infrared radiation which would be otherwise radiated out to space, so warming the land and oceans beneath (Figure 8.1).

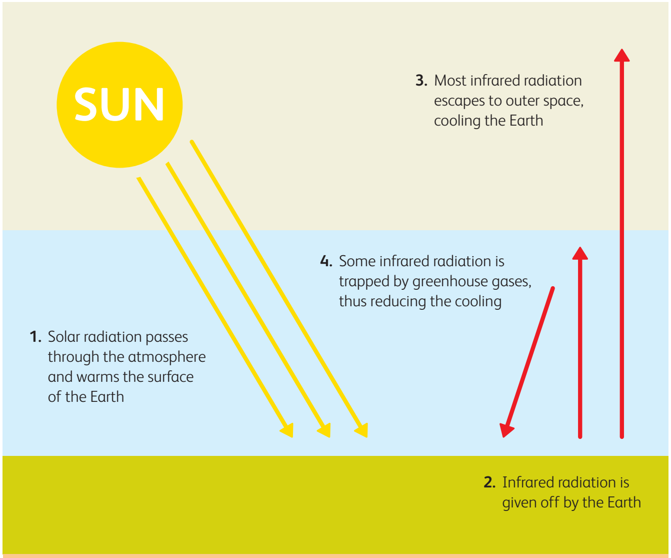
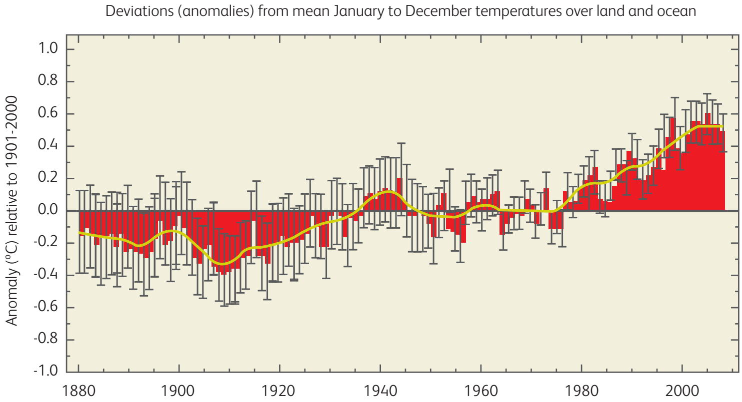


Figure 8.1 – The Greenhouse Effect[1]

As a consequence the world as a whole is warming – so far by more than 0.7°C since the industrial revolution (Figure 8.2).

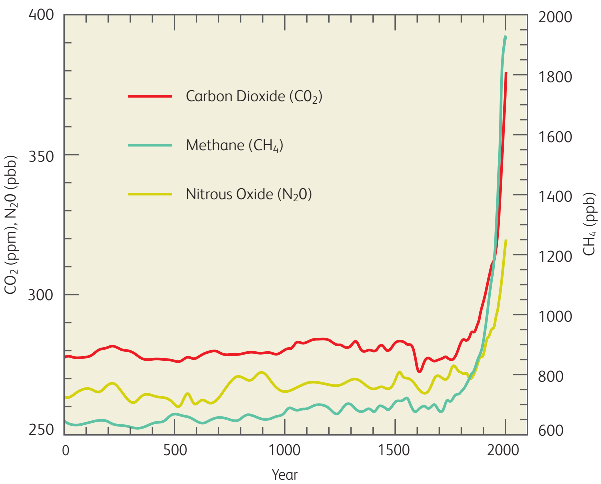
Since pre-industrial times (around 1750), CO_2 concentrations have increased by just over one third from 280 parts per million (ppm) to 385 ppm in 2008 (Figure 8.3).[3] Taking the six GHGs included in the Kyoto protocol together, the total is now about 436 ppm of CO_2 equivalent and is predicted to reach 570-700ppm by the middle of the century.

Figure 8.2 – Global warming has increased by about 0.7° C since 1900[2]



There has been no comparable rise in these long lived greenhouse gases since at least the beginning of the Ice Ages, 600,000 years ago. Their cumulative radiative forcing, that is the balance of incoming and outgoing energy they cause has, over the past two decades, been about 1 Watt per metre² more than that in pre-industrial times and sufficient to explain the global warming we are now experiencing.

Figure 8.3 – The rise in carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) over the past 2,000 years has been unprecedented. Measurements using ice cores and modern data[4]



Alternative explanations

There have been exhaustive studies of alternative explanations for the rising temperature (Box 8.1).

Box 8.1 Why some of the most plausible alternative explanations of recent global warming are inadequate[5-7]

1. There have been major changes in temperatures before, for example, the Younger Dryas, a cold period lasting about 1,300 years that occurred some 12,000 years ago and, more recently, the 'Warm Period' followed by the 'Little Ice Age' in Europe. But neither appears to be a global phenomenon (the Younger Dryas may be the result of significant reduction or shutdown of the North Atlantic thermohaline circulation).

2. Temperatures and CO_2 levels rose in past interglacials, but the cycles of glacial and interglacial periods were probably caused by the 'wobbles' in the Earth's orbit around the Sun (known as Milankovitch cycles) and the CO_2 rise followed the temperature rise not vice versa.
3. Sunspots can increase global temperatures. Greater sunspot activity emits more heat and light, but while there is evidence of a link between solar activity and some of the warming in the early 20th century, measurements from satellites show that there has been very little change in underlying solar activity in the last 30 years and there is even evidence of a detectable decline.
4. Galactic cosmic rays may increase warming through the effect of the tiny particles on cloud formation, but the effect is likely to be very small.
5. Aerosols and volcanic eruptions affect global warming. But they are primarily cooling factors; for example the 1991 eruption of Mount Pinatubo in the Philippines reduced the global surface temperature by about 0.3°C over the following two years. Without these effects global warming would be much greater.

The conclusion in the Stern Review, a comprehensive report by economist Sir Nicholas Stern was: '*It is now clear that, while natural factors, such as changes in solar intensity and volcanic eruptions, can explain much of the trend in global temperatures in the early nineteenth century, the rising levels of greenhouse gases provide the only plausible explanation for the observed trend for at least the past 50 years.*'[1]

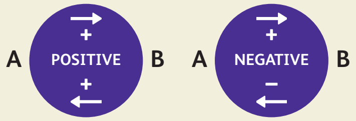
The importance of feedback loops

A doubling of CO_2 levels results in an increase in temperature of 1°C, but the likely increase is going to be considerably greater because of a number of feedback loops in the global climate (Figure 8.4).

Water vapour is an example of a phenomenon that can create either positive or negative feedback loops. The greater the temperature the more evaporation and the more clouds are produced. An increase in high clouds traps outgoing long-wave radiation so warming the planet – a positive feedback. But low clouds tend to reflect incoming radiation so cooling the planet – a negative feedback.[8]

Complications

- Positive loop increasing A, increases B and which in turn further increases A.



- Negative loop increasing A increases B but that decreases A.

Figure 8.4 – Complicating feedback loops in the climate system

Some of the other feedback loops are as follows:

- A major positive feedback results from the reduction of snow and ice cover. This exposes a greater area of darker land and sea, creating more heat absorbing surfaces that result in more melting;
- Rising temperatures and changes in rainfall patterns are also expected to weaken the ability of the Earth's natural land and ocean sinks to absorb CO_2, causing a larger fraction of human emissions to accumulate in the atmosphere;
- Widespread thawing of permafrost regions could release large quantities of methane, as well as CO_2, which will add to the warming;

- The most significant negative feedback is caused by the production of particles into the atmosphere, some of which have a strong cooling effect. However, the known positive feedbacks far outweigh such negative loops and will add to the direct effects of the CO_2 emissions.

Figure 8.5 – Estimates of global surface warming for different scenarios[9]

	Temperature Change (°C at 2090-2099 relative to 1980-1999)		Sea Level Rise (m at 2090-2099 relative to 1980-1999)
Case	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations	0.6	0.3–0.9	N/A
B1 scenario	1.8	1.1–2.9	0.18–0.38
A1T scenario	2.4	1.4–3.8	0.20–0.45
B2 scenario	2.4	1.4–3.8	0.20–0.43
A1B scenario	2.8	1.7–4.4	0.21–0.48
A2 scenario	3.4	2.0–5.4	0.23–0.51
A1FI scenario	4.0	2.4–6.4	0.26–0.59

- The A1 storyline 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. A1 is divided into three groups that describe alternative directions of technological change:
  - fossil intensive (A1FI);
  - non-fossil energy resources (A1T);
  - and a balance across all sources (A1B).
- B1 describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy.
- B2 describes a world with intermediate population and economic growth, emphasising local solutions to economic, social, and environmental sustainability.
- A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change.

Current estimates are, that if we assume balanced energy based economic growth (the A1B scenario), the surface warming is likely be 1.7–4.4°C above 2000 levels by the end of the century (Figure 8.5).[9]

A rise in temperature of this amount may not seem significant but a *drop* of 5°C in temperature marked the coldest period of the last ice age.

Tipping points

Moreover, there are concerns that the temperature increases may result in a ‘tipping point’ phenomenon where the positive loops start to generate new phenomena, with consequences that are difficult, or impossible, to reverse.[10-13] In 2005 a workshop at the British Embassy in Berlin brought together a large group of experts who identified 15 so-called tipping elements:[11]

1. Arctic summer sea – ice;
2. Greenland ice sheet;
3. West Antarctic ice sheet;
4. Atlantic thermohaline circulation;
5. El Niño – southern oscillation;
6. Indian summer monsoon;
7. Sahara/Sahel and West African monsoon;
8. Amazon rainforest;
9. Boreal forest;
10. Antarctic bottom water;
11. Tundra;
12. Permafrost;
13. Marine methane hydrates;
14. Ocean anoxia;
15. Arctic ozone.

Three of these are described in more detail in Box 8.2.

Figure 8.6 – Glacial melt on the Greenland ice sheet

Box 8.2 Possible climate tipping points

1. The disintegration of the Greenland ice sheet

The ice sheets of Greenland and Antarctica hold enough ice to raise sea level about 64 metres if fully melted.[14]

Current measurements in Greenland suggest that the ice sheet inland is growing slightly but there is significant melting and flows of ice near the coast. This is greater than predicted by the models. It appears that melt water is seeping down through the crevices of the melting ice, lubricating glaciers and accelerating their movement to the sea.[8,15-17]

Model simulations suggest that there is a critical temperature threshold beyond which the Greenland ice sheet would be committed to disappearing completely (Figure 8.7). This would result in a rise in sea level of about seven metres. Although this would take many hundreds of years, the threshold could be crossed during this century.[18]

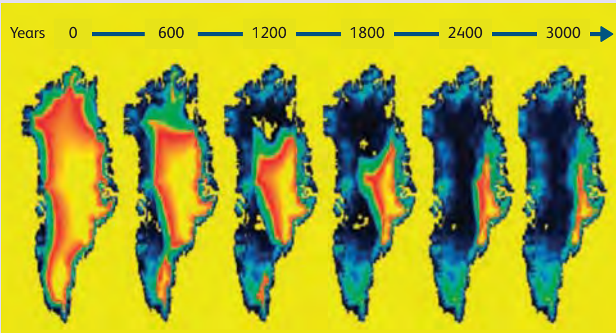


Figure 8.7 – Predicted loss of the Greenland Ice sheet with a fourfold increase in CO_2. (Red, indicates high, and black, low, elevations)[19]

2. Collapse of the West Antarctic ice sheet

Recently the western ice sheet has experienced sustained warming and significant thinning (about 20 mm/year on the Larsen-B Ice Shelf). A large section of the shelf, the size of the state of Rhode Island in the US (over 3,200 km^2 in area and 200 m thick), collapsed in 2002. The shelf is now only about 40 % of the size of its previous minimum stable extent.[20]

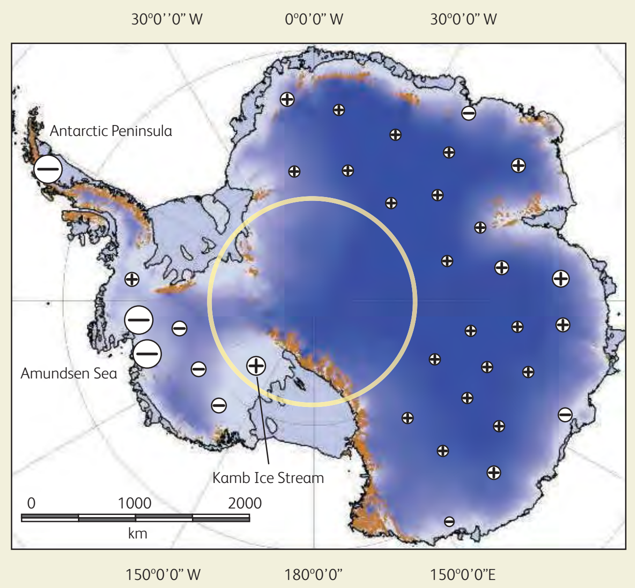


Figure 8.8 – Gains and losses of snow and ice in the Antarctic[21]

The Antarctic peninsula as a whole has warmed by 2°C over the last 40 years and this may be the cause of the spectacular collapses of the ice shelves there. However, for Antarctica as a whole there appears to be a small growth in snow and ice due to increased precipitation (Figure 8.8). For the West Antarctic ice sheet the danger is that ocean warming and the acceleration of ice flows will cause a runaway discharge into the oceans. The critical threshold is unknown but it could be as low as 2°C to 5°C. Estimates of the time for the West Antarctic Ice Sheet to totally melt range from 250 to 700 years.[22,23]

3. Release of deep sea methane hydrates

An immense quantity of methane (equivalent to 500-2,500 gigatonnes of carbon) may be trapped in marine sediments in the form of solid gas hydrates (Figure 8.9).[24] They also occur in, and under, the Arctic permafrost.[25] The amounts are prodigious – the total carbon bound in gas hydrates (mostly methane) is estimated to be twice the amount present in all known fossil fuels.

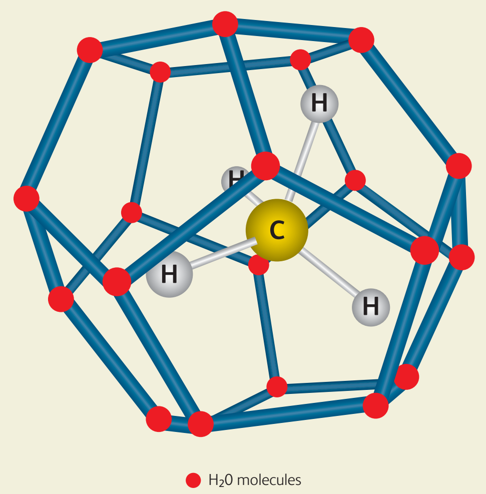


Figure 8.9 – Methane hydrates consist of crystalline solids similar to ice in which water molecules form a cage-like structure around a methane molecule[26]

They exist in oceanic regions sufficiently cold and under enough high pressure to keep them stable. If ocean warming penetrated as far as the deep oceans it could destabilise the methane, releasing it into the atmosphere, so leading to a rapid increase in global warming (Figure 8.10).

In 2008 a British research team discovered about 250 methane plumes bubbling from the seabed in an area of about 30 square miles, in water less than 400 metres deep, off the west coast of the archipelago of Svalbard, that lies about 80°N. These releases have been occurring since the last Ice Age, but it is not yet known whether ocean warming is increasing the rate of release.[28]

There was a period of massive methane hydrate destabilisation 55 million years ago which led to rapid climate change, when the deep-sea temperature rose 5° to 6°C.[29]

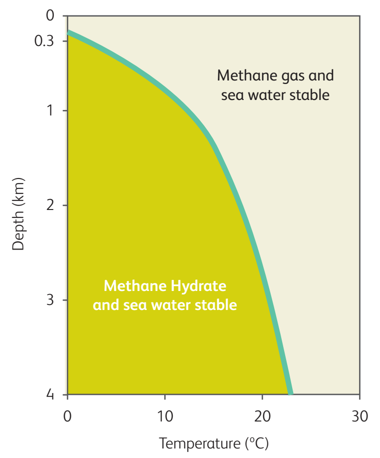


Figure 8.10 – Methane hydrates are only stable at low temperatures and high pressures. If conditions shift the hydrates can be released as methane gas[27]

It is very difficult, given our current state of knowledge, to determine when and how these tipping points are likely to occur. What is certain is that the consequences from any one of these will be devastating for many regions of the world, if not for the planet as a whole. Some believe that the risks are very low and the dangers overstated. However, the Berlin workshop concluded that *'Our synthesis of present knowledge suggests that a variety of tipping elements could reach their critical point within this century under anthropogenic climate change. The greatest threats are tipping the Arctic sea-ice and the Greenland ice sheet, and at least five other elements could surprise us by exhibiting a nearby tipping point.'* James Hansen (Head of NASA Goddard Institute for Space Studies in New York City) and his colleagues go further and conclude from their modelling that a rise of just 1°C in global temperature above the 2000 level would be 'dangerous,' and may well trigger a number of these tipping points.[30]

Global and regional consequences

Despite these longer term uncertainties there are near term consequences that are highly likely. There will be:

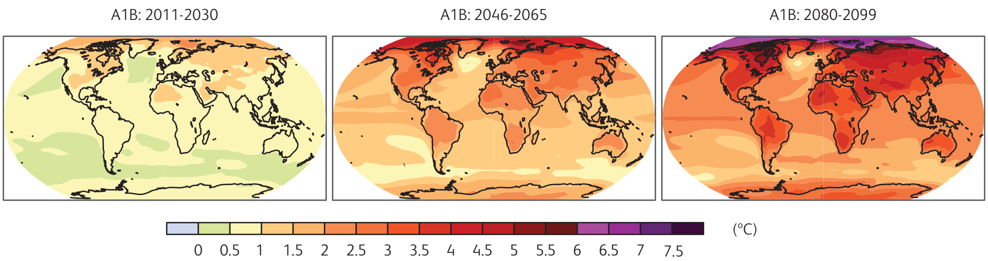
- Regions that are warmer or colder;
- Regions more prone to drought or flooding;
- Higher sea levels;
- More storm surges;
- Greater variation in the weather and more intensive extreme events – hurricanes, tropical cyclones, floods and droughts.

Figure 8.11 – A father carries his daughter after floods caused by tropical storm 'Noel' hit Soleil, Haiti in 2007

It is striking that although the driving force is global warming the main consequences are related to water – either too much or too little in any one place.

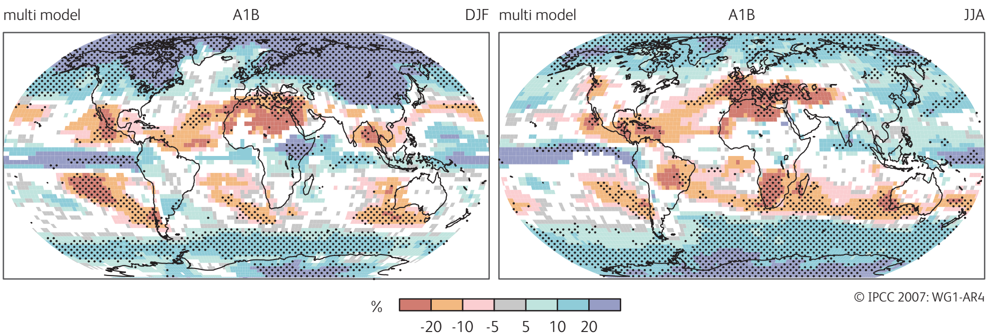
Figure 8.12 shows the probable temperature patterns for the globe over the next 100 years. These suggest that, at least to begin with, the biggest temperature increases will occur in the upper latitudes.

Figure 8.12 – Increases in temperature over the next 100 years using the IPCC rapid growth scenario A1B[18]



For rainfall the biggest impact is likely to be the greater incidence of drought in northern and southern Africa and in some parts of Asia (Figure 8.13).

Figure 8.13 – Changes in precipitation over the next 100 years for December to February (left) and June to August (right). (These are composites of many different models. The white areas indicate where less than 66 % of the models agree; the dotted areas are where more than 90 % of the models agree.)[31]



2. What are the global drivers?

Underlying these changes are global climate phenomena that interact in complex, and still not yet fully understood, ways.[8] Most of the developing countries are located in the tropics and subtropics i.e. they lie between 0° and 30° north and south of the equator. Within this latitudinal band are three critical processes:

Two of these – tropical convection and the alternation of the monsoons – are relatively 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 local, in one respect, but strongly influences the year to year rainfall and temperature patterns on a global scale. 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 – will affect their outcomes, increasing the incidence and severity of the droughts, floods and other extreme weather events that they produce.

Tropical convection

Intense solar heating near the equator leads to rising warm, moist air and heavy rainfall (Figure 8.14). As it rises the air creates a surface low-pressure area, known for centuries by sailors as the *Doldrums*, and 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° north and south of the equator) as warm, dry air. From there it is carried back towards the equator by the trade winds.

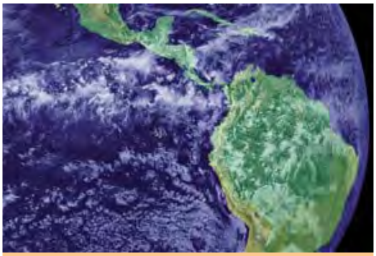


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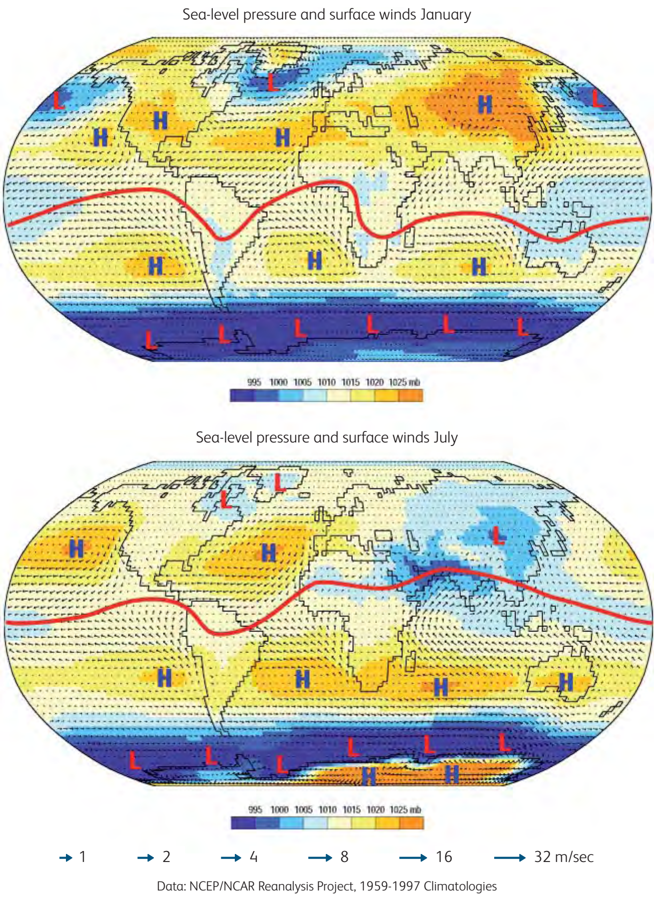
Figure 8.14 – The thunderstorms over the Pacific along the ITCZ

Each year the ITCZ moves north and south following the seasonal tilting of the globe towards the sun. In Africa four distinct climatic zones result[9]:

1. The tropical moist climates with around 2,000mm of rain that support the equatorial rainforest;
2. Tropical climates that alternate between wet summers (brought by the ITCZ) and short dry winters, giving a total rainfall of 1,000-2,000mm;
3. Tropical semi-arid climates, with long dry seasons, at the northern-most limits of the ITCZ and rainfall of 300-800mm;
4. Arid climates located between 30° and 40° north and south, with less than 250 mm year rainfall.

In Africa and elsewhere, these are not distinct zones; their boundaries overlap and vary from year to year with both the latitudinal and longitudinal movement of the ITCZ (Figure 8.15).

Figure 8.15 – The position of the ITCZ in January and July (red lines)[32]



The monsoons

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Figure 8.16 – Heavy monsoon rains in Delhi

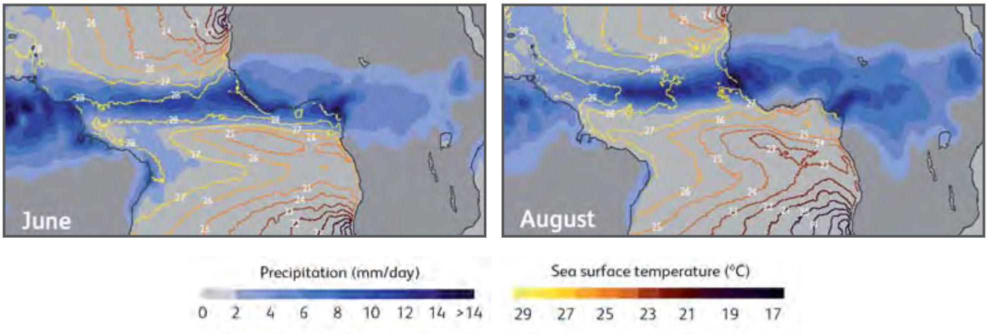
Another phenomenon, closely linked to tropical convection, is the marked seasonal change in the direction of the monsoonal winds (compare the wind patterns for Jan and July in Figure 8.15) brought about by the changes in temperature gradients as the sun 'moves' north and south during the year.[9] The global monsoon system turns out to be a complicated phenomenon involving several processes (including the movement of the ITCZ) which interact in ways that are still not fully understood.[33,34] In simple terms, monsoon winds occur because land heats up and cools down more quickly than the sea. This results in changes in the surface winds and the associated precipitation. The strongest monsoons occur over the tropics of southern and eastern Asia and northern Australia, and parts of western and central Africa. In these regions the wet season migrates north and south from one hemisphere to the other following the sun.

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 area drawing in warm, moist air from over the ocean. The air moves first northward, and then because of the effects of the Earth's rotation is diverted north-eastward. It begins to rise and cool and sheds its moisture as rain. In winter the reverse occurs, the land cooling down more than the oceans, creating the north-east monsoon. These monsoon wind changes also affect lands far distant from south Asia, for example along the eastern margins of Africa.

The East Asian monsoon, while less extreme in its reversal, acts as a particularly influential climate driver, carrying moist air from the Indian and Pacific oceans to countries in East Asia such as China, Japan, North and South Korea and Taiwan, and affects up to one-third of the global population. The monsoon tends to concentrate rainfall in rain 'belts' which stretch for thousands of kilometres, acting as important, and often hard to predict, determinates of agricultural production in the affected countries. Adding to this, the East Asian summer monsoon contributes to heightened typhoon activity and increasing rainfall in the North Pacific. The monsoon also brings a cold and dry winter season, which is partly responsible for the dust deposition that created the Loess Plateau in China discussed in Chapters 1 and 2.

West Africa is affected by a south-west monsoon which arises in a similar fashion. In the summer, as the land becomes hotter than the ocean and as the air over the Sahara starts to rise, cooler, more humid air from the Atlantic Ocean is drawn in 1,000 km to the south. It brings rainfall from May to September in two phases (Figure 8.17). The first in April, May and June centres on the Gulf of Guinea (about 4°N) and appears to be influenced by sea surface temperatures. Then suddenly, usually in early to mid-July, the rainfall maximum follows the ITCZ northwards into the southern Sahel (about 10°N) over a period of a few days. So sudden is the event that it is called the "monsoon jump". The second phase is apparently influenced by easterly atmospheric waves (which are also associated with the ITCZ).

Figure 8.17 – The two phases of the West African Monsoon[35]



Monsoon activity has been affected by a transition in global atmospheric circulation which occurred in the mid-1970s.[32] Some studies have found that the most vigorous monsoonal circulations have weakened, leading to decreased long rainy spells and increased shorter spells, and in general a more erratic rainfall pattern (Figure 8.18).[36-38]

Figure 8.18 – Changes in the annual range of monsoon rainfall, comparing 1976-2003 with 1945-1975[34]

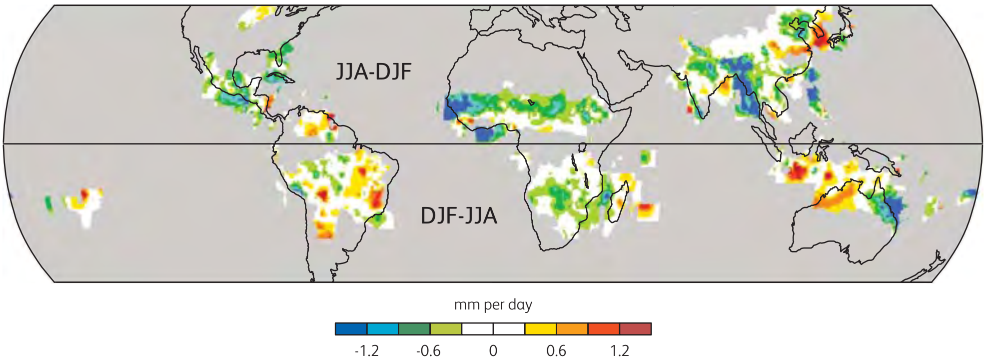
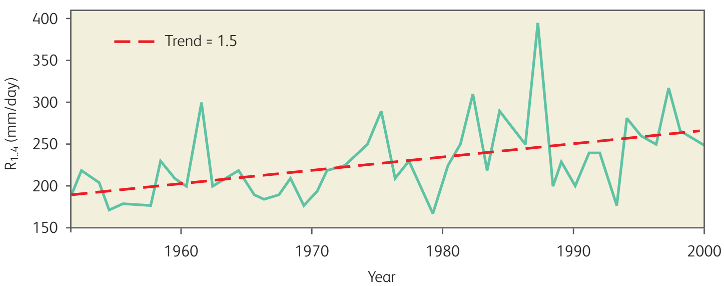


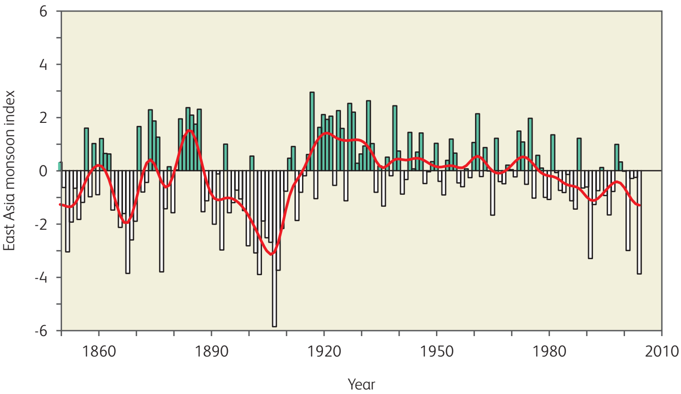
Figure 8.19 – Growth in the mean rainfall of the four highest rain events every season ($R_{1..4}$) in Central India over the past 50 years[39]



However, there are uncertainties about the data and how it is interpreted. A study of Indian rainfall over central India reveals considerable year to year variation but no trend in daily rainfall over the past 50 years. Yet when the authors focussed on extreme monsoon events, i.e. the four highest rain events each season they found a significant increase in the frequency and the intensity of such events over the past 50 years (Figure 8.19).[39]

At the same time, a particularly marked decline is evident in the East Asian monsoon (Figure 8.20).

Figure 8.20 – The decline in the East Asian monsoon since the mid-1970s[34]



The West African monsoon is also in a major period of weakening, leading to droughts lasting several decades.[40,41] There was a dramatic shift from the wetter conditions of the 1950s and 60s to the much drier decades of the 70s, 80s and 90s.

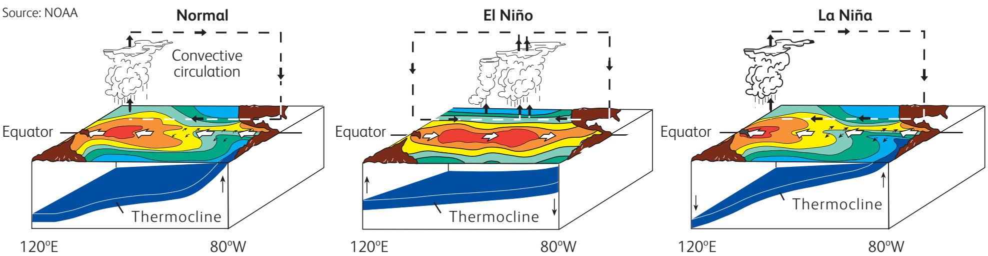
The evidence suggests a number of inconsistencies. Moreover it is debatable whether these shifts in rainfall pattern are simply a natural phase, as has occurred in the past, (for example, there was a major decline in the East Asian Monsoon at the end of the 19th century – see Figure 8.20) or whether they are partly a response to a combination of recent factors including the effects of land degradation, water pollution and biomass burning, or climate change. What is certain is that these changes have made it extremely difficult for farmers and others to predict the key seasonal rains. More advanced prediction tools and modelling will hopefully provide a more nuanced understanding of monsoonal changes.

The El Niño-Southern Oscillation

The third driver, the El Niño-Southern Oscillation (ENSO) is a phenomenon of the Pacific Ocean. It is characterised by a close coupling of the ocean and the atmosphere and is referred to as an oscillation because of the characteristic switch in the Pacific between two phases, La Niña, and El Niño (Figure 8.21).

Under 'normal' conditions the Peru current brings cool water to the Central Pacific, but from there trade winds move increasingly warm water westwards from the Central Pacific's high pressure to the low pressure located over Indonesia. This results in the sea surface being about ½ metre higher on the Indonesian coast than at the Ecuadorian coast and the temperature 8-10°C warmer. Very heavy and extensive rainfall, partly fed by the trade winds, occurs over the warm water of the western Pacific, while the eastern Pacific experiences relatively dry weather.[42]

Figure 8.21 – Comparison of atmospheric and oceanic flows in the Pacific during normal, El Nino and La Niña years.[43] Water temperatures: warm: red cold: blue



Sometimes the pattern is reversed, with wide ranging consequences.[44] Every three to seven 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.

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.

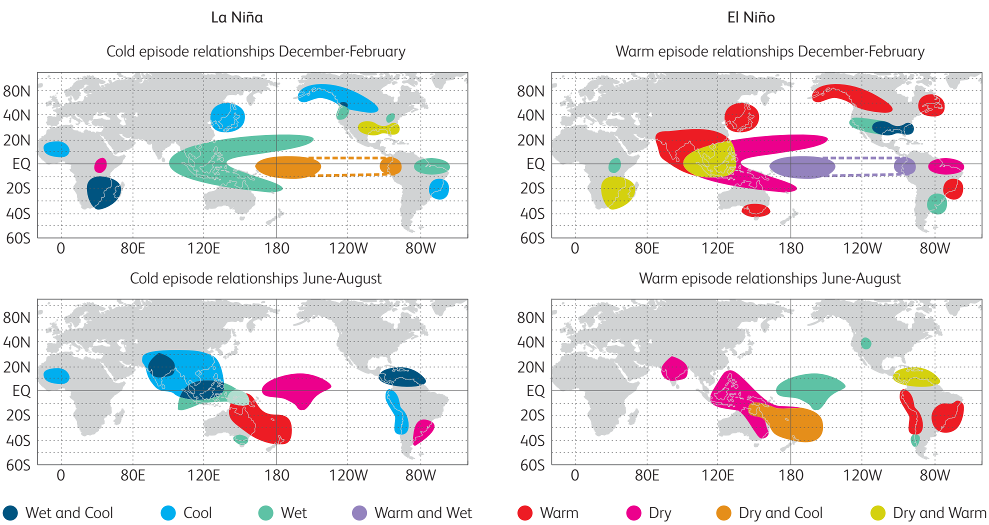
The phenomenon is called El Niño, the Spanish for 'the boy child,' because the warm waters tend to arrive off the South American coast at Christmas time. The more common westward flow phenomenon is referred to as 'the girl child' (La Niña).

There are many theories as to whether this 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.

In the Pacific, ENSO accounts for up to 40 % of the variation in temperature and rainfall.[45] Moreover, although it 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 the ocean and atmosphere and hence affect the global climate. During an El Niño phase the eastward displacement of the atmospheric heat source overlaying the warmest water results in large changes in the global atmospheric circulation, which in turn force changes in weather in regions far removed from the tropical Pacific. Thus, six months after an El Niño phase the global mean surface air temperature increases. It is estimated that after the severe El Niño of 1997-98 it went up by nearly 0.2°C.[46,34]

Relatively simple statistical models predict that during an El Niño year the December to February weather is usually wetter in eastern Africa but drier to the south, while La Niña produces the reverse effect. El Niño is also associated with a drier Sahel and La Niña is correlated with a wetter Sahel and a cooler West Africa (Figure 8.22).

Figure 8.22 – The El-Niño – La Niña Oscillation has global effects[42]



An El Niño event with strong warming in the central Pacific can also cause the Indian monsoon to switch into a "dry mode", characterised by significant reductions in rainfall leading to severe droughts. These delicate interactions can cause abrupt shifts in rainfall patterns.

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.[47] 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.[48,49]

How is climate change affecting these drivers?

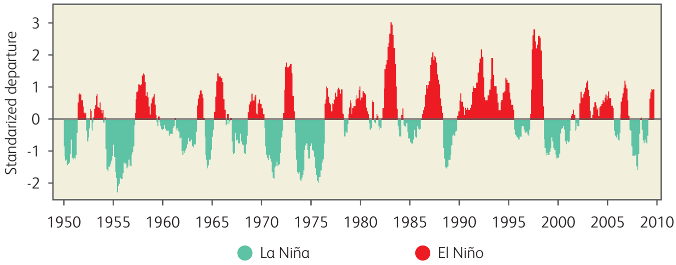
These drivers are powerful forces, yet it is still not clear to what extent they are affected by climate change. There are some observations and conjectures. As a general hypothesis each of the drivers should be influenced by the rising sea surface temperatures resulting from global warming.

We know, for example, that when the ITCZ migrates further north than usual it brings heavy rain and floods to the Sahel (as happened in 2007), and when it lies quite far south over the SW Indian Ocean it will be very dry over South Africa. The question is whether these movements are a product of changes in sea-surface temperature and hence are a consequence of climate warming.[50]

Similar questions apply to the pattern of monsoons. Simulations suggest that there is a greater intensity of monsoons with climate change.[51,52] With surface temperature increases, the land will heat up faster and there will be a greater contrast between the land and the ocean, and thus more intense monsoons. However this is the opposite of the weakening which has been observed in recent decades for all the major monsoons.[51] It is evident that monsoons are highly complex phenomena governed by a range of conflicting influences, some of which are weakening and others intensifying. What is generally agreed is that future monsoons, whether weakening or not, will be characterised by a greater frequency of extreme rainfall events. They may also become more erratic, or subject to new patterns, making them harder to predict.[51]

The ENSO phenomenon raises further complicated issues, because there is still no consensus of opinion over why the oscillation occurs in the first place. For example, it may be simply the result of a random 'trigger,' El Niño occurring very approximately at three to seven year intervals. However, this does not explain the shift in the pattern that seems to have occurred in 1976–1977. This shift was associated with marked changes in El Niño evolution with a tendency towards more prolonged El Niños, accompanied by generally above-normal sea surface temperatures (SSTs) in the eastern and central equatorial Pacific. The long run of El Niño in the early 1990s is unprecedented (Figure 8.23).[53,54]

Figure 8.23 – The increase in frequency of El Niño events since the mid-1970s. (The multivariate ENSO Index is based on six variables measured across the Pacific)[55]



This has caused speculation that the shift is a consequence of global warming, but, so far, there is no evidence to substantiate the connection.[56] It is certainly plausible that the oscillation is influenced by global warming, since both phenomena involve large changes in the earth's heat balance. As the world warms, many models suggest that the East Pacific may warm more intensely than the West Pacific, mimicking the pattern of an El Niño, although significant uncertainties remain. However, current models do not agree on the nature of changes in the frequency or intensity of the El Niño.[57] Moreover, '*all models show continued El Niño-Southern Oscillation (ENSO) interannual variability in the future no matter what the change in average background conditions, but….there is no consistent indication at this time of discernible changes in projected ENSO amplitude or frequency in the 21st century.*'[18]

Tropical cyclones

One of the many consequences of these interacting drivers is the occurrence of tropical cyclones. The severity of the weather they generate can be extremely damaging to the many vulnerable populations that live in low-lying coastal areas (Box 8.3).

Box 8.3 The nature of tropical cyclones

A cyclone is an area of closed, circular fluid motion, characterised by inward spiralling winds, rotating in the same direction as the earth. Cyclones can take many forms, depending on how and where they originate. They have impacts that range from influencing trade winds and seasonal temperatures, to causing large storm surges, flooding and damage to coastal areas.

© NASA

Figure 8.24 – A south Atlantic tropical cyclone viewed from the International Space Station on March 26, 2004

Most of the highest impact storms are tropical cyclones, the more severe ones known as hurricanes or typhoons, depending on the ocean where they form. The intense solar heating near the equator leads to a large amount of evaporation, with water vapour condensing as it rises, releasing heat. The release of this latent heat of condensation then acts as the primary energy source for cyclones.

Once formed, a positive feedback loop begins, where the condensation leads to higher wind speeds, bringing about lower pressure, increased surface evaporation and more condensation. The storm will continue in this manner as long as it stays over warm water and conditions are favourable. But when it passes over land it is cut-off from its heat source and rapidly diminishes.

Thus, coastal areas receive the brunt of the damage. Heavy wind, rain and flooding can destroy infrastructure as well as take lives, as seen for example in the Orissa Super Cyclone of 2000 (Chapter 9). An average of 86 tropical cyclones of tropical storm intensity formed annually worldwide between 1970 and 1995, with 47 reaching hurricane/typhoon strength, and 20 becoming intense tropical cyclones.[58]

There is still disagreement over the effects of climate change on cyclones.[32] They are strongly influenced by sea surface temperatures and it is therefore reasonable to assume that global warming will have an effect, but other factors are also important. Experts remain divided on whether cyclones are likely to increase in frequency and / or intensity. Nevertheless, there has been a large increase in the numbers and proportion of hurricanes reaching categories four and five globally since 1970 even though the total number of cyclones and cyclone days has decreased slightly in most basins. The largest increase was in the North Pacific, Indian and Southwest Pacific Oceans.[59,60]

It seems likely that the already complex nature of cyclones could become even more unpredictable as the climate changes, and temperatures and sea levels rise. Whether or not the intensity of cyclones will increase, rising sea levels, along with increasing populations in coastal areas, will compound the damage caused by these storms.[31,61]

3. The regional changes

The uncertainties at the global level are repeated and magnified as we move to assessing regional impacts. We need better models, more fine-grained in their dynamics and also better ground data.

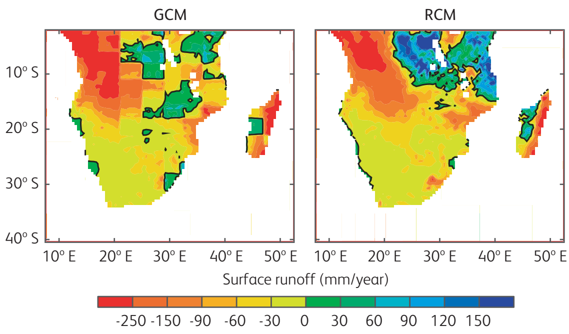
The need for better information

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: 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 most developing countries.

A major challenge is to downscale the GCMs in some way so as to produce a finer scale of prediction. One approach is to adapt the GCM to a specific region using a smaller resolution regional climate model, e.g. a 50 km scale, 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.[62]

Such models are valuable tools for understanding local climate dynamics (see Figure 8.25). They are more sensitive to the effects of local topographies and other phenomena. But, it must be stressed, they act by applying the coarse-resolution GCM dynamics to a regional level and, as a result, the GCM uncertainties are likely to become 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.

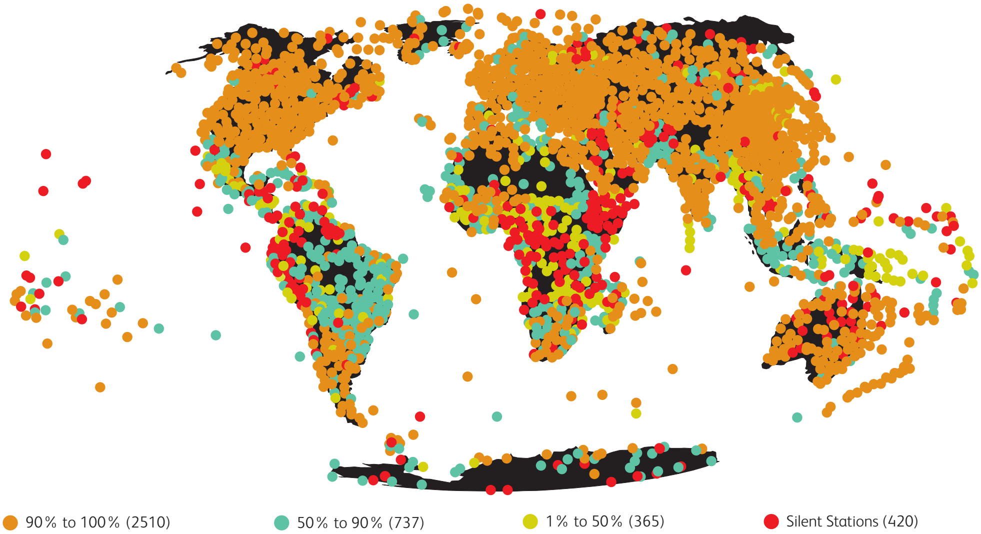
Figure 8.25 – Predicted changes in annual surface run-off for Southern Africa over the next 80 years (A2 scenario). The PRECIS model on the right shows a much finer grained, and more useful, analysis than the GCM on the left[62]



An alternative approach, known as empirical downscaling, works by trying to identify 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.[63] 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, in particular in Africa. The global network of World Watch Weather Stations, which provide real time weather data, is very sparsely represented in Africa. There are only 1,152 stations in Africa, a density of about 1 per 26,000 km^2 which is eight times lower than the level recommended by the World Meteorological Organisation. Moreover, the location of the stations is very scattered. Vast areas are unmonitored, including Central Africa and the Horn of Africa (Figure 8.26).[64]

Figure 8.26 – The paucity of reports received by the World Meteorological Office from African World Weather Watch Stations 1998 – 2002[65]

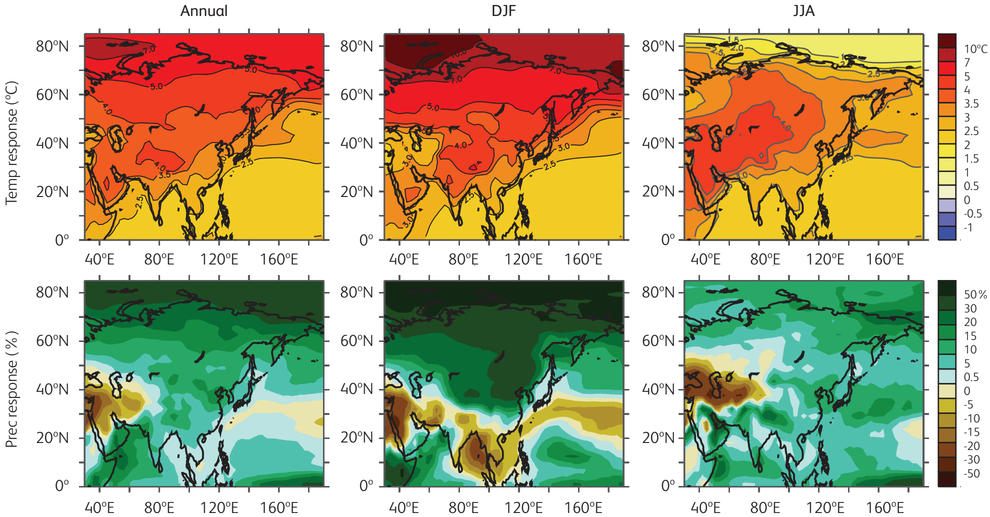


One attempt to improve the availability and use of climate information in decision-making processes, the Climate for Development in Africa Programme (ClimDev-Africa), aims to strengthen Africa's response to climate variability and change. Endorsed by the African Union Commission, the United Nations Economic Commission for Africa (UNECA) and the African Development Bank (AfDB), ClimDev-Africa was developed in 2006, and is planned for an 11 year period.[66,67]

What are going to be the effects on Asia?

Despite the various complications, unknowns and the poor fits of many of the existing climate models, it is possible to detect a number of trends in Asia related to global warming.[52] Asia is very likely to warm during this century; with increases above the global mean of 3°C in East and South Asia and 4°C further north by the end of this century (Figure 8.27). Rainfall will increase over most of Asia, as much as 30% or more in the north. South and East Asia will experience increases of 5 to 15%, except for declines of 5 to 15% in the December to February period over Northeast India and the Southeast Asian mainland.

Figure 8.27 – Temperature and precipitation changes over Asia (Multi model data set for the A1B scenario see below). Top row: Annual mean, December, January, February and June, July, August temperature change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Bottom row: same as top, but for fractional change in precipitation[53]



Of perhaps even greater significance is the very likely increase in the frequency of intense precipitation events in parts of South Asia, and in East Asia over this period. Extreme rainfall and winds associated with tropical cyclones are also likely to increase in East, Southeast and South Asia.[52]

China

In China there are clear differences between the expected climates in the north and west and those in the south and southeast. For example mean temperatures are expected to rise by 5° to 6°C in the north by 2080 (Figure 8.28). In effect this means considerably warmer winters.

Rainfall will also increase by up to 0.5 mm/day or more in the north and west over the same period. There will be small increases in the northeast, but reductions in the centre and southeast (Figure 8.29).

Figure 8.28 – Significantly increasing mean winter surface air temperatures by 2080 in the north of China (A2 scenario)[68]

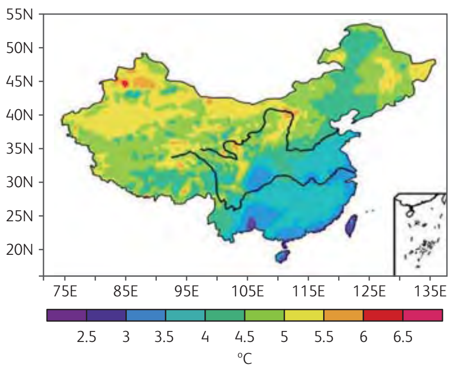
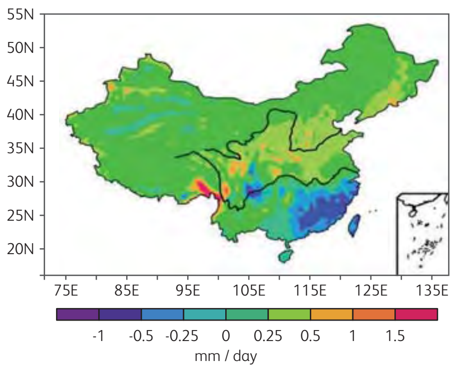
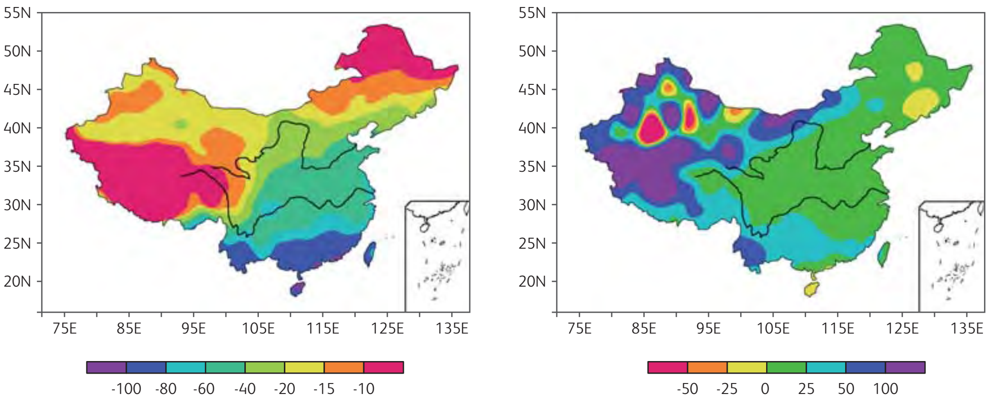


Figure 8.29 – Increased winter precipitation in the west and north of China (A2 scenario)[68]



The PRECIS model, which reflects topographic features, has also been used to examine the changes in extreme events (Figure 8.30). For example, consistent with the general increases in minimum and maximum temperatures, it suggests that by 2080 China will have experienced a large reduction in the maximum consecutive number of frost days, as much as 80 % in the south of the country. It also reveals a greater incidence of extreme rainfall events (measured as days with rainfall greater than or equal to 20mm) throughout China but especially in the north and west, by 50 % to over 100 %.

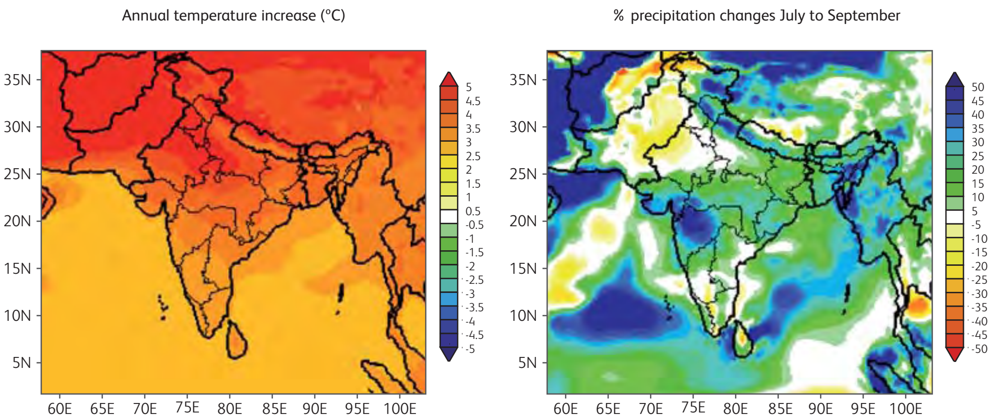
Figure 8.30 – Percentage changes in (left) maximum number of consecutive frost days and (right) number of days with rainfall over 20mm[69]



South Asia

As for China, India shows a marked north-south gradient in key predicted climatic variables over the next century. Temperatures will increase by as much as 4° to 5°C in the north. Precipitation will increase in much of the region, with up to 50 % increase along the Himalayan range, in western India and western Burma. Pakistan is predicted to experience 10 % to 15 % decline in rainfall (Figure 8.31).

Figure 8.31 – PRECIS model predictions of rising temperatures (left) and changes in precipitation (right) for South Asia by the end of the century under the A2 scenario[70]



The PRECIS model also indicates future increases in extreme daily maximum and minimum temperatures throughout South Asia. Another study suggests that night temperatures will increase faster than the day temperatures, with the implication that cold extremes are very likely to be less severe in the future.[71] Such models also predict increases in the frequency, as well as intensities, of tropical cyclones in the Bay of Bengal, causing heavy precipitation during both southwest and northeast monsoon seasons.[70]


© Dieter Telemans – Panos Pictures

Figure 8.32 – Monsoon rains in a flooded area of Dhaka, Bangladesh. In 2004 the rains caused flooding in 40 of Bangladesh's 64 districts, displacing up to 30 million people and killing several hundred.

Bangladesh

One country that will experience the impacts of climate change perhaps more than most, and with increasing severity over the next decade, is Bangladesh. Most poor people in Bangladesh suffer from severe disasters on an annual or even more frequent basis. This has been true for decades. The list of disasters includes flash floods, storm surges, tornados and cyclone winds, river bank erosion and drought. Poor Bangladeshis are used to dealing with these, as are many Bangladeshi institutions, including those of the government. But the disasters appear to becoming more frequent or intense in their actions (Box 8.4).

Box 8.4 The impacts of climate change on Bangladesh[72,73]

1. Sea levels are rising – 70 % of Bangladesh is less than 10 metres above sea level. A 62 cm sea level rise would engulf 16 % of the country, affecting 43 million people by 2080;
2. Increased rainfall – will cause greater frequency of flash floods and river bank erosion;
3. Increased salinity – of soil and ground water is predicted to affect two million hectares of land by 2050, as a consequence of sea level rises, rainfall and temperature changes;
4. Greater drought – particularly in the north-west which is likely to reduce agricultural production.

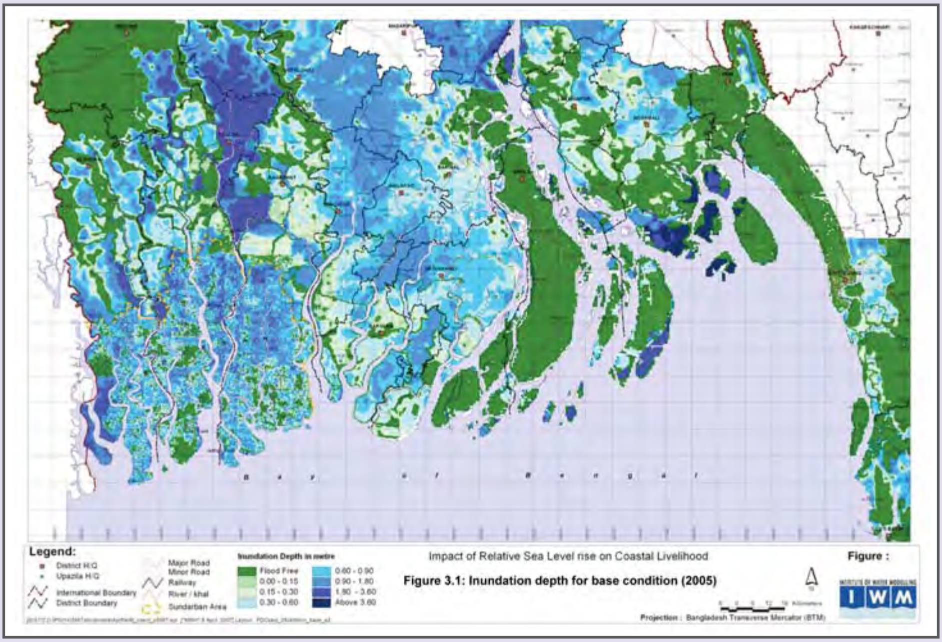


Figure 8.33 – A map showing how the coastal areas of Bangladesh are inundated during typical monsoon flooding. About 50% of land is flooded to a depth of more than 30cm.[72]

What are going to be the changes in Africa?

As in Asia, there is already evidence that Africa is warming faster than the global average and this is likely to continue (Figure 8.34). The warming occurs for all seasons of the year and, although the overall trend is geographically widespread, there are variations. In general the drier subtropical regions will warm more than the moister tropics.[52] But, for example, the tropical forests have warmed by 0.29°C per decade since 1970. 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.[74-77]

The 21 Atmosphere-Ocean General Circulation Models (AOGCMs), analysed by the 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 based on the A1B scenario.

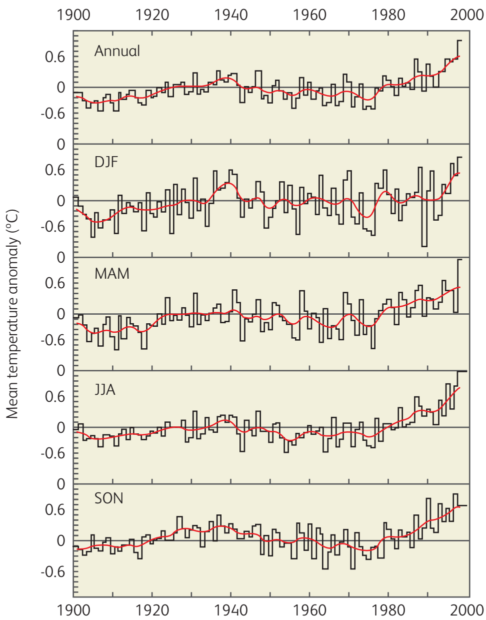
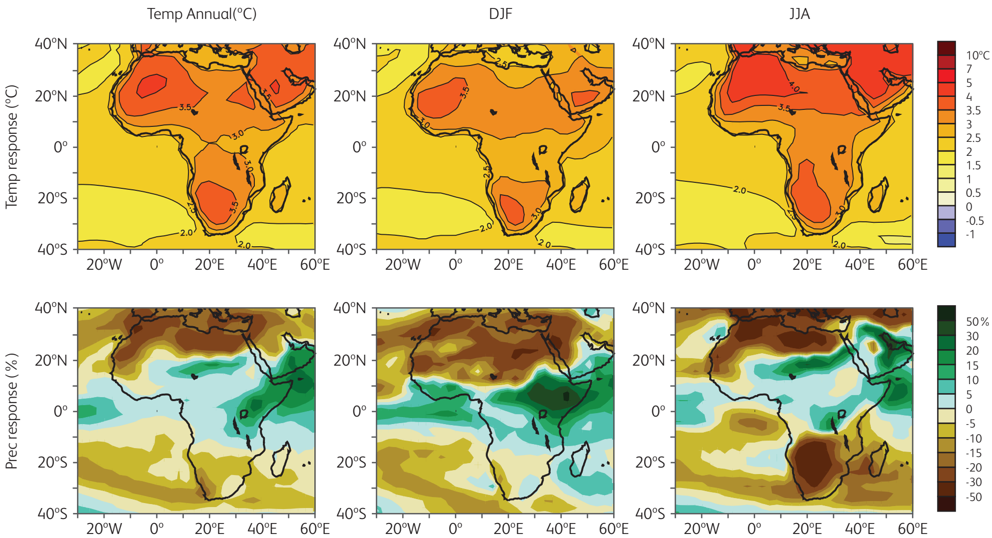


Figure 8.34 – Increasing African mean temperature anomalies over the past 100 years[78]

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 8.35). Over much of the rest of Africa (including the Sahel) there is considerable uncertainty as to how the rainfall patterns will evolve.

Figure 8.35 – Temperature and rainfall projections for Africa, 1980 to 1999 versus 2080 to 2099 for scenario A1B[52]



These are, it should be stressed, large scale predictions and provide a poor guide to local climates. As an illustration, an empirical downscale 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 winter rainfall (Figure 8.36).

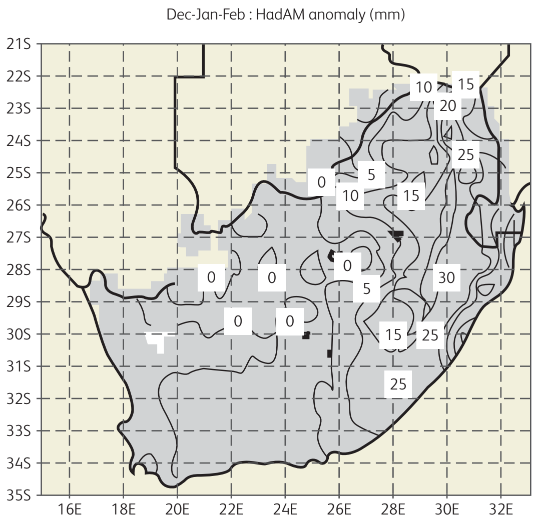


Figure 8.36 – Projected mean monthly rainfall increases for the summer period in South Africa from the downscaled Hadley model HadAM3[63]

The increasing rainfall variability is already apparent.[79] Inter-annual rainfall variability is large over most of Africa and, for some regions, multi-decadal variability is also substantial.[52] In Zimbabwe, for example, there are more cooler and hotter days, and the length and severity of the drier periods is increasing.[80] In the future, the frequency of extremely dry winters and springs in southern Africa is likely to increase as will 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 the increase in atmospheric water vapour.[81] 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.[52]

The southeast 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.[82,83]

It should be added that Africa's climate is also a driver at a global level. The latent heat released in deep cumulonimbus clouds in the ITCZ over Africa represents one of the major heat sources on the planet. There is also a correlation between West African rainfall and Atlantic hurricane frequency. The hurricanes appear to be generated by the easterly atmospheric waves that pass over Africa at the time of the monsoon. Around 20% of the world's total of fires burning biomass occur in Africa's forests and sarannahs. Africa is also the world's largest source of atmospheric dust.[84] Both the fire aerosols and dust play a major role in the global climate.[85]

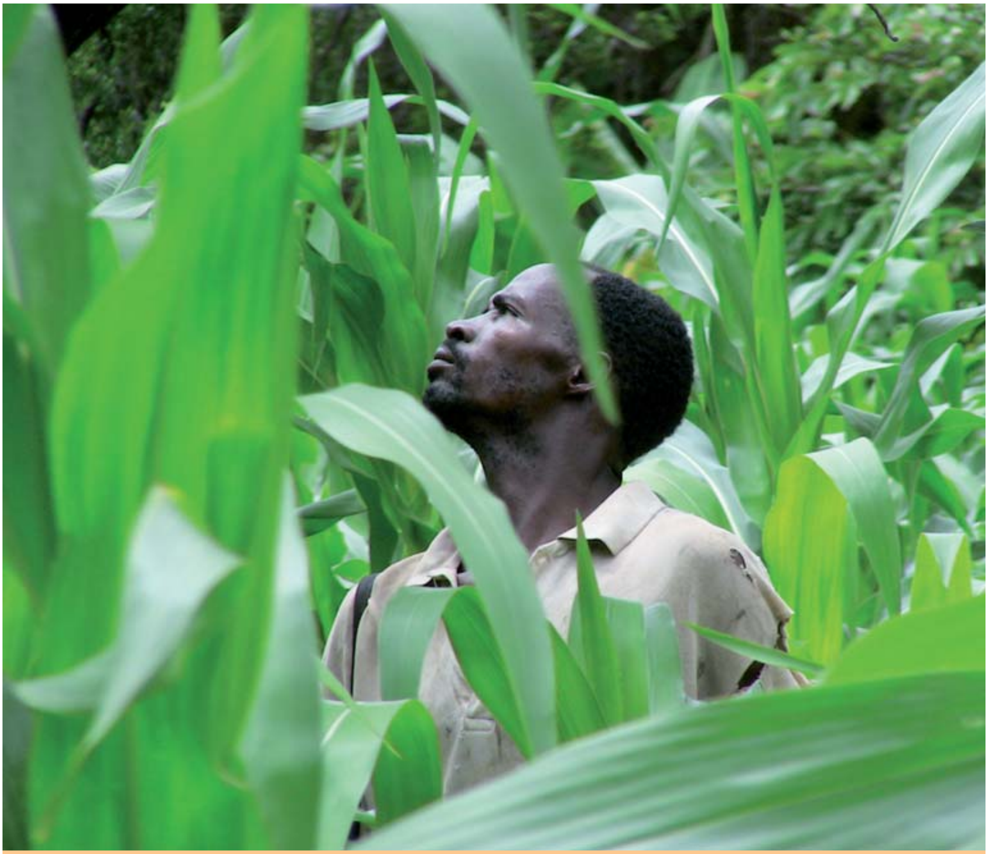


Figure 8.37 – A farmer in Mali surveys the sky

4. Conclusion

There is widespread agreement in the scientific community that global warming is a reality and is a consequence of the anthropogenic release of greenhouse gases into the atmosphere. This warming, and the associated climatic changes, will have far-reaching effects throughout the developing regions. In summary, although there remain many unknowns, we do know, at least in general terms, what is likely to happen over the next 50 years.[52]

Africa and Asia are very likely to get:

- Warmer (colder in a small number of places).

Africa will get:

- Drier, but with more rainfall and floods in some regions.

Asia will get:

- Mostly wetter.

and throughout the regions there is likely to be:

- More intense tropical cyclones;
- Higher sea levels;
- More storm surges;
- More climatic variability and extreme weather events.

What is not known is how these various scenarios are affected by the three big drivers of regional climates – tropical convections, the monsoons and the El Niño – Oscillation. Nor is it yet clear how these drivers are in turn affected by global warming. Until research provides better answers it is going to be difficult to predict with any high degree of certainty how the climate of a particular region or country will unfold over the next few decades.

What is clear is that, for most regions, extreme events – heavy rainfall, prolonged hot and dry spells, and severe storms and cyclones – will be more frequent and intense. It is largely to this reality that adaptation will have to address itself, as we discuss in the next chapter.

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