# Section I

# Climate change, climate variability and adaptation options

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This section introduces some basic concepts surrounding the climate system, climate change and climate variability. We will provide some insights into the challenges of climate modelling and what the inherent uncertainty really means for us, before exploring the way adaptation has so far been discussed and institutionalised (Figure A.1).

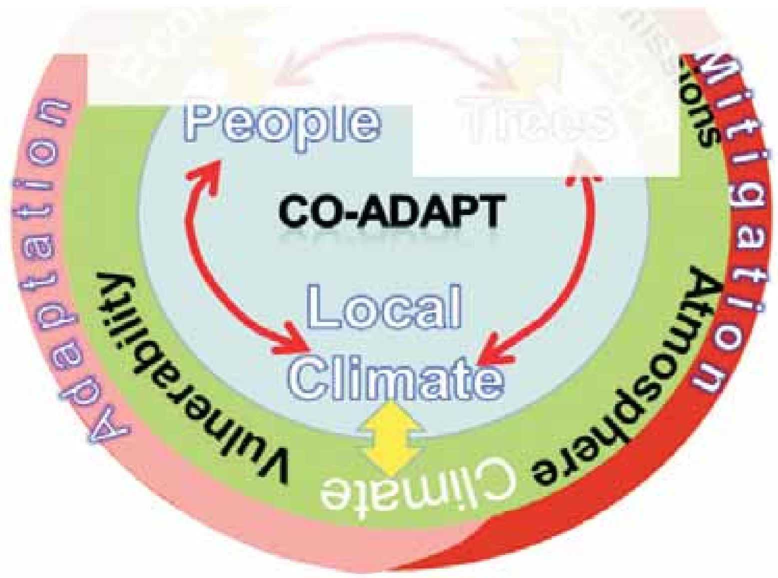


Figure A.1. The co-adaptation wheel: climate quadrant

## A. Climate change and climate variability

### Chapter summary

- Climate change is happening and will require strong mitigation action to achieve the goal of keeping average global warming to 2 °C above pre-industrial levels. Agriculture, forestry and land-use change contribute to climate change with about 25% of total emissions of greenhouse gases. But while reduction of deforestation rates is an effective mitigation mechanism, controversy arises regarding biofuels and reduction of emissions from agricultural lands.

- Climate change is already detectable through statistical analysis of long-term weather patterns, but no single weather event, no matter how extreme, can be associated with climate change as it is a fundamental characteristic of the climate system to show variation. Climate variability can, with sufficient accuracy, be linked to a few large-scale climate patterns that may change in the future and hence affect climate variability.
- Modelling efforts have by now reached a level of complexity that allows us to say much about changes of the climate in the future although all of the global circulation models also show significant deviations in their simulations. While temperature changes are fairly evident across the range of models, changes in precipitation are still very difficult to foresee. Another challenge is downscaling of the global model results to scales that are useful for land-use planning at local and regional levels.

## The climate system and the greenhouse gas effect

The Earth's climate system is essentially driven by the sun's radiation. It is a complex, interactive system consisting of the atmosphere including clouds, the land surface, oceans, snow and ice, and other factors. About one third of the energy that arrives at the top of the atmosphere is reflected back to space (albedo). Most of the albedo is caused by clouds and aerosols as well as snow, ice and other light-coloured surfaces. The energy that is not reflected is absorbed and causes the Earth to heat up. The Earth itself thus radiates, but mostly in the infrared (whereas most of the radiation of the sun is in the ultraviolet to visible range). Over the long run the same amount of energy that is absorbed by the Earth's surface is also released again through various processes (Figure A.2).

The climate system evolves over time, either through internal or external factors (called forcings). Examples of external forcing are: a) changes in the Earth's orbit that alter the incoming solar radiation; b) volcanic eruptions that change the albedo; or c) burning of fossil fuels that change the chemical composition of the atmosphere. These forcings can change the Earth's climate for periods lasting from days (for example, particles in the troposphere) to millennia (orbital changes) and can have profound effects on life on Earth. During the ice ages, which were mainly caused by regular orbital changes (the so-called Milankovitch cycles), for instance, global average temperatures were about 5–6 $^{0}$C below current average temperatures and sea levels were 80–120 m below present. A large volcanic eruption can reduce the global temperature by about 0.5 $^{0}$C for as much as a year or more.

The 'greenhouse gas effect' is vital for the development and maintenance of life on Earth: without it temperatures on Earth would be on average 19 $^{0}$C below freezing point. In summary, the greenhouse gas effect can be explained like this: some of the sun's short-wave radiation is absorbed by the surface of the Earth and reemits mostly in the infrared band. This radiation is captured by water molecules as well as carbon dioxide and other trace gases, which are collectively called greenhouse gases, thereby heating up the Earth's atmosphere to about 14 $^{0}$C on a global average. Owing to the similarity with the heating effect inside a greenhouse (though by different physical processes), this additional warming is called the greenhouse gas effect. Human action has increased the amount of greenhouse gases in the atmosphere, in particular, carbon dioxide. The additional warming caused by these emissions is called the 'anthropogenic greenhouse gas effect' and is the cause of the climate change we are currently dealing with.

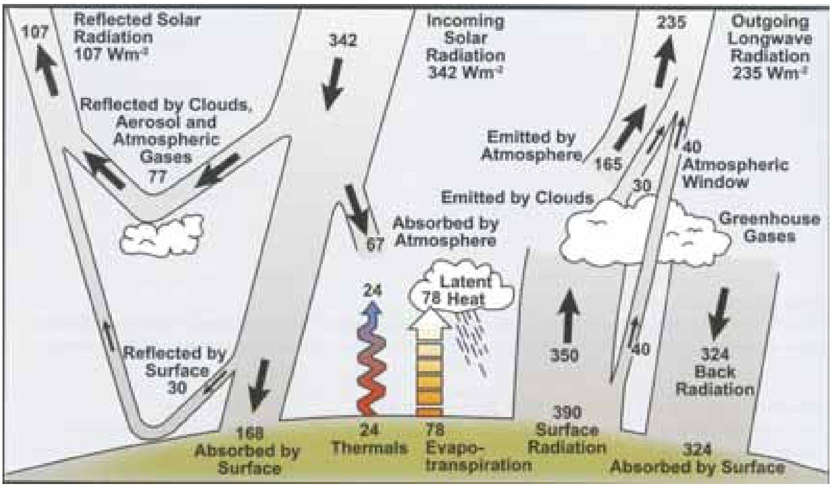


Figure A.2. Estimate of the Earth's annual and global mean energy budget. Source: Kiehl and Trenberth (1997)

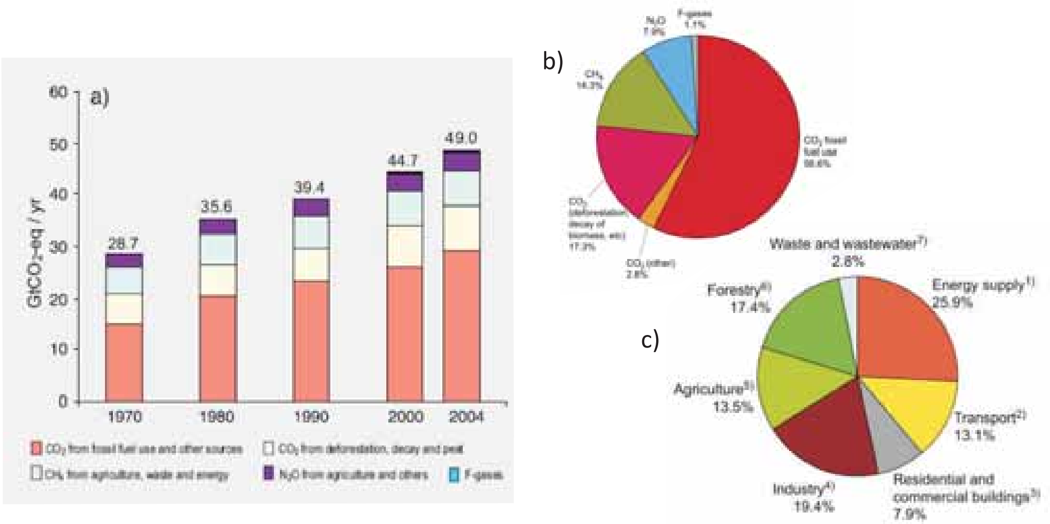


Figure A.3. Global anthropogenic greenhouse gas emissions (GHG):
a) Global annual emissions of anthropogenic GHGs from 1970 to 2004; b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of carbon dioxide equivalents ($CO_2e$); c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of $Co_2e$ (forestry includes deforestation). Source: IPCC 2007b

## Anthropogenic climate change

The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC 2007a) presented further evidence that current climate change is to a large extent due to human activity and will profoundly alter the living conditions for all humans, flora, fauna and ecosystems.

The main sectors and gases contributing to the changing climate through ‘anthropogenic’ greenhouse gases are depicted in Figure A.3. It shows that carbon-dioxide-equivalent ($CO_2e$) concentrations have been rising over the past decades and that carbon dioxide ($CO_2$) emissions, mainly from fossil fuels and deforestation, contribute to over three quarters of all emissions.

Methane and nitrous oxide ($N_2O$) together are responsible for most of the remaining radiative forcing. Although emissions are produced through non-land-use-related sectors (energy supply, industry, transport and buildings), agriculture and forestry (including land-use change) together add up to over 30% of current emissions[5].

Future greenhouse gas emissions will continue to rise as long as no effective mitigation policies are put into place. In order to stabilise global average temperatures at no more than 2 $^0$C above pre-industrial levels[6] with greater than 70% chance of success[7], current projections indicate that the total greenhouse gas concentration of the atmosphere must be stabilised at below 400 $ppm_v$ $Co_2e$[8]. Achieving such an ambitious target is technically feasible and economically viable, but will require forceful and internationally coordinated action in the next few years (Knopf et al. 2010). However, current emissions are at the upper end of all projections and continuation of such a 'business-as-usual' trajectory would likely lead to 3–4 $^0$C above pre-industrial levels (Figure A.4).

While agriculture and forestry are vulnerable to climate changes, these sectors also contribute strongly to climate change. Within these sectors, major emissions occur from clearing forests for other land uses, use of nitrogen-based fertilisers, senescence of peat soils used for agriculture, topsoil degradation and erosion, methane emissions from livestock and rice production as well as energy-related emissions such as irrigation, heating, fertiliser production and feed. Owing to strong drivers like population growth, a rising share of animal products in the diet and continued demand for forest products, the emissions from land-use-based sectors will continue to rise in a business-as-usual scenario. In order for agriculture and forestry to effectively contribute to climate-change mitigation, deforestation must be reduced and eventually stopped (while meeting the demands for forest products), productivity must rise (relative to land use and emissions), biofuel production must increase (without competing for agricultural and forest lands) and land degradation must be stopped. Next to technological advances such as plant breeding and bioenergy conversion, improved management options such as conservation agriculture, minimum tillage, drip irrigation or agroforestry systems can significantly contribute to greenhouse gas emission reductions. However, to achieve emission reduction while raising food security and reducing its climate vulnerability an integrated approach is needed to address the multiple complexities.

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[5] Recent recalculations have reduced the contribution of emissions from forestry to around forestry 12% (Canadell et al. 2007), such that overall emissions from agriculture, forestry and land-use change add up to 25.5%. Reasons for this reassessment are rising emissions from developing countries, particularly China, and a reduction of deforestation rates, mainly in Brazil.

[6] When referring to the 2 $^0$C stabilisation target, we refer to a global average temperature that is less than 2 $^0$C above pre-industrial levels (normally 1860). Considering that we are currently already nearly 0.8 $^0$C above that value and are committed to something in the order of another 0.6 °C through past emissions that are not yet apparent owing to the considerable inertia of the global climate system, the temperature increase related to future emissions may not be higher than another 0.6 $^0$C over the course of this century.

[7] According to Hare and Meinshausen (2006), there is about a 70% chance of achieving the target for a 400 $ppm_v$ $CO_2e$, a 50% chance with 450 $ppm_v$ $CO_2e$ and a 25% chance with 500 $ppm_v$ $CO_2e$.

[8] The chance of reaching the 2 °C target falls with increasing GHG concentrations in the atmosphere. The total concentration of greenhouse gases can be expressed in terms of the radiative forcing (RF) of all gases as if it was caused by $CO_2$ alone (the so-called '$CO_2$-equivalent concentration' or $CO_2e$). The current net RF of the atmospheric components is highly uncertain but probably similar to the current $CO_2$ concentration, that is, 386 $ppm_v$ (IPCC 2007).

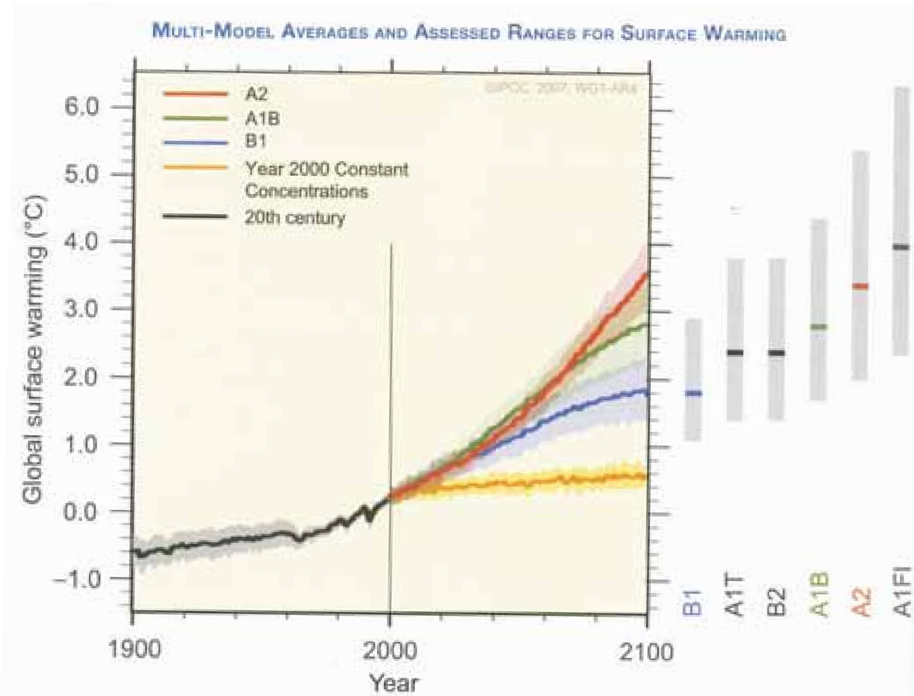


Figure A.4. Solid lines are multi-model global averages of surface warming for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes ± 1 standard deviation range of individual model annual averages. The orange line shows the temperature evolution with year 2000 forcing held constant. The grey bars at the right indicate the best estimate (solid line) and the likely range assessed for six *Special Report on Emissions Scenarios* marker scenarios. Source: IPCC 2007b

## Climate variability

Climate is usually characterised as the 'average weather' of a specific place, that is, mean and variability of temperature, precipitation, wind and other relevant parameters and is normally measured over a period of 30 years. Anthropogenic greenhouse gas emissions are causing the climate to change over time.

However, in the short term, climate variability will by far outweigh climate-change effects. This is because the variability of the climate covers the full range of deviations from the mean state of the climate, including very hot or cold and very wet or dry periods. Individual weather events, including extreme events like floods or droughts, will also likely be affected by future climate change and could become more frequent and more intense. Current weather extremes can sometimes give us a glimpse of the possible future, such that a season that is untypically hot now will be the average in the future. And, of course, atypically hot seasons then will be much hotter than they are today.

Climate variability is defined as the variation of the mean state and other statistics (for example, standard deviation and the occurrence of extremes) of the climate on all spatial and temporal scales beyond that of individual weather events and may be due to natural processes within the climate system or to anthropogenic external forcing (IPCC 2007b). The climate variability of the future may be similar to that of today, but it could also change significantly. So even if the projection is for the future climate to be hotter and wetter, a season, a year or even a decade may be cooler and drier than today. And even if the average amount of rain in a region does not change, climate change could lead to fewer but heavier rains and thus longer dry spells or to a change in the spatial distribution with more rain falling over the sea than over the land.

To a significant extent, climate variability can be described by fluctuations of a fairly small number of climate patterns, such as El Niño Southern Oscillation, North Atlantic Oscillation, Arctic Oscillation, Northern Annular Mode, Southern Annular Mode, Pacific-North American Pattern and Pacific Decadal Oscillation. Changes in the fluctuations of these climate patterns will likely have effects on the distribution and extent of the monsoonal rains, a decrease of subtropical precipitation due to the poleward movement of the transition zone and possibly more and stronger tropical storms. The extent to which these patterns can be described accurately with today's generation of climate models is limited and remains an area of intense research, but several 20th century changes can be viewed as alterations of these distinct climate patterns (IPCC 2007b).

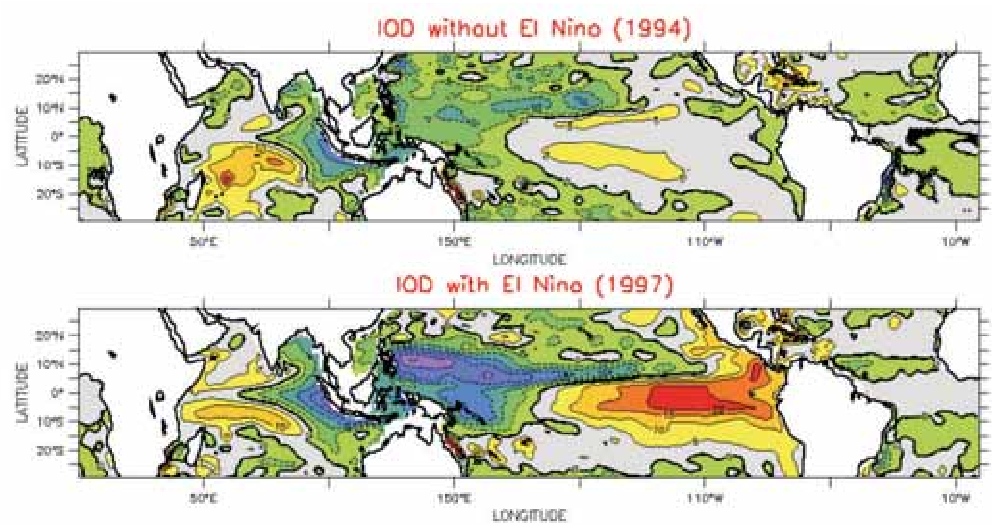


Figure A.5. Temperature patterns in the Indian (IOD) and Pacific (El Niño) oceans that affect rainfall in the adjacent land areas. Source: http://www.jamstec.go.jp/frcgc/research/d1/iod/ogcm1.html

Another distinction to be made is related to the frequency and intensity of extreme weather events, such as droughts or floods. Extreme weather events are responsible for the majority of direct climate impacts and can have disastrous effects on human health and wellbeing and on the economy. No individual extreme event can be directly attributed to climate change because there is limited knowledge (records generally date back no more than 150 years) about how extreme weather events have occurred in the past, but in some cases it is possible to assign the probability with which an event has been affected by climate change. Figure A.7 illustrates how a fairly small shift could affect weather events at the upper and lower end of the probability distribution function.

## Box A.1

### Teleconnections and repetitive patterns

The El Niño/La Niña effect, technically known as the El Niño Southern Oscillation (ENSO), which is linked to the temperature difference across the Pacific Ocean between the west coast of Peru and Southeast Asia, has become part of common understanding of climate variability. Yet there are similar temperature anomalies in other oceans. The temperature difference across the Indian Ocean, known technically as Indian Ocean Dipole (IOD), influences the South Asian monsoon as well as weather in East Africa and the western part of Indonesia. In the 'IOD+' mode there are abnormally warm sea surface temperatures in the western Indian Ocean, with long dry seasons in Indonesia and heavy rainfall over East Africa. When the ENSO and IOD patterns coincide, which is not always the case, extreme droughts and flooding may be the result, as in the 1997/8 period. There is reason to believe that global warming effects on the western Indian Ocean have increased IOD variability and that this may have replaced the ENSO as the major driver of climate patterns over the Indian Ocean region.

While a process-based understanding of 'teleconnections' is slowly emerging, empirical tools to pick signals and explain rainfall variability relative to global phenomena are critical. One such approach is the 'wavelet analysis' that has been used to show links between climatic variability to IOD and ENSO, among other factors (Jevrejeva et al. 2003, Grinsted et al. 2004). For the Nyando and Yala river basins, evidence emerged for repetitive cycles at quasi bi-annual scale, the ENSO time series and the solar cycle. Using rainfall data for the March–April–May and June–July–August periods (Figure A.6), repetitiveness of the different cycles was found at a level of 2–3, 5–7 (attributed to ENSO) and 11 years (attributed to the solar cycle).

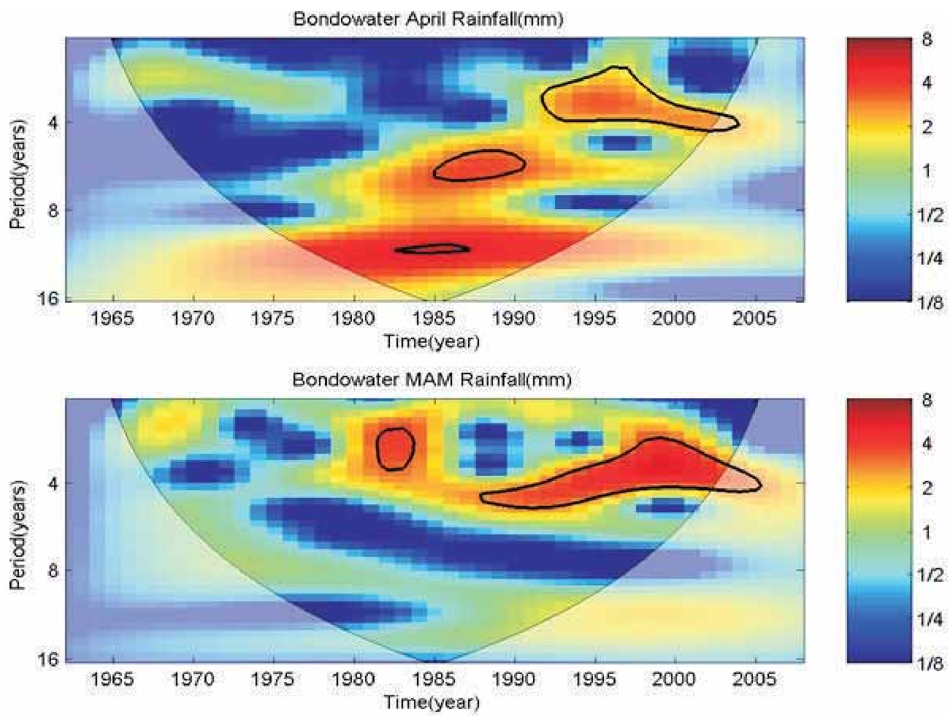


Figure A.6. Wavelet power spectrum (Morlet Wavelet) factors influencing March–April–May (MAM) and June–July–August (JJA) rainfall at the Bondowater climate station in Kenya. Source: Yatich (in preparation)

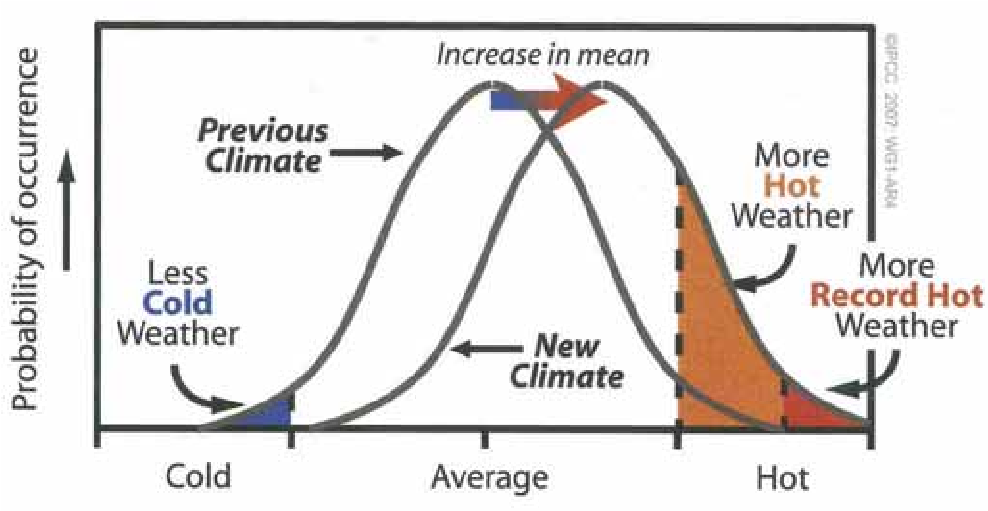


Figure A.7. Schematic showing the effect on extreme temperatures when the mean temperature increases, for a normal temperature distribution. Source: IPCC 2007b

***Climate models, scenarios and downscaling***

Future climate is nowadays projected by a host of different general circulation models (GCMs). These vary in their degree of sophistication from simple climate models that allow rapid estimation of climate responses to a wide range of emission scenarios through Earth-system models of intermediate complexity and eventually to the most comprehensive atmosphere–ocean general circulation models (AOGCMs) that describe atmospheric, oceanic and land surface processes, as well as sea ice and other components, with a high level of spatial and temporal accuracy (IPCC 2007b). There are over 20 AOGCMs and whilst comparable in their large-scaled dynamics, differences in their structure and the need to parameterise some processes lead to diverging climate projections. In addition, considerable uncertainties exist regarding net radiative forcing of atmospheric components (there are warming and cooling agents and the processes of some agents are poorly understood) and particularly uncertainty of the climate sensitivity (essentially the temperature response of doubling radiative forcing), which is likely to be in the range of 1.5 $^{o}$C to 4.5 $^{o}$C with a best estimate value of about 3 $^{o}$C. This means that whilst aiming for 2 $^{o}$C we should be prepared for 4 $^{o}$C (Figure A.4).

Scenarios of climate change have been defined to account for different potential developments with impact particularly on the emission pattern of greenhouse gases. In 2000, the IPCC defined six future emission scenarios to be used in modelling activities for the third and fourth assessment reports (IPCC 2000). The distinction of the scenarios rests on assumptions of future global political, demographic, socioeconomic and technological developments, for example, the integration or division of the world, population growth and the ecological orientation of policies culminating in different greenhouse gas emission patterns (Table A.1).

Given their complexity and the uncertainties and different scales of input parameters, global circulation models are associated with a significant degree of uncertainty and hence projections also differ between models (Figures A.8 and A.9). Current models' projections can reach a spatial resolution of up to 1 degree ( km). This is sufficient at the global level but too coarse for regional climate projections and hence insufficient for regional impact studies. To obtain estimates of changes in climate at some particular location of interest, a model's outputs are downscaled and may reach a spatial resolution of up to 5 km grids.

A wide variety of downscaling procedures exist but all require additional input data for calibration, such as long-term historic climate records or fine-scale digital elevation models. Owing to the limited availability of such data, the availability of downscaling and other regionally focused studies remains uneven geographically, particularly for extreme weather events.

Table A.1. Assumptions of global development underlying the definition of the *Special Report on Emission Scenarios*. Source: IPCC 2000

| | | |
|---|---|---|
| **A1**: a more integrated world<br>• Rapid economic growth<br>• Global population reaches 9 billion in 2050 before it gradually declines<br>• New and efficient technologies spread quickly<br>• Income and way of life converge between regions<br>• Extensive social and cultural interactions worldwide<br>It is subdivided based on emphasis on technology and energy sources: | | |
| **A1FI**: emphasis on fossil fuels | **A1B**: balanced emphasis on all energy sources | **A1T**: emphasis on non-fossil energy sources |
| **A1**: a more integrated world<br>• Nations are self-reliant and operate independently<br>• Population continues to increase<br>• Regionally oriented economic development<br>• Slower and more fragmented technological changes and improvements to per capita income | | |
| **B1:** a more integrated and more ecologically friendly world<br>• Rapid economic growth (A1), but with rapid changes towards a service and information economy<br>• Global population reaches 9 billion in 2050 before it gradually declines (A1)<br>• Material intensity reduced and clean and resource-efficient technologies introduced<br>• Emphasises global solutions to economic, social and environmental stability | | |
| **B2:** a more divided but more ecologically friendly world<br>• Population increases continuously, but more slowly than A2<br>• Emphasises local rather than global solutions to economic, social and environmental stability<br>• Intermediate levels of economic development<br>• Less rapid and more fragmented technological change than in A1 and B1 | | |

Figure A.8 shows that agreement between different models regarding precipitation change (that is, more or less rain) is lowest for the inner tropics. Hence, it is important to close the knowledge gap, especially for vulnerable regions in the tropics where long-term climate records are scarce. A promising approach is to resort to climate proxies reflecting historical climate (events). These include, among others, tree-ring analysis showing more or less favourable growth conditions, farmers' accounts and newspaper articles of extreme weather events, lake sediment cores and prevalence of disease occurrences.

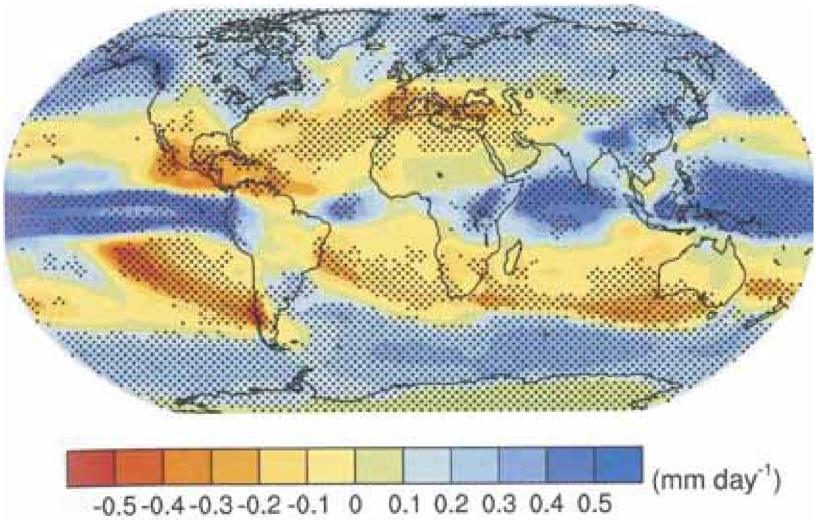


Figure A.8. Multi-model mean changes in precipitation. To indicate consistency in the sign of change, regions are stippled where at least 80% of models agree on the sign of the mean change. Changes are annual means for the *Special Report on Emission Scenarios* A1B scenario for the period 2080 to 2099 relative to 1980 to 1999.
Source: IPCC 2007b

In conclusion, climate-change projections help to identify and describe potential future climate risks or pinpoint geographically the areas of increasing climate risk. When using such projections responsibly, their highly aggregated nature must be considered. Figure A.8 exemplifies that agreement between models for a 100-year projection is lowest in the tropical belt, which may be most vulnerable to such changes. In addition, the models do not reflect the rainfall distribution and much less the occurrence of extreme events over the course of the year. Also, current natural inter-annual climate variability often exceeds the effects of either land-use change or climate change, for example, on runoff, when viewed separately. An overall moister climate annually may actually include exceptionally severe dry spells within the course of that year. Including this variability into that may only become conspicuous when a model is downscaled both temporally as well as spatially (see Box A.2).

## Box A.2

**From monthly precipitation to a daily time-series**

The 'downscaled global climate model' available at the WorldClim site (http://www.worldclim.org) can provide a prediction of a monthly mean rainfall at 1 $km^2$ spatial resolution but that doesn't, in itself, help us understand risk and opportunities for plant growth and river flow. Further processing is needed. If there are historical rainfall records for a place, these can be analysed for 1) the statistical distribution of daily rainfall (with a gamma distribution providing a 2-parameter description of the shape of the distribution: scale parameter $\theta$ and shape parameter k); and 2) the temporal autocorrelation (probability that rainy days are followed by rainy days and dry days by dry days within the mean probability of rainfall for a given month; sometimes a second or third step Markov chain is needed to capture all the autocorrelation). If data for multiple stations are available, the spatial autocorrelation of rainfall can also be assessed. Simple models treat areas as either homogeneous or statistically independent. Reality is in between these assumptions and an 'extreme event' at a watershed level may be based on 'extreme' autocorrelation' rather than 'extreme events' at station level. If the space-time scaling rules of current rainfall are captured, the same rules can be applied to the modified monthly means of downscaled global climate models. A further exploration of the possible impact of changes in local scaling rules can also be done, to test the robustness of proposed vegetation and land management scenarios.

## Intermezzo 2.

### Climate variability, consequences and responses by farmers in the Philippines

METHODOLOGY


Surveys were made of farmers' experience with climate variability and extremes in Lantapan, Bukidnon (the Philippines). They reported the following as most important to them.

| Climatic event | Frequency | Percent |
|---|---|---|
| Prolonged rains | 120 | 29 |
| El Niño | 115 | 28 |
| Delayed onset of rainy season | 91 | 22 |
| Early onset of rainy season | 60 | 14 |
| La Niña | 29 | 7 |

| ***Early start of rains*** | **Response options** |
|---|---|
| Increased yield for many farmers (+) | Use of fertilisers and chemicals |
| Early cropping (+) | Loan |
| No need to irrigate crops (+) | Prepare for early cropping |
| Favourable in some crops like abaca and banana (+) | Crop diversification |
| Appearance of blight and fungi (-) | |
| Increased pests and diseases (-) | Construct temporary drainage canal |
| Crops rot easily (-) | Do nothing |
| Decreased yield for some farmers (-) | |
| ***Late start of rains*** | **Response options** |
| Crops dry up (-) | Ask for help from government |
| Decreased yield (-) | Water crops |
| Crops produced are of poor quality (-) | Use early-maturing crops |
| Delayed planting (-) | Wait for rain |
| Short period of time that farmers can plant (-) | Apply fertiliser and chemicals |
| | Engage in off-farm work |
| | Crop diversification |
| | Pray |

## Intermezzo 3.

### Climate variability, land use and climate change interact on river flow

Global climate change will likely increase temperature and variation in precipitation in the Himalayas, modifying both supply of, and demand for, water. A recent study by Ma Xing et al. (2010) assessed the combined impacts of land-cover and climate changes on hydrological processes and a rainfall-to-streamflow buffer indicator of watershed function, using the Soil Water Assessment Tool, in the Keji watershed of the eastern Himalayas. The Hadley Centre Coupled Model Version 3 (HadCM3) was used for two IPCC emission scenarios (A2 and B2) for 2010–2099. Four land-cover-change scenarios increased forest, grassland, crops or urban land use, respectively, reducing degraded land. The SWAT model predicted that downstream water resources would decrease in the short term but increase in the long term. Afforestation and expansion of cropland would probably increase actual evapotranspiration and reduce annual streamflow but would also, through increased infiltration, reduce the overland flow component of streamflow and increase groundwater release. An expansion of grassland would decrease actual evapotranspiration, increase annual streamflow and groundwater release, while decreasing overland flow. Urbanisation would result in increases in streamflow and overland flow and reductions in groundwater release and actual evapotranspiration. In the short and middle terms, land-cover change produced more effect on streamflow than climate change. The predicted changes in buffer indicator for land-use and climate-change scenarios reached up to 50% of the current (and future) range of inter-annual variability. Dealing with current climate variability remains the immediate target for climate-change adaptation in this catchment.

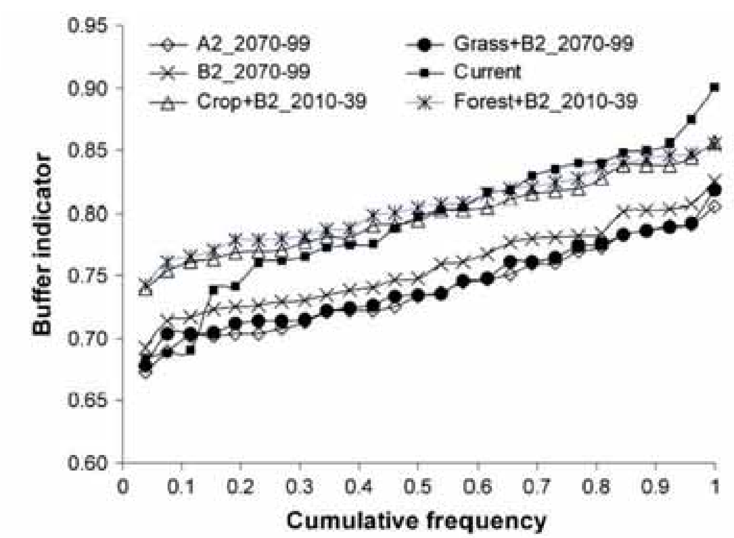


Figure A.9. Predicted cumulative frequency of watershed buffering relative to rainfall patterns in the Keji watershed in Southwest China, for a range of IPCC scenarios (compare Table A.1), time period and land-use change scenarios (only the highest and lowest three lines are shown). Source: Ma Xing et al. 2010

# B. Adaptation options for climate change

## Summary


- The impact of climate change will mostly be negative and require adaptation in addition to measures against existing constraints of environmental degradation, poverty and food insecurity, lack of education, health issues and lack of functioning governance systems and institutions.
- Adaptation to climate change is here understood as a broad concept to increase resilience to climate variability and change through reducing vulnerability, targeted action to be prepared for directional change and increasing adaptive capacity. Climate-change impacts will mostly be local but responses need to take place at local, national and international levels to address the challenges involved with equity, fairness, economic efficiency and environmental effectiveness.
- One option for achieving such resilience, especially among rural populations, is to diversify their cropping systems within, or between, farms leading to multifunctional landscapes. But farmers, government agencies and development organisations require training to help them adopt these practices. By increasing woody biomass in the system, multifunctional landscapes also contribute to mitigation efforts and thereby provide a good example for synergies between adaptation and mitigation.


## Adaptation in the context of mitigation

The extent of future climate change will strongly depend on the scope and ambition of mitigation actions undertaken to reduce greenhouse gas emissions in the next two decades. But even if global average temperature rise can be limited to 2 $^{0}$C, the impact of this will be great on small islands and coastal zones and on human health, agriculture, forestry and water resources. We will have to deal with these changes through adaptation and/or by reversing the current trends that increase vulnerability and risk.

For a long time, adaptation to climate change was not talked about, rather, it was argued that 'mitigation is the best adaptation'. However, as the realisation grows that climate change is not being readily brought under control and that people who contribute little to the overall problem are the most vulnerable, adaptation and mitigation are seen as complementary strategies.

Whilst the need for adaptation is clear, implementing adaptation in practice is complex because there is disagreement on how, when and where to act (Hulme 2009). First, because of uncertainties about local forms of the changes and their interaction with ongoing development efforts, the way to respond is highly disputed, including the roles of the public, private and informal sectors. Second, there may be as many perspectives on what to do when and where as there are scientific disciplines, even when the analysis of current trends is based on the same scientific evidence. Finally, local responses to global climate change depend on context and place, and include winners and losers. At which level, and how, to respond will affect lives and ecosystems and may lead to undesirable effects. These questions need to be taken into account to avoid a situation where adaptation efforts lead to greater harm than good. This has led to the idea of 'no regrets' options: things that have other reasons and rationales beyond climate change. To be effective, adaptation strategies for rural livelihoods need to be robust in the face of considerable and often unquantifiable uncertainties.

### Box B.1

The term 'adaptation' can refer to a process of continued change, and to 'adaptedness' as a state, based on features that were derived from adaptive processes. Adaptedness (whether a system 'is adapted') can be empirically assessed for a given set of conditions and their patterns of variability. Adaptation as a process can only be assessed in hindsight, but preconditions and predictors are known and refer to three steps: 1) Lifecycle and demographic shift per generation (implying microbes adapt faster than trees, which may yet be faster than elephants); 2) Levels of genetic diversity as substrate for selection (the more the better); 3) Predictability and continuity of environmental selection pressure (the more the better). The latter points to ambiguity in the relation between adaptedness and adaptation: higher genetic diversity due to variable selection pressures may reduce average 'adaptedness' of current generations but provide a better basis for future change. Natural history is full of examples of 'over-adapted' or 'over-specialised' species that became extinct whereas more basic forms had a chance to 'radiate out' under new conditions.

## Adaptation concepts

Working Group 2 of the IPCC defines adaptation as 'adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities' (IPCC 2007b). Adaptation may include reducing and transferring risks, as well as building the capacity to make such changes in the future (see Table B.1). Adaptation to climate change has been conceptualised as a continuum with activities ranging from a vulnerability focus that addresses the underlying drivers of vulnerability to a more impact-oriented focus that includes measures or actions that reduce the impacts of climate change or takes advantage of them (such as dikes or irrigation measures) (McGray et al. 2007) (Figure B.1). Learning is an important aspect as it is required to respond to climate stimuli with the right measures or actions. Other important distinctions to be made in the context of adaptation are planned versus reactive and public versus private adaptation.

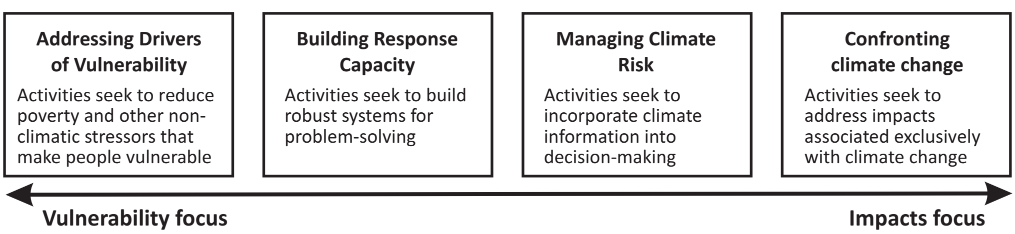


Figure B.1. Adaptation as a continuum. Source: Klein (2008) adapted from McGray et al. 2007

How high the local risk to climatic stimuli is and hence how strong the response has to be depends on three factors—hazard, exposure and vulnerability—and is often illustrated as a 'risk triangle' (Figure B.2a). A hazard is a climatic stimulus, such as increased frequency of drought or flood. However, for a hazard to become problematic, one must be exposed to it directly or indirectly. The climate risk rises with exposure to the hazard, for example, if people don't live in the pathway of mudflows and landslides, they may not suffer; cities built on floodplains are vulnerable to flooding. Finally, those who are similarly exposed to any hazard will likely be differently vulnerable[9] to its effects, for example, depending on the level of socio economic development (including quality of houses and buildings) and the sensitivity of the ecosystem. Hence, the climate risk will likely rise with growing vulnerability.

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[9] 'Vulnerability' is in itself a fuzzy concept and difficult to define because it includes a number of indicators that are not necessarily evident; there are a range of definitions in use by different scientific communities, for example, vulnerability has also been conceptualised in terms of exposure, sensitivity and adaptive capacity (Adger 2006).

Vulnerability to climate impacts depends on many factors. It can be conceptualised as an n-dimensional index, covering, for instance, ecosystem stability, livelihoods and institutions (Figure B.2b); other dimensions are likelihood of violent conflict (for example, Diamond 2005). The multi-dimensional index is particularly valuable to measure vulnerability over time and at different spatial, social and political scales.

Table B.1. Differentiation of adaptation by response type. Source: Stern (2006) (modified)

| Type of response to climate change | Autonomous (private) | Policy-driven (public) |
|---|---|---|
| Short-run (reactive) | • Spreading the loss, for example, pooling risk through insurance<br>• Retaining diversity in crops, planting dates and other management decisions to spread risk<br>• Making short-term adjustments for example, staggered crop planting dates | • Developing greater understanding of climate risks, for example, researching risks and carrying out a vulnerability assessment<br>• Improving emergency response, for example, early-warning systems<br>• Stimulating collective action and insurance schemes |
| Long-run (planned) | • Investing in directional adjustments if future effects are relatively well understood and benefits are easy to capture fully, for example, localised irrigation on farms<br>• Investing in climate resilience through planned diversity where direction and magnitude of future effects remains uncertain | • Investing to create or modify major infrastructure, for example, large reservoir storage, increased drainage capacity, higher sea-walls<br>• Avoiding the impacts, for example, land use planning to restrict development in floodplains or in areas of increasing aridity |


Figure B.2a. The risk triangle shows risk as the product of hazard × exposure × vulnerability. Source: Crichton (1999)

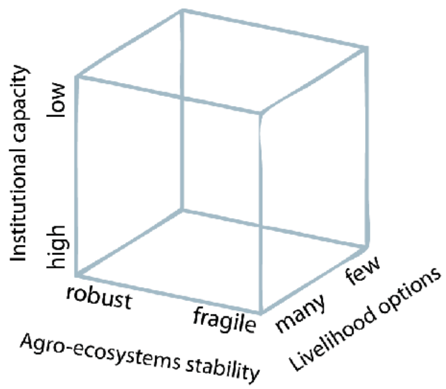


Figure B.2b. Vulnerability to climate change framework. Source: Fraser (2007) (modified)

Which responses are taken depends strongly on the 'adaptive capacity' of those who are experiencing the impacts. Lack of adaptive capacity is included in some definitions of vulnerability. In the context of land management, diversity can reduce vulnerability, for example, when farmers with income from tree products in addition to crops may have a better ability to cope with climate stresses than farmers who rely on one crop for their living. Diversity can also enhance other aspects of adaptive capacity as it maintains options for change in the landscape. The adaptive capacity and resource base for adaptation is influenced by the farmers' assets, the human and social capital in the community in which the farmer lives, the ecological resilience (or sensitivity) of the natural capital and by presence/absence of appropriate laws and institutions.

In the context of climate change, the term 'resilience' is commonly used to characterise an individual or a community's ability to cope with climate impacts and other external stressors. Frequently, resilience rises with adaptive capacity but it is expressed relative to targets and expectations. A low productivity crop may be able to cope with drought whereas a high productivity variety cannot. Given the need for crop improvements to satisfy growing food production requirements, a high-resilience, low-productivity crop can be considered a form of mal-adaptation. But from the individual farmer's perspective, a drought-resistant, low productivity crop may be the preferred survival strategy. This problem illustrates the need to design strategies where private and public adaptation measures complement each other.

Finding the best responses to climate impacts is often a result of learning by doing. However, as climate impacts are mostly experienced locally, responses must be tailored to match the needs at the scale and time of impact and cannot be designed in a 'one size fits all' manner. Depending on the type of adaptation to climate change, that is, reactive or planned and public or private, responses will differ in scale and timing and can have strong distributional effects with implications for equity and fairness as opposed to efficiency and effectiveness. Effective adaptation requires different approaches within a comprehensive and integrated framework, where bottom-up meets top-down at international, regional, national, sub-national and community levels and where public and private sectors collaborate to achieve emission reduction and economic growth.

Table B.2 describes typical adaptation practices that people in rural areas rely on (Agrawal and Perrin 2008). The practices can be broadly classified as mobility, storage, diversification, communal pooling and market exchange. While the UNFCCC database shows no example of mobility as a strategy to cope with climate impacts, this has been used by herders and nomads in dry areas for centuries, whereby conditions that cannot be tolerated are avoided. Storing follows a different strategy in the sense that otherwise unbearable conditions are bridged through the stored food and water. Diversification is a totally different strategy and often goes hand in hand with market exchange wherein rural populations attempt to hedge against the loss of one product by pursuing the production (and marketing) of others. Finally, communal pooling can be considered a risk-sharing approach and makes use of the fact that the community can support the individual in difficult times (although there are limits to this kind of support depending on the extent of the extreme event and the number of community members affected). The database also showed that local institutions played crucial roles in enabling conditions that allowed households to deploy specific adaptation measures. It is clear from this that without functioning local institutions, adaptation measures become much more difficult to pursue. Finally, the database allows us to conclude that in rural, poor environments public and civic institutions are much more important for adaptation actions than private and market-based institutions (Agrawal and Perrin 2008).

## Responses to climate change at international to local levels

### International

Adaptation responses at the international level have been slow to develop compared to mitigation efforts, although adaptation has become more important over time. There are currently several funding mechanisms introduced under the climate-change regime (Global Environment Facility Trust Fund; Least Developed Country Fund; Special Climate Change Fund; Adaptation Fund) and there are expectations of new funds. The aggregate value of the funds is only likely to cover the most immediate and urgent adaptation needs of the least-developed countries as described in the national adaptation programs of action (NAPA)[10].

The current set of NAPAs covers a broad range of areas and associated costs, from USD 50 000 to 700 million. The technical, engineering approaches tend to be more costly than those that focus on human capital and institutions and/or enhancement of natural capital. Several NAPAs include agroforestry and community-based forest management (see Box B.2).

Responses focusing on technology transfer and development assistance can also contribute to adaptation and raising adaptive capacity, such as through the World Bank´s Climate Investment Funds, including the Clean Technology Fund and other bi- and multi-lateral initiatives financed through official development assistance, particularly when climate issues are mainstreamed into the programs.

## Box B.2

**National adaptation plans of action for least-developed countries**

***Focus***

Each NAPA focuses on urgent and immediate needs: those for which further delay could increase vulnerability or lead to increased costs at a later stage. NAPAs should use existing information; no new research is needed. They must be action-oriented and country-driven and be flexible and based on national circumstances. Finally, in order to effectively address urgent and immediate adaptation needs, NAPA documents should be presented in a simple format, easily understood both by policy-level decision-makers and the public.

***The NAPA process***

The steps for the preparation of the NAPAs include synthesis of available information, participatory assessment of vulnerability to current climate variability and extreme events and of areas where risks would increase due to climate change, identification of key adaptation measures as well as criteria for prioritising activities and selection of a prioritised short-list of activities. The development of a NAPA also includes short profiles of projects and/or activities intended to address urgent and immediate adaptation needs of least-developed countries.

Source: http://unfccc.int/national_reports/napa/items/2719.php

**Regional**

At the regional level, responses focus on regional processes and on greater cooperation in transboundary water and soil management, since water and soil are the most vulnerable resources. Strengthening the network of the Global Water Partnership[11] is an example. Approaches for mainstreaming adaptation into development processes at the regional level must be flexible to address the needs of multiple regions (MONRE 2009). For example, in Vietnam, the draft National Target Program for adaptation focuses on two major areas: (i) technologies/infrastructure, such as dikes, irrigation system and safe houses; and (ii) ecosystems, such as forest protection and reforestation (MONRE 2009).

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[10] http://www.napa-pana.org/; http://unfccc.int/cooperation_support/least_developed_countries_portal/ldc_work_programme_and_napa/items/4722.php

[11] http://www.gwp.org/

Table O.1. Examples of NAPA project titles linked to agriculture, with tentative classification into three strategies: technical engineering, green infrastructure and adaptive land-use. Source: http://unfccc.int/files/cooperation_support/least_developed_countries_portal/napa_project_database/ (October 2009)

| ***Engineering solutions to quantified climate change*** | **Green infrastructure for reducing vulnerability** | ***Reducing vulnerability of land use*** |
|---|---|---|
| Realising food security through multi-purpose, large-scale water development project in Genale Dawa Basin in Ethiopia | Reduction of climate change hazards through coastal afforestation with community participation in Bangladesh | Continue the slash-and-burn eradication program and permanent job creation program in Lao PDR |
| Reducing the vulnerability of coastal urban areas (Monrovia, Buchanan) to erosion, floods, siltation and degraded landscapes in Liberia | Promotion of on-farm and homestead forestry and agroforestry practices in arid, semi-arid and dry sub-humid parts of Ethiopia | Improving food security in drought-prone areas by promoting drought-tolerant crops in Tanzania |
| Development and improvement of community irrigation systems in Cambodia | Climate-change adaptation through participatory reforestation on Mt Kilimanjaro in Tanzania | Promoting drought/crop insurance program in Ethiopia |
| Implementation of technical infrastructure for protection of the coastal region in Senegal | Production of bio-pesticides in Cambodia | Construction of flood shelter and information and assistance centre to cope with enhanced recurrent floods in major floodplains in Bangladesh |
| Rehabilitation of Upper Mekong and provincial waterways in Cambodia | Environmental conservation and biodiversity restoration in northern Kordofan as a coping mechanism for rangeland protection under conditions of increasing climate variability in Sudan | Development and improvement of small-scale aquaculture ponds in Cambodia |
| Rehabilitation of aquaculture sites in Mali | Eradication of invasive alien species in Zambia | Promoting the use of meteorological information to improve agricultural production and contribute to food security in Mali |
| Enhance adaptive capacity to manage climate change-related risks to fresh-water availability through appropriate technologies and improved storage facilities in Maldives | Rehabilitation, sustainable management of natural vegetation and enhancement of non-timber forest products in the eastern region in Burkina Faso | Implementation of communication infrastructure in areas of high potential production capacity to increase exchange and trade in Madagascar |
| Artificial lowering of Lake Thorthomi in Bhutan | Restoration of mangrove vegetation in Senegal | Promote secondary professions in order to improve the livelihoods of farmers affected by natural disasters induced by climate change in Lao PDR |
| Improving agricultural production under erratic rains and changing climatic conditions in Malawi | Reforestation of coastal sites in Senegal | Reorganisation of the communities adversely affected by climate change in Mauretania |
| Implementation of alternative measures to the exploitation of coastal sand in Senegal | Reforestation of rural areas with their specific reforestation plans based on locally appropriate species in Madagascar | Implementation of institutional measures for protection of the coastal region in Senegal |

**Local**

At the local level, responses depend very much on the kind of climate impacts to be expected, such as sea-level rise and storm surge in coastal areas, floods owing to heavy rains or droughts. The responses can consist of reducing exposure to the hazards or raising the adaptive capacity and/or reducing climate vulnerability. In the context of land-use management, measures could include water-harvesting techniques and erosion protection such as dikes and water pans, but also improved irrigation systems or more drought- or salt-tolerant crop varieties. They could also include integrating trees into agricultural systems because trees have many features that can help reduce vulnerability to climate impacts. Involving all stakeholders, appropriate monitoring and enforcement are paramount to developing appropriate adaptation strategies at community level.

Table B2. Frequency distribution of major classes of adaptation practices that people in rural areas rely on as reported by Agrawal and Perrin, 2008 (118 cases studied)

| Class of adaptation practice | Corresponding adaptation strategies | Fre-quency |
|---|---|---|
| I. Mobility | • Agropastoral migration<br>• Wage labour migration<br>• Involuntary migration | |
| II. Storage | • Water storage<br>• Food storage (crops, seeds, forest products)<br>• Animal live storage<br>• Pest control | 11 |
| III. Diversification | • Asset portfolio diversification<br>• Skills and occupational training<br>• Occupational diversification<br>• Crop choices<br>• Production technologies<br>• Consumption choices<br>• Animal breeding | 33 |
| IV. Communal pooling | • Forestry<br>• Infrastructure development<br>• Information gathering<br>• Disaster preparation | 29 |
| V. Market exchange | • Improved market access<br>• Insurance provision<br>• New product sales<br>• Seeds, animals and other input purchases | 1 |
| Combination strategies: | II + III | 4 |
| | II + IV | 4 |
| | II + V | 6 |
| | III + IV | 4 |
| | III + V | 26 |

## Intermezzo 4.

### Home and forest gardens reducing vulnerability in Central Vietnam

Vietnam, with its long coastline and high population density in river deltas, is one of the most exposed countries to global warming and climate change. Understanding how farmers have responded to past environmental change provides important insights for future action. To this end, a participatory appraisal of vulnerability and tree-based solutions was carried out in two villages in Cam My commune in Central Vietnam. This is an area with high annual rainfall concentrated in only two months of the year; it faces both floods and drought. The two villages shared the problem of lack of access to irrigation water and fully depended on rainfall, but they responded in different ways. One focused on trees, the other on livestock.


Through village sketches, transect walks and participatory geographic information system mapping the researchers began to understand local knowledge and responses about vulnerable areas in the local socio-ecological landscape. It became clear that access to land, water and markets were key factors in determining vulnerability and adaptive capacity. In focus groups it was found that villagers often lost half of their crop yields owing to variable weather events. Furthermore, harvesting tree products in one village and raising cattle in the other were local adaptation strategies.

Through an in-depth analysis of resilience, home and forest gardens in particular were identified as important to help farmers to adapt to climatic variability and to ensure food security through income security. The home gardens were diverse combinations of fruit trees, herbaceous (crop) species and animals on a small area around homes. Forest gardens were usually a mixture of trees, crops and livestock on land classified as forest and allocated to households. All 188 households surveyed in the two villages made use of trees in such gardens, especially when rice and rain-fed crops failed. Thirteen tree species in these gardens, in particular, were found to be less sensitive to climate variability than crops, while providing multiple benefits besides cash income and food. More than half (55%) of households in villages grew acacia, eucalypt, tea, rattan and jackfruit and these trees survived and provided products even during multiple flooding events in 2007 and severe, prolonged cold in 2008. A range of species that responded differently to various environmental pressures were found to be suitable for combining in garden systems to increase local resilience to climate variability.

## Intermezzo 5.

### Current climate maps assume that there are no trees in the landscape

Existing climate maps and climate change projections are based on data (and models calibrated on such data) that refer to 'landscapes without trees' because the standard instruction for synoptic World Meteorological Organization (WMO) weather stations is to avoid locations where tree effects influence the results. Climate-change projections predict shifts in daily average temperature, day-night temperature differential, humidity and wind speed that are likely to affect crop growth and yield. The microclimate effect of trees, however, can influence these same properties and probably over at least as wide a range as the next 30 years of climate change. Micro- and mesoclimatic effects need to be explicitly added to climate maps as a basis for discussing climate-change adaptation options based on changing tree cover. Micro- and mesoclimatic effects of trees and forests can be approached by process-level models of radiation, water balance and wind speed (Stigter et al. 2005, Stigter 2010), compared to compilations of data for synoptic WMO weather stations and measurements with various degrees of tree cover.

Modifying tree cover in agricultural landscapes to adjust micro-climates for crops has a long history: in the parklands of the Sahel, trees protect grain crops from excessive heat and maintain crop-zone soil moisture in critical periods; in the coastal zones of Southeast Asia, intercropping under coconut has a long tradition; on the mountain slopes where coffee, cocoa or tea provide farmers' income, manipulating 'shade trees' depending on elevation and local climate is relatively well studied but its use for vegetables and local food crops is less well understood (Beer et al. 1997). None of this has yet made it into national climate-adaptation planning. Acknowledging farmers' ecological and climatic knowledge and response options, and testing the limits, will provide a good platform for extending new global climatic findings to local farming communities.

Active management of tree cover can buffer the initial local effects of global climate change but is no substitute for efforts to reduce the drivers of the changes. Recognition of the opportunities and limitations of these effects and respect for local knowledge systems that relate to this can lead to more locally appropriate adaptation planning, replacing top-down 'reforestation' targets that are insensitive to local needs and preferences.

While the current debate on trees, forests and climate is overly 'carbonised' and linked to global climate feedbacks via atmospheric concentrations of greenhouse gasses, the more immediate benefits (and potential negative effects) of enhancing tree cover in landscapes can increase synergies in global climate action.