

# Effects of 2°C Warming



*IMPACT2C modelling results for a 2°C climate  
for key global vulnerable regions*



ecosystems infrastructure small islands africa water forestry energy risks air pollution vulnerability impact assessment health  
**Quantifying projected impacts under 2 C warming**  
decision making transport tourism europe agriculture adaptation



***Policy Brief N°3***

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## Summary

The IMPACT2C project provides information on the potential impacts of 2°C of global warming. To help summarize the results, a series of Policy Briefing Notes have been produced. This note provides a summary of the findings on the impacts of 2°C on key vulnerability global hot-spots, focusing on the Maldives, Bangladesh and the Niger and Upper Blue Nile River Basins in Africa.

### When do we hit 2°C?

The IMPACT2C project has analysed the RCPs (Representative Concentration Pathways) to see when global mean warming might exceed the 2°C goal, relative to pre-industrial levels. With the exception of the deep mitigation RCP2.6 scenario, the results indicate we are likely to pass the goal before the middle of this century.

The analysis indicates that under the RCP4.5 stabilisation scenario, the 2°C goal will be exceeded before 2050, while under the high emission scenario (RCP8.5) it will be exceeded in the next 25-30 years, at around 2040. However, these are central (mean) estimates, and there is a range reflecting projections from different climate models. Indeed, the models that project the fastest levels of warming indicate the 2°C goal could be exceeded as early as 2030 under both RCP4.5 and 8.5 scenarios. This has major implications for the speed and urgency of the current policy discussions and in particular the impact on key vulnerable global regions, which are likely to experience major impacts even if the 2°C goal is achieved.

### What does 2°C of warming mean for the Maldives?

Global mean sea-levels have risen over the last century, and are projected to rise over the next. This will threaten the very existence of some low-lying small island developing states (SIDS), such as the Maldives, Kiribati, Tuvalu and the Marshall Islands.

The IMPACT2C project undertook a case study on the Maldives to explore these issues. The country is widely recognised as one of the most vulnerable to climate change, particularly from the effects of sea-level rise, as the islands are on average only 1.5 metres above sea level.

The analysis first assessed potential sea-level rise scenarios for the Maldives: under the RCP2.6, 4.5 and 8.5 scenarios, the regional sea-level rise is projected as 0.26, 0.50 and 1.07 metres respectively by 2100. The study then analysed the potential impacts of this increase.

An important finding is that even if surface temperatures stabilise and achieve the 2°C goal, sea-level rise will continue over the century, and this will be a major threat to many of the low-lying islands in the Maldives during periodic extreme events.

Moreover, the earlier in time that 2°C of warming is exceeded, the higher the levels of sea-level rise that will arise over this century. This has major implications for low-lying islands such as the Maldives (which may not be able to accrete sediment at a sufficiently fast rate under rapid levels of sea-level rise).

Detailed analysis was also undertaken on one newly created island, Hulhumalé, which is situated near to the capital city. When the island was designed, it was built around 1 metre higher than surrounding natural islands, to take account of the potential threat of flooding from current surges. As a consequence, this island is not currently at risk.

However, with sea-level rise of 0.4 – 0.6 metres, the study found there is the potential for an increasing frequency of nuisance flood events, caused by long-period swell waves (as occurred in 1987 and 2007). Above 0.6 metres of sea-level rise, however, potential risks and damages rise rapidly. At 1 metre of sea-level-rise, flooding risk would become very serious (under swell wave conditions), inundating the entire island. While it would be possible to adapt to such risks, this would involve extensive engineered protection.

Overall the study finds that many of the islands of the Maldives are at major risk even under a 2°C world, and above this goal, even recent adaptation measures (such as the higher design of the new island Hulhumalé) are likely to be severely affected.

### What does 2°C of warming mean for Bangladesh?

Bangladesh is one of the most vulnerable countries in the world to current climate variability, as it

is regularly affected by floods, cyclones and droughts. It is also acknowledged that Bangladesh is one of the world's most vulnerable countries to future climate change due to the combined threats of sea-level rise, cyclones and changes in the South Asia monsoon, affecting river flows and rainfall variability. These threats are compounded by the very high population density and high poverty rates of the country.

Against this background the IMPACT2C project investigated the potential risks to Bangladesh under 2°C of global warming.

As a low-lying deltaic nation, Bangladesh is potentially very vulnerable to sea-level rise. Following the analysis presented for the Maldives, a set of sea-level rise scenarios were developed for Bangladesh. These indicate similar findings, i.e. even if the 2°C goal is achieved, sea-level rise will continue over the century and there is the potential for higher levels of sea-level rise the earlier that 2°C is exceeded. However, Bangladesh also experiences tropical cyclones, and sea-level rise will increase storm surge and high water levels, exacerbating the potential impact of these extremes.

Alongside these coastal risks, Bangladesh is situated at the convergence of three major river systems and regularly experiences floods. The IMPACT2C project therefore investigated how climate change might alter the flow of these rivers in Bangladesh. A key finding was that even for 2°C of warming, climate change is likely to increase river flows during the monsoon season in Bangladesh and this has the potential to increase river flooding.

Finally, the project then assessed the potential combined effects of changes in major river flows, sea-level rise, subsidence, salinization and local precipitation and evapotranspiration changes under 2°C of warming in three vulnerable regions of the country. The analysis found large increase in monsoon flows and flood risk and duration during the wet season. During the dry season there will be a major increases in salinity levels and reduced water availability. These combined impacts will have major impacts on local livelihoods and economic production. A key message is that even if warming is limited to 2°C, Bangladesh will experience multiple and potentially large increase in climate related risks.

## **What does 2°C of warming mean for the Niger and Upper Blue Nile River Basins in Africa?**

Africa is one of the most vulnerable continents due to its high exposure and low adaptive capacity. The continent already suffers major challenges from climate variability and extreme events. Climate change has the potential to exacerbate existing risks as well as introducing new ones.

Some of the largest future risks arise from potential changes in the water cycle and water resources in sub-Saharan Africa, increasing variability and changes in patterns of extremes (including floods and droughts). The IMPACT2C project set out to investigate these issues, focusing on two major river basins in Africa, for the Niger Basin (West Africa) and Upper Blue Nile (East Africa).

The project first investigated the potential changes in future temperature and precipitation patterns using Africa-CORDEX results. These were then used in a series of hydrological and water management models, to investigate the potential impacts on the water cycle, considering changes in the intensity of floods, hydrological droughts and agricultural droughts, as well as water infrastructure.

The results show that under 2°C of warming, high flows and flood risks are generally projected to increase for these major river basins.

For West Africa, agricultural drought events are also projected to become more severe and of longer duration in most locations, increasing the number of drought affected people.

Finally, an analysis of early adaptation options identified the need for enhanced climate services, to tackle current annual and seasonal rainfall variability as well as future climate change, and the need to mainstream climate change into integrated water resource management and water infrastructure design

## **Conclusions**

Overall, the analysis finds that large impacts are projected for all three key vulnerability global hot-spots, even for 2°C of global warming. The analysis also shows very significant increase in these impacts at higher levels of warming. Early adaptation is needed to address these challenges.



## Introduction

Internationally, there is an ambition to limit global warming to 2°C relative to pre-industrial levels. This goal is in broad alignment with the objective of the United Nations Framework Convention on Climate Change (UNFCCC) to prevent dangerous anthropogenic interference with the climate system.

The IMPACT2C project (see box) aims to provide information and evidence on the impacts of 2°C global warming for Europe and key vulnerable global regions, and thus provide policy relevant evidence. This includes detailed analysis using regional climate models and impact assessment models.

To help summarise and disseminate the results and information from the project, a series of Policy Briefing Notes are being produced.

This Policy Brief (Number 3) provides a summary of the potential impacts of 2°C of global warming on key vulnerability global hot-spots. The note provides discussion around a number of key questions that are relevant in the context of the 2°C goal. These are:

- What does 2°C of warming mean for the Maldives?
- What does 2°C of warming mean for Bangladesh?
- What does 2°C of warming mean for the Niger and the Upper Blue Nile River Basins in Africa?

### The IMPACT2C Project

Political discussions on the European goal to limit global warming to 2°C need to be informed by the best available science on projected impacts and possible benefits. IMPACT2C enhances knowledge by quantifying climate change vulnerability and impacts, using a clear and logical structure. It also considers the economic costs of these impacts, as well as potential responses, within a pan-European sector-based analysis. The project uses a range of models within a multi-disciplinary international expert team and assesses effects on water, energy, infrastructure, coasts, tourism, forestry, agriculture, ecosystems services, and health and air quality-climate interactions. IMPACT2C introduces a number of key innovations.

First, harmonised socio-economic assumptions/scenarios are being developed, using the new RCPs and SSPs (Representative Concentration Pathways and Shared Socio-economic Pathways), to ensure that both individual and cross-sector assessments are aligned to the 2°C scenario for both impacts and adaptation.

Second, a core theme of uncertainty has been developed to integrate uncertainties from the climate projections, socio-economic scenarios and impact models within and across sectors. In so doing, analysis of adaptation responses under uncertainty will be enhanced.

Finally, a cross-sectoral perspective is adopted to look at linkages between sectors, to capture direct and indirect effects and to look at areas of Europe that are particularly vulnerable (hot-spots) even to 2°C of warming.

While the focus is on Europe, a number of case studies are being developed to investigate some of the world's most vulnerable regions, i.e. those most at risk under 2°C of warming, with analysis in Bangladesh, Africa (Upper Blue Nile and Niger basins) and the Maldives.

The IMPACT2C aims to integrate and synthesize the findings for awareness-raising and to communicate to a wide audience, relevant for policy.

## When might we hit 2°C?

At the Conference of the Parties in Cancun (UNFCCC, 2010), the Parties agreed to a goal to reduce global greenhouse gas emissions so as to hold the increase in global average temperature below 2°C above pre-industrial levels, and to consider lowering the goal to 1.5°C in the near future. However, there has already been an increase of about 0.85°C over the period 1880–2012 (IPCC, 2013), and at the current time, international negotiations have had modest success. Current commitments and pledges are therefore not on track to achieve the 2°C goal. Indeed, at the current time (November 2015), based on the pledges from countries as part of the INDC process (Intended Nationally Determined Contributions), it is estimated (UNFCCC, 2015) that warming would only be limited to 2.7°C by 2100 (noting there is actually a significant range around this due to the sensitivity of the models). This is of particular relevance for this policy brief because one of the key factors driving the lower 1.5°C goal was concerns for particularly vulnerable key regions.

Against this background, a useful question is therefore to ask is when might we exceed the 2°C global goal and thus when might the impacts on these vulnerable regions arise? The answer is informative in highlighting the further implications of inaction.

The IMPACT2C project set out to investigate this question – and to examine uncertainty – using the Representative Concentration Pathways (RCPs) presented in the IPCC 5<sup>th</sup> Assessment Report (IPCC, 2013). These include a set of four new pathways developed for the climate modelling community as the basis for long-term and near-term modelling experiments. These scenarios cover the range from scenarios consistent with the 2°C goal to high emission futures (see box).

The IMPACT2C project looked at the global climate model simulations from the Coupled Model Intercomparison Project Phase 5 (CMIP5) results, to look which year the 2°C goal could be exceeded. This compared results from the available model runs to look at the central year (in a 30–year time window).

The results (Figure 1) are first shown for the RCP2.6 mitigation scenario. This shows that there is a good chance that the 2°C goal will be achieved

under this scenario, as more than half the modelled projections do not reach the goal. It is noted, however, that even under this deep mitigation scenario, some models still project higher levels of warming and thus exceed the goal.

### The Representative Concentration Pathways

The four RCPs span a range of possible future emission trajectories over the next century, with each scenario corresponding approximately to a level of total radiative forcing ( $\text{W/m}^2$ ) in the year 2100. The RCPs are different to the SRES, in that they are not unique and self-consistent socio-economic scenarios and emission pathways over time.

The first RCP is a deep mitigation scenario that leads to a very low forcing level of 2.6  $\text{W/m}^2$  (RCP2.6), only marginally higher compared to today's situation (2.29  $\text{W/m}^2$ , IPCC, 2013). It is a “peak-and-decline” scenario and is representative of scenarios that lead to very low greenhouse gas concentration levels. This scenario has a good chance of achieving the 2°C goal.

There are also two stabilization scenarios (RCP4.5 and RCP6). RCP4.5 is a medium-low emission scenario in which forcing is stabilised by 2100. It is similar to the A1B scenario from the SRES. It is stressed that even in this scenario, it is likely that annual emissions (of  $\text{CO}_2$ ) will need to sharply reduce in the second half of the century, and thus it is likely to require significant climate policy (mitigation).

Finally, there is one rising (non-stabilisation) scenario (RCP8.5), which is representative of a non-climate policy scenario, in which greenhouse gas emissions carry on increasing over the century and end up with very high concentrations by 2100.

These scenarios corresponds to  $\text{CO}_2$  concentrations reaching 421 ppm (RCP2.6), 538 ppm (RCP4.5), 670 ppm (RCP6.0), and 936 ppm (RCP 8.5) by the year 2100 (IPCC, 2013).

Source: van Vuuren et al, 2011; IPCC, 2013.

The analysis has then considered the higher RCP4.5 stabilisation scenario, and the non-stabilisation RCP8.5 scenario. The results are striking. The mean of the model simulations indicates that the 2°C goal could be exceeded by around 2040 under RCP8.5 (only thirty years away) and just before 2050 under RCP4.5. There is a considerable spread across the models. Importantly, models that have faster warming indicate the 2°C goal could be exceeded by 2030 under both (RCP4.5 and 8.5) scenarios, only fifteen years away. Moreover, even the model

simulation with the slowest rate of warming shows that the 2°C goal will be exceeded before 2060 under high (RCP8.5) pathways.

This has major implications for the speed and urgency of the current policy discussions. It also indicates that early adaptation is likely to be needed to address the changes already anticipated over the next 20 to 30 years. In the context of this policy brief, it highlights that the potential impacts on key vulnerable regions could arise in the next few decades.

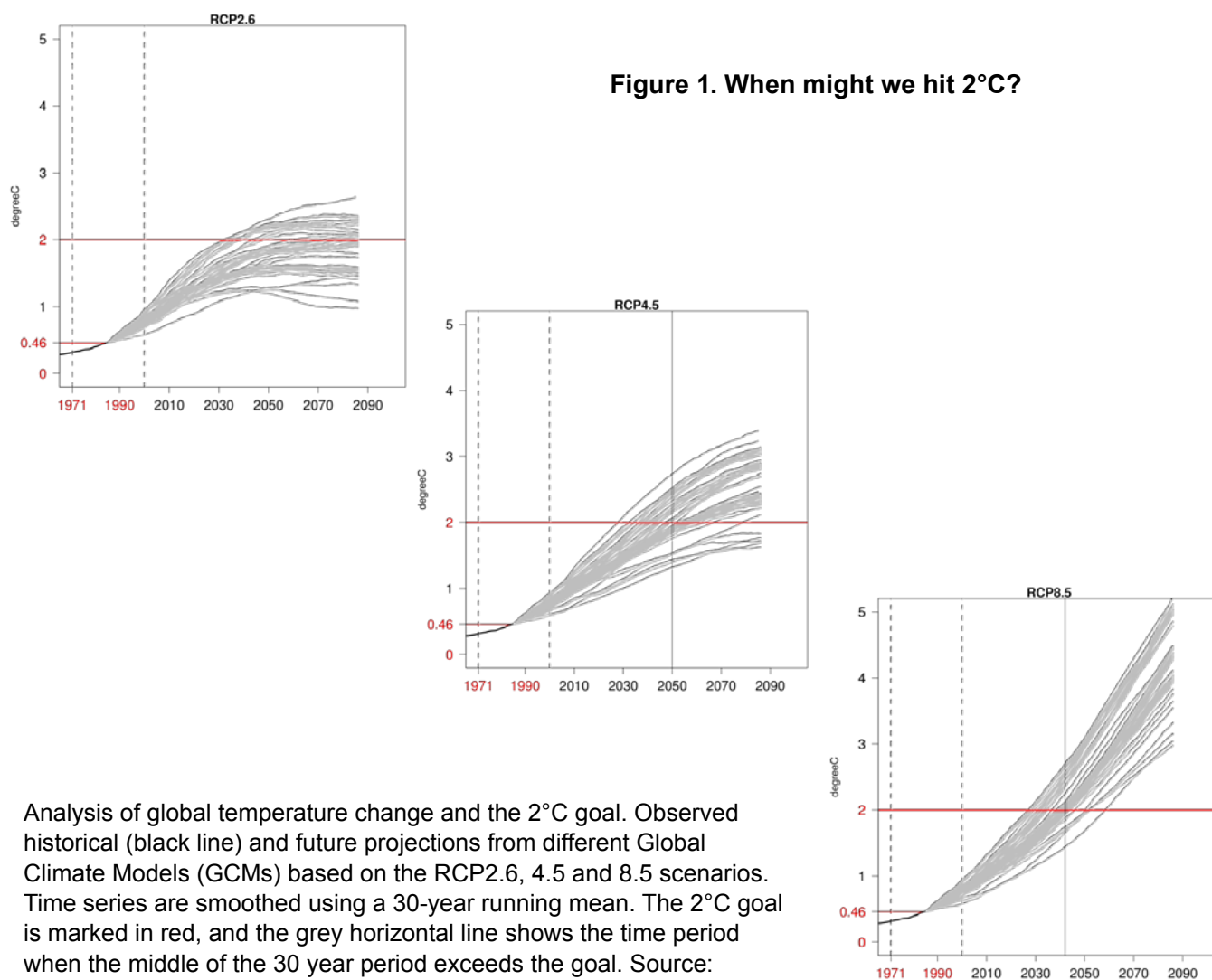


Figure 1. When might we hit 2°C?

Analysis of global temperature change and the 2°C goal. Observed historical (black line) and future projections from different Global Climate Models (GCMs) based on the RCP2.6, 4.5 and 8.5 scenarios. Time series are smoothed using a 30-year running mean. The 2°C goal is marked in red, and the grey horizontal line shows the time period when the middle of the 30 year period exceeds the goal. Source: Andreas Gobiet and Thomas Mendlik, 2014.

**Key message.** An analysis of climate model projections indicates that the 2°C goal could be exceeded in the next 30 years, at around 2040 under a high emission (RCP8.5) scenario, and just before 2050 under the RCP4.5 stabilisation scenario. This has major implications for the speed and urgency of the current policy discussions and in particular the impact on key vulnerable regions, which are likely to experience major impacts over the next 20 to 30 years.

## What does 2°C of warming mean for the Maldives?

Over the last century (1901–2010), global mean sea-levels have risen by  $0.17 \pm 0.2\text{m}$ , posing threats to low-lying coastlines world-wide (Church et al. 2013). This trend is expected to continue and for some low-lying nations, their very existence is threatened. Low-lying atoll nations, such as the Maldives, Kiribati, Tuvalu and the Marshall Islands fall into this category.

The IMPACT2C project undertook a major case study on the Maldives to investigate the potential impacts of 2°C of warming, working with the Ministry of Environment and Energy, to investigate the potential impacts of climate change and planned responses.

### The Maldives and sea-level rise

The Maldives is a very low-lying small island developing state (SIDS) in the Indian Ocean. It is widely recognised as one of the most vulnerable countries globally to climate change from sea-level rise as the islands are on average only 1.5 metres above mean sea-level. An example of this low lying nature can be seen for

the island capital Malé in the photograph below.

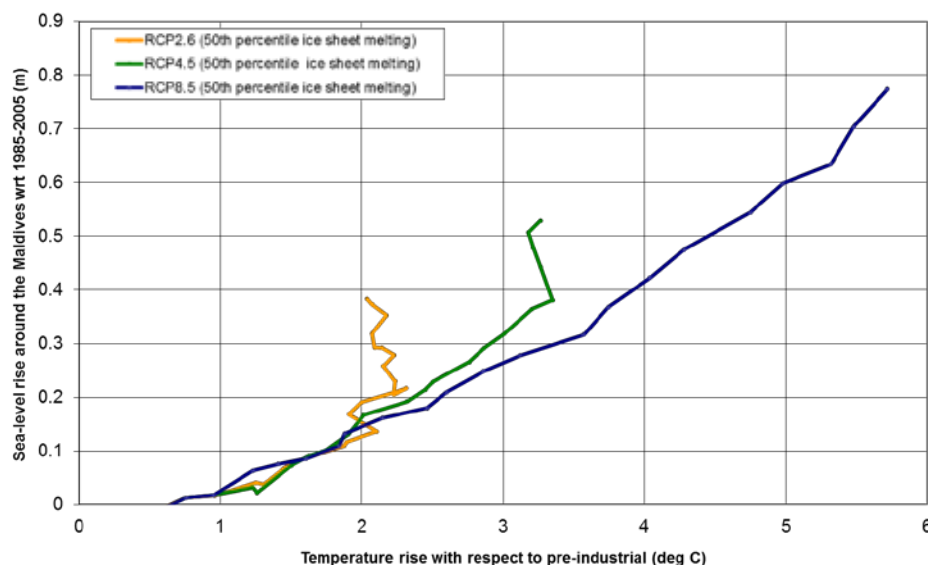
The country comprises a large number of small islands (1192) that are very remote and dispersed in nature, and have a limited resource base. They are already highly vulnerable and affected by periodic flooding. These risks are exacerbated by the high population and urbanisation pressures, which increases competition for land.

Given their low lying nature, the islands are threatened by anthropogenic sea-level rise caused by warming temperatures. The IMPACT2C project first investigated the potential risks to the island over the next century, developing sea-level rise projections.

The results (Hinkel et al. 2014) project that regional sea-level rise for the Maldives under the RCP2.6, 4.5 and 8.5 scenarios would be 0.26, 0.50 and 1.07 metres respectively by 2100, relative to 1986–2005 (using the HadGEM2-ES climate model projections), although there is a considerable range around these central figures.







**Figure 2. Mean sea-level rise (metres) around the Maldives under the different RCP scenarios, with respect to 1985 – 2005.**

Source Hinkel et al. 2014

However, unlike other climate parameters, sea-levels do not respond immediately to an increase in global mean surface temperature: there is a time lag between surface warming and ocean response. This can take several decades up to millennia and is known as the commitment to sea-level rise (Wigley and Raper, 1993).

This has two important implications. First, the time profile and rate of warming affects sea-level rise, thus the increase can vary even for the same level of temperature rise. Second, even if emissions and temperature could be stabilised today, there would be an increase in sea levels from past warming.

Figure 2 shows this commitment to sea-level rise (Hinkel et al. 2014). Even when temperatures stabilise around the 2°C goal (RCP2.6), sea-level continues to rise over the rest of the century (and even beyond) – shown by the line moving vertically up the figure, although the rate of increase slows. This can be compared to the RCP4.5 and RCP8.5 scenarios. RCP4.5 is also a stabilisation scenario,

but temperatures and therefore sea-levels stabilise later in time. However, the pattern for RCP8.5, the high warming scenario, differs dramatically, as temperatures and sea level rise continue to increase over the century and beyond.

It is also highlighted that sea-level rise may also extend beyond the RCP8.5 scenario if ice sheets melt quicker than presently anticipated (in this century or beyond), as ice sheet dynamics could lead to the partial collapse of ice shelves (Joughin et al, 2014; Rignot et al, 2014). This could result in a further rise in sea-level of several tens of centimetres (Church et al. 2013) over and above the levels shown.

This analysis has particularly important implications for the Maldives and other low-lying SIDS. Even if surface temperatures stabilise and achieve the 2°C goal, sea-level rise will continue over the century, affecting these countries. The earlier 2°C is reached, the greater the potential for higher levels of sea-level rise.

**Key message.** Even if surface temperatures stabilise and achieve the 2°C goal, sea-level rise will continue over the century. Furthermore, the earlier 2°C is reached, the greater the potential for higher levels of sea-level rise. These issues are a particular concern for low-lying small islands, such as the Maldives.



## Sea-level rise, land-use pressure and adaptation

The increase in sea-levels, projected above, will lead to an increased risk of flooding of low-lying areas, as well as increased erosion, salinization, and loss of coastal habitats. However, the effects of sea-level rise need to be seen in the context of other natural process and socio-economic drivers.

As a developing upper-middle income country, the Maldives is undergoing rapid population growth and urbanisation. The capital city, Malé is home to 100,000 people and has a population density of over 44,000 people/km<sup>2</sup> making it one of the most densely populated cities in the world. Rising population and urbanisation trends are therefore creating land-use pressures.

In the past, engineers reclaimed land and built out onto the reef. However, this solution is no longer sustainable, particularly as national population continues to rise. This fact was recognised some years ago, and thus the focus of expansion was on a new island, Hulhumalé, located 4km north-east of the capital. The initial phase reclaimed 244 hectares of land on the reef flat (completed 2002) at a height of approximately 2 metres above mean sea-level, shown in the photograph right. The next phase is to use the island to create a new economic hub.

Sea-level rise was considered in the design of the island, but the science and projections of sea-level rise have increased in recent years, thus raising the question of whether the island been built high enough.

The IMPACT2C project therefore investigated if the new island would be able to cope with sea-level rise in a 2°C world, including overtopping and flooding under sea-level rise.

The project collected relevant data and went through a series of steps to investigate the potential risks. This used tide gauge and hindcast data to examine extreme events and flooding in the past, then used a model to look at the risks of overtopping under scenarios of sea-level rise, and the potential impacts using a flood inundation model.

1997



2002



2003



2004



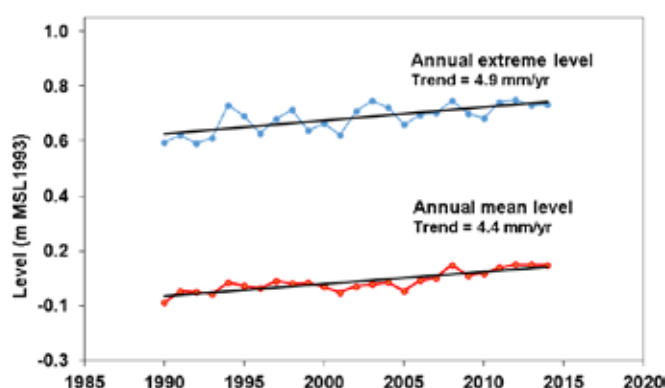
2009



**Figure 3. The development of the new island, Hulhumalé.**

Used with permission from the Hulhumalé Development Corporation.

Analysis of historic data (Figure 4) revealed there has been an increase in sea level over the past 25 years, and also that the extremes are increasing at a slightly higher rate. However, the data also revealed that the surge in water levels has been relatively small compared with other parts of the world.



**Figure 4. Sea-level trends for Malé for annual extreme and annual mean sea-level**

Nonetheless, there have been periodic flood events, caused by long-period swell waves from the Southern Ocean, such as in 2007. Interestingly while this inundated (flooded) many islands in the Maldives, Hulhumalé was not flooded due to its higher elevation.

The IMPACT2C project then looked at the risks associated with future sea-level rise. As highlighted above, this is a real concern for the low-lying islands across the Maldives. It is also a potential threat to Hulhumalé, even though this has a higher elevation, and so is not considered at risk under current conditions. This was therefore chosen for a case study.

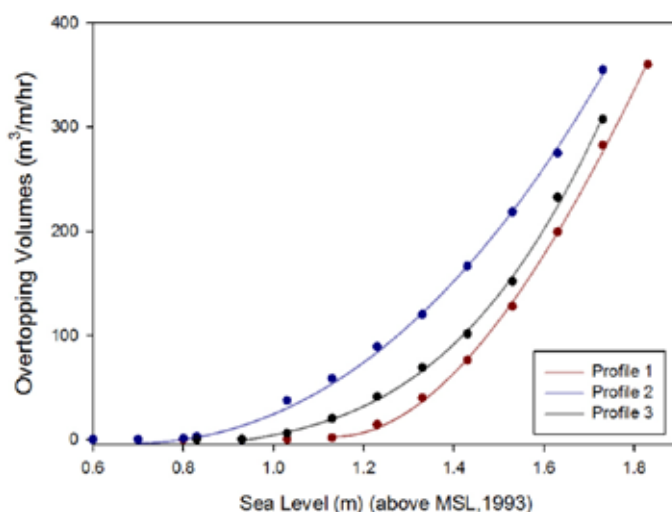
A range of sea-level scenarios were used to investigate the potential risks to the island. The results are shown below and show the overtopping volumes (from flooding) for a range of sea-level rise (including the combined effects of tides, surges and sea-level rise). The results show there is an exponential rise in the risks of overtopping as sea-level increases.

Existing tides and surges have the potential to raise water levels by 0.6 metres during extreme events (as in the 2007 event), and these will act in the future on top of rising sea-levels. The 2007 flooding event took place during a spring tide: although the sea level was not exceptional, it took place during sustained swell wave conditions. The results indicate that above 0.4 to 0.6 metres of sea-level rise, the risks of overtopping and major flooding increases rapidly.

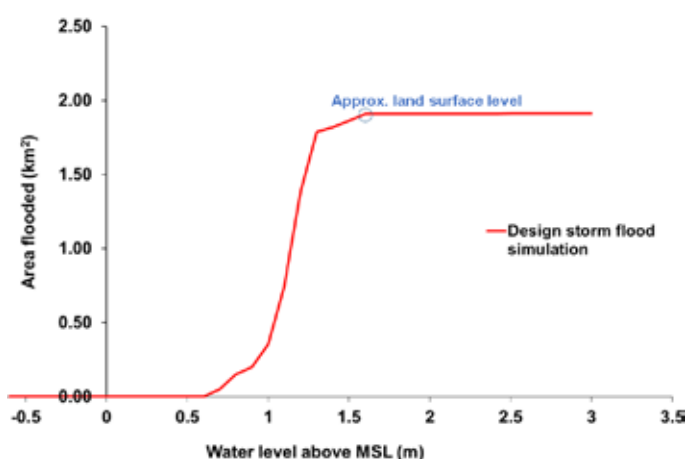
The final step was to investigate the potential impacts in terms of land inundated. The analysis found that the risks of flooding were low under

current conditions. However, flood risks suddenly increased above 0.4 to 0.6 metres of sea level rise, due to the combined effect of tide and swell conditions acting on top of this higher baseline level (in the figure this is shown by an overall increase above 1 metre, which reflects the 0.6 m of swell conditions on top of SLR).

Furthermore, due to the flat and low-lying nature of the island, once overtopping occurs, flooding is extensive. This therefore reflects a physical tipping point, above which large-scale damage will occur. Indeed, with 1 metre of sea-level rise, all of Hulhumalé is likely to be flooded (assuming its current status in terms of no defences).



**Figure 5. Overtopping volumes for sea-level rise for different land elevation / bathymetry profiles**



**Figure 6. Area of land flooded on Hulhumalé against elevation above mean sea-level**



## Conclusions

The IMPACT2C analysis has shown that sea-level rise will have potentially large impacts on the Maldives – as well as implications for other low-lying small island states.

Analysis of local data reveals that local average and extreme sea-levels are already increasing, and that even with 2°C of global warming, the rise in sea-level would be a major threat to many of the low-lying islands in the Maldives under periodic surge events.

A case study has been undertaken on the new island, Hulhumalé, which is not currently at risk of flooding due to its higher elevation. Under sea-level rise of 0.4 – 0.6 metres, there is a rise of nuisance flooding during a swell wave flood event

(a water depth of 0.1 metres). However, above this level of sea-level rise, potential risks and damages rise rapidly. With 1 metre of sea-level rise, flooding under extreme swell wave conditions would become very serious, covering the entire island (with greater than 0.25 metres of water depth). While it would be possible to adapt to such risks, this would involve extensive and expensive engineered protection.

Therefore, while many of the islands of the Maldives are at major risk even under a 2°C world, it is only above this level of warming that Hulhumalé is likely to be severely affected. However, the risks even to this island increase above the goal, and it is likely that adaptation measures will be needed under current emission pathways towards the latter part of the century.



## What does 2°C of warming mean for Bangladesh?

Bangladesh is one of the most vulnerable countries in the world to current climate variability. It is affected by floods, cyclones and droughts, as well as problems from river and coastal erosion, soil erosion and salt-water intrusion. This combination of climate hazards leads to impacts across all sectors, affecting agriculture, water, fisheries and forests, people and livelihoods, the built and natural environment.

Given these existing challenges, and the very low lying nature of the country, it is widely acknowledged that Bangladesh is one of the world's most vulnerable countries to future climate change.

There are major threats from sea-level rise and the potentially additional effects of higher cyclone intensity/frequency. Furthermore, there are potential changes in the South Asia monsoon and subsequent river flows, as well as a potential increase in the intensity of rainfall, increasing the existing flood problems. These threats are

compounded by the very high population of the country, high urbanization rates and high poverty rates. Indeed, future climate change could severely impact livelihood and lead to very large economic costs of Bangladesh this century (ADB, 2014) that would reverse development gains.

Against this background the IMPACT2C project has investigated the potential risks to Bangladesh under 2°C of global warming.

### Sea level rise

As a low-lying, subsiding deltaic nation, Bangladesh is potentially very vulnerable to sea-level rise. Following the analysis presented earlier in this policy brief for the Maldives, a set of sea-level rise projections were developed for Bangladesh, based on global mean values. These considered regional patterns of change for the Bay of Bengal from a range of models and found that the levels were very slightly higher than the global values, i.e. similar to the values shown in Figure 2.



**Key message.** As a low-lying delta, Bangladesh is highly vulnerable to future sea-level rise. Even if the 2°C goal is achieved, sea-level rise will continue over the century, and there is the potential for higher levels of sea-level rise the earlier that 2°C is exceeded. Sea-level rise will also exacerbate existing cyclone storm surges, increasing the risks of these high impact events.

Under the RCP scenarios, a rise of 2°C occurs between 2015 and 2085, depending on the scenario and model, corresponding to a 0.08 and 0.40 metres of sea-level rise, with larger increases for higher warmer scenarios. However, following the earlier discussion, even if emissions and temperature could be stabilised today, there would be an increase in sea levels from past warming. The earlier that 2°C is reached, the greater the potential for high levels of sea-level rise. It is also highlighted that sea-level rise may be quicker and more extensive than this if ice sheets melt quicker than presently anticipated. Given the high vulnerability of the coastal areas of Bangladesh, all of these issues are critical.

The main coastal flood risk to Bangladesh – now and under future climate change – will be from cyclones, and the additional storm surge and high water levels, which cause flooding, as well as posing multiple risks from storm damage to people, buildings, infrastructure, salinization of freshwater sources and land, etc.

Bangladesh currently experiences major cyclones: the last major one (in 2007), Cyclone Sidr resulted in thousands of deaths and damages and losses of \$1.7 billion (2.6% of GDP) (World Bank, 2010). While there are not clear signals on how climate change will affect cyclone frequency, intensity and storm tract paths, sea-level rise is likely to increase storm surge levels (Sindhu and Unnikrishnan, 2012), and these higher surge heights will increase impacts. These increases are a particular issue if events coincide with high-tides.

### Case study analysis on highly vulnerable districts

Bangladesh is situated at the convergence of three major river systems, the Ganges, Brahmaputra and Meghna. These rivers can experience extremely high flows during the monsoon period, frequently leading to major floods, indeed, there have been 7 major floods since the 1980s. However, there are

also complex patterns of rainfall variability in the country, and a major drought occurs once every five years (particularly affecting the west). Climate change has the potential to exacerbate these existing extremes, by altering the regional water cycle. These impacts will act with other risks, such as sea-level rise, salinization, etc.

The South West region of Bangladesh is particularly vulnerable to the potential impacts of climate change, including from multiple risks. The IMPACT2C project therefore focused on this region and assessed the potential effects from 2°C of warming on three districts: Kushtia, Bagerhat and Shariatpur. They were chosen as they each have different vulnerability characteristics. Kushtia is a drought prone area, Bagerhat is threatened salt water intrusion and Shariatpur is an area affected by river floods.

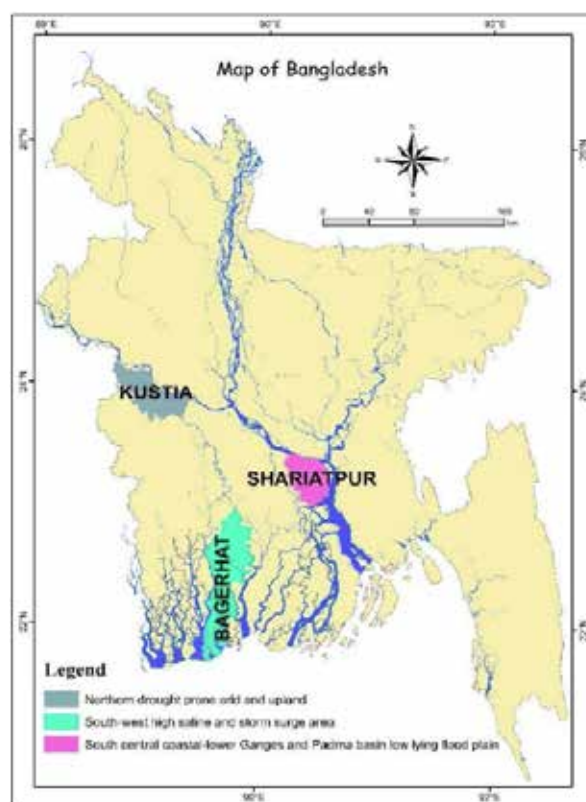


Figure 7. The Bangladesh Case Study Areas.

To capture these various aspects, a series of inter-linked models were used. This included bias corrected regional climate models, hydrological assessment of the major river system (the Ganges-Brahmaputra-Meghna Basin), a southwest regional hydrodynamic model that combines river and sea-level rise inputs, and a river salinity model.

The IMPACT2C analysis first looked at how climate change might change the flow of the three main river of Bangladesh under 2°C of warming relative to pre-industrial levels. This compared two climate model simulations for a RCP 8.5 scenario at 2°C. A key finding was that climate change is likely to increase the flow of these rivers during key parts of the year.

For the Ganges, there was a projected 20% increase in flows during the monsoon months and a 30% increase in the dry season, with high model agreement.

For the Brahmaputra flow, there was also an increase in monsoon flows (15%) but with a lower increase in the dry season. While there was broad model agreement, one of the models did show larger increases in flows.

For the Meghna, there was a projected increase in flows in monsoon and post-monsoon season (~20% increase) and in dry season (~10% increase);

This is in itself an important finding: under 2°C of warming, climate change is likely to increase river flows during the monsoon season in Bangladesh: this has the potential to increase river flooding.

These projections will be determined by upstream water management policies, in particular the abstraction levels during the dry season, which highlights the importance of trans-boundary analysis.

The project then analysed the potential combined effects of changes in major river flows, SLR, subsidence, salinization and local precipitation



and evapotranspiration changes under 2°C of warming.

In Kushtia, the analysis indicated an increase in monsoon and post-monsoon flows but little change in dry season flows due to siltation at the Gorai River mouth.

In Bagerhat, the assessment projected a large increase in salinity levels and duration in the northern part of the district (with good model agreement). This could potentially have a large impact on drinking water provision and agricultural production.

In Shariatpur, the analysis projected a significant increase in monsoon flood levels and a much longer flood risk duration.

These changes would lead to multiple impacts, increasing floods, salinity intrusion, river bank erosion, storm surge, coastal flooding, water logging, and in turn leading to multiple secondary impacts, reducing agricultural production, increasing health impacts, asset and infrastructure losses from flooding, and affecting local livelihoods and economic production.

Finally, working with the local communities, the case study identified a large number of possible adaptation options, and evaluated these using cost benefit analysis, multi criteria assessment, and a decision matrix.

**Key message.** Even if warming is limited to 2°C, Bangladesh is projected to experience multiple and potentially large increase in climate related risks, from the combined effects of sea-level rise, storm surge, river flooding, rainfall variability, and salinity. These will lead to multiple impacts across society and the economy.



## What does 2°C of warming mean for the Niger and Upper Blue Nile River Basins in Africa?

The recent IPCC 5<sup>th</sup> Assessment Report (Niang et al, 2014) highlights that Africa is one of the most vulnerable continents due to its high exposure and low adaptive capacity. A large part of the African population lives at the subsistence level and these livelihoods are strongly dependent on climate sensitive ecosystems.

The continent already suffers major challenges from climate variability and extreme events, which have large impacts due to current livelihood and food production systems. Climate change has the potential to exacerbate these existing risks as well as introducing new ones. These stresses are also exacerbated by high population growth and governance challenges: many African institutions lack sufficient capacity and resources to address existing climate variability (the adaptation deficit) and to prepare adequately for future climate change.

Some of the largest future risks from climate change arise from potential changes in the water cycle and water resource availability in sub-Saharan Africa, including the changing variability and changes in patterns of extremes (including floods and droughts) and the subsequent effects on agriculture and health. These are likely to compound existing and growing water stress and degradation.

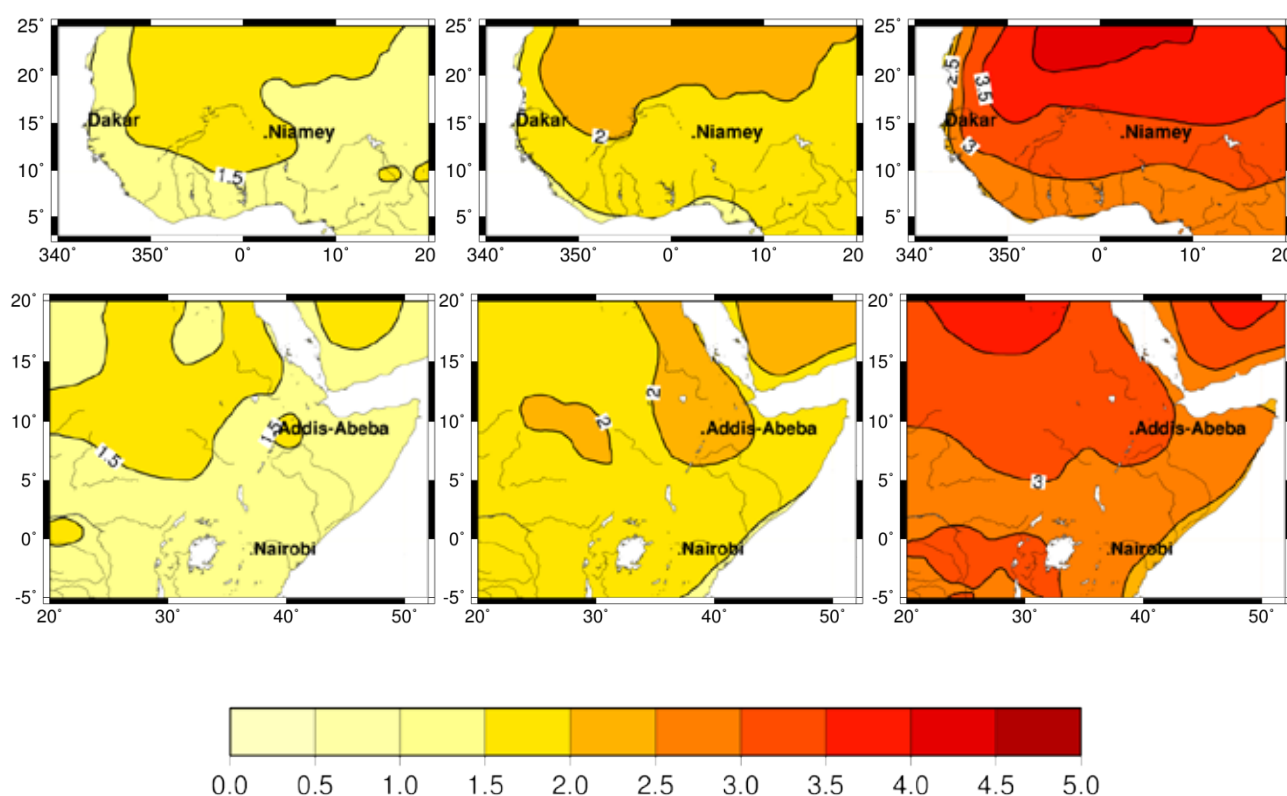
The IMPACT2C project set out to investigate these potential issues, focusing on two major river basins in Africa, the Niger in West Africa and the Upper Blue Nile River in East Africa. Both of these experience high levels of current rainfall variability and periodic extremes, which have multiple impacts.

The project first investigated the potential changes in future temperature and precipitation patterns in West and East Africa. This used the latest regional climate models for Africa from the Africa-CORDEX (COordinated Regional Downscaling EXperiment) international program to investigate the potential changes under 2°C of global warming. The assessment then used these projections to explore the potential impacts on flood dynamics and on food security.

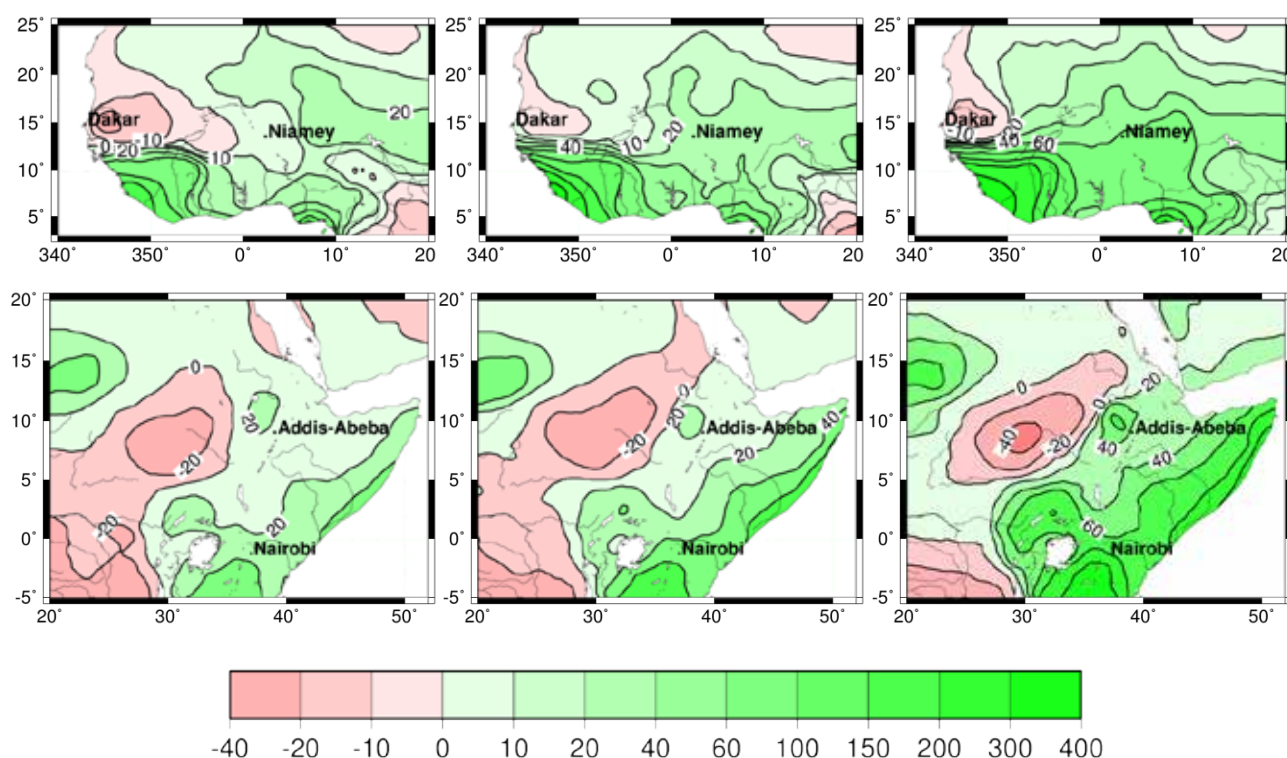
### Projections of future change under 2°C

The IMPACT2 first investigated the potential changes in West and East Africa, studying the changes under warming of +1.5°C, +2°C and +3°C, relative to pre-industrial. While in general the changes are similar to the global mean, there is a stronger warming signal in the South Sahara and North-eastern Africa.





**Figure 8: Ensemble mean of the projected temperature increase over West Africa (°C) [top] and East Africa [bottom]; from left to right for a global warming of +1.5°C, +2°C and +3°C above pre-industrial. The figure shows the temperature increase with respect to the period 1971-2000.**



**Figure 9: Ensemble mean of the projected change in annual precipitation over Africa (mm/year); from left to right, +1.5°C, +2°C and +3°C above pre-industrial. The figure shows the change with respect to the period 1971-2000.**

The analysis of annual precipitation shows more complex changes, and there is higher uncertainty.

In West Africa, there is a projected annual increase, although this is low (around 10% in the +3°C scenario), with the response pattern generally showing an increasing amplitude with temperature. The pattern for East Africa shows more complex patterns of change across the region. Interestingly, these patterns do not follow the classical “dry areas become drier, wet areas become wetter” and indeed the reverse of this is projected in the East (increased rainfall in a dry zone), in Sudan (decrease in a wet zone), and an increase along the Somalia coast (increase in a dry zone).

There are also important seasonal changes and patterns of extremes. In both regions, the projections show increasing rain intensity and a decreasing number of rain days, so less days but with more rain. In many regions, there are also indications of changes in the onset and cessation of rainy seasons. For example, a recurring feature in West Africa is the presence of large fluctuations between dry and wet periods, which in many cases exceed the amplitude of the baseline variability.

However, some caution is needed in interpreting the results. There is large variation between climate model simulations, both from the driving GCM and the regional climate model, highlighting significant uncertainty. What is also clear is that there will be large year to year variability of seasonal rainfall and addressing this will remain a priority in the future.

### **Changes in the water cycle under 2°C**

Climate change is projected to have a significant impact on global and regional water cycles. The IMPACT2C project assessed the impacts of climate change on the terrestrial water cycle in East and West Africa for 2°C of global warming, relative to pre-industrial.

The project therefore used the climate projections above in a series of hydrological and water management models to investigate these potential impacts. This focused on analyzing the changes in the intensity of floods and hydrological droughts in the Niger Basin (West Africa) and Upper Blue Nile (East Africa).

Large parts of the Niger Basin contain flood-pulse dependent ecosystems, on which livelihoods depend. However, the Niger Basin has also experienced extensive hazardous flooding over the past two decades, with more than ten million people affected since the year 2000 (Aich et al. 2014). A critical issue is therefore whether these impacts might increase under climate change.

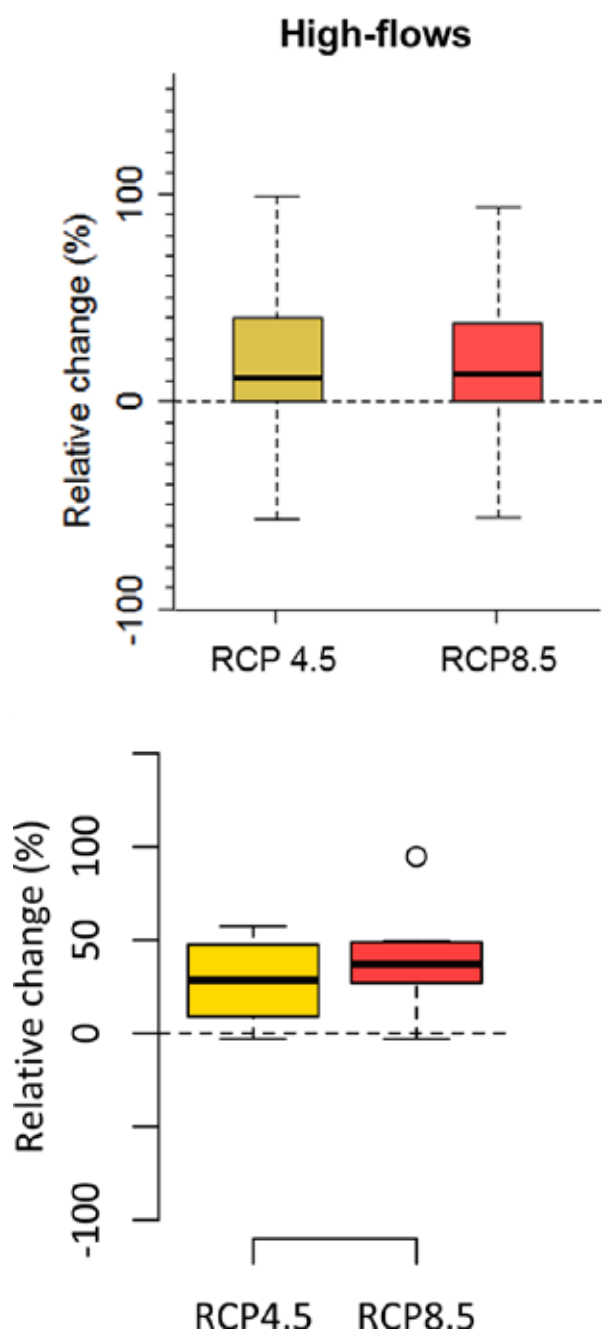
The IMPACT2C project looked at the potential changes in flood magnitude under 2°C of warming using the HYPE (HYdrological Predictions for the Environment of SMHI and Soil and Water Integrated Model (SWIM). While there are some regional differences in magnitude, for most parts of the Niger basin, the analysis found that hazardous floods are expected to increase, though the uncertainty range is large.

A similar analysis was undertaken for East Africa, which also experiences periodic extremes (including droughts and floods) that have major impacts on livelihoods as well as high economic costs. The IMPACT2C project looked at the Upper Blue Nile Basin, using the Soil and Water Integrated Model (SWIM) and a water availability model (\*HBV) models. This also projected that flood magnitudes are expected to increase for almost all model runs, with the potential to increase existing flood impacts. The mean increase for scenario RCP4.5 is around a 25% increase between the base period and the period when 2°C global warming is reached, although again the uncertainties are large.

A similar analysis was undertaken for hydrological droughts (low-flows). The potential impact of these events is high, as the national economies in these countries are largely agricultural based and production is mainly rain-fed (and flood recession-fed) and thus highly climate sensitive. The hydrological cycle also affects other natural resources – in the Inner Niger Delta in Mali, for example, fish yields are directly related to the delta's inundation extent, which is determined by flood levels.

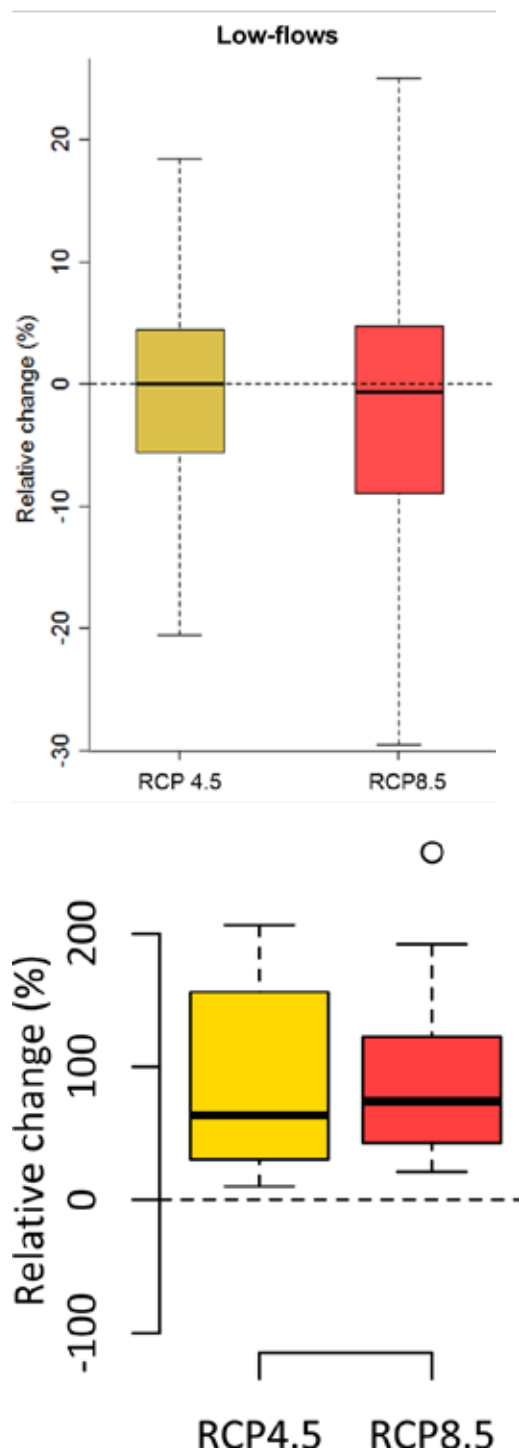
The results (Figure 11) indicated a much greater variation in outcomes, depending on the projection and location. For some areas of West Africa, notably the central Benue valley, the southern Bani basin and parts of the Guinea highlands, there were consistent trends of longer periods of low flows and more severe hydrological droughts. For East Africa, for the location shown,





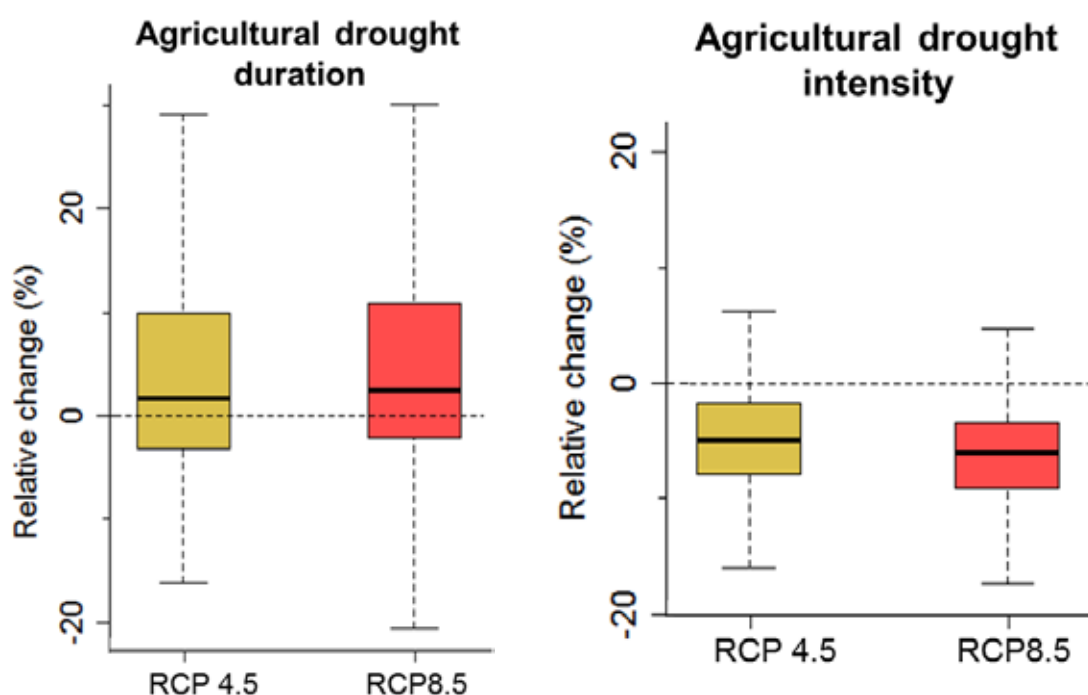
**Figure 10.** Change in a high-flow index from the reference period to the period of +2°C for the Niger [top] and Upper Blue Nile at El Diem [bottom].

The spread in each projection represents from variation between locations across the basin and the projections within each projection group. The index is the change in the 90th percentile of the daily river flow. A positive change means increasing peak-flows and potentially more severe floods.



**Figure 11.** Change in a low-flow index from the reference period to the period of +2°C for the Niger Basin (Top) and Upper Blue Nile at the gauge El Diem (Bottom).

The spread in each projection represents from variation between locations across the basin and the projections within each projection group. The index is the change in the 10th percentile of the daily river flow.



**Figure 12. Change in agricultural drought duration (right) and agricultural drought intensity (left) from the reference period to the period of +2°C for the Niger Basin**

The index for drought duration is based on the daily soil moisture fraction of the field capacity in the root zone. The drought duration is the number of days for which the soil moisture is below the 10th percentile. A positive change means longer drought duration.

The index for agricultural drought intensity is based on the daily soil moisture fraction of the field capacity in the root zone. The drought intensity is the mean soil moisture magnitude of the days which fall below the 10th percentile. Hence, a negative change means more severe droughts.

there was a more consistent trend of increasing low flows.

Finally, the analysis considered the potential impact on agricultural water stress (agricultural drought), considering root soil moisture, although this was only undertaken for the Niger Basin (Figure 12). In the Niger, the analysis indicates that agricultural drought events will be more severe and of longer duration in most locations. Further, the number of days below an indicator of crop water stress and irrigation water need increases considerably at most locations. The analysis indicates that agricultural drought events are projected to become more severe and of longer duration in most locations on the Niger, although the uncertainty in the projections is important.

Finally, the analysis has looked at the projected number of drought-affected people for the Nile and Niger basin under climate change. The projections indicate that in the Nile, the food-

security outlook is relatively steady. In the Niger basin, however, climate change leads to potentially large fluctuations in the number of drought-affected people, with major impact periods over time scales of decades.

Overall, the results show that potentially important changes to water resources will arise in East and West Africa even in a + 2°C warmer world, though there are differentiated patterns of change across the continent. Importantly, many of the projected changes will increase the existing risks today. A key priority is to build adaptation to better cope with climate variability – now and for the future.

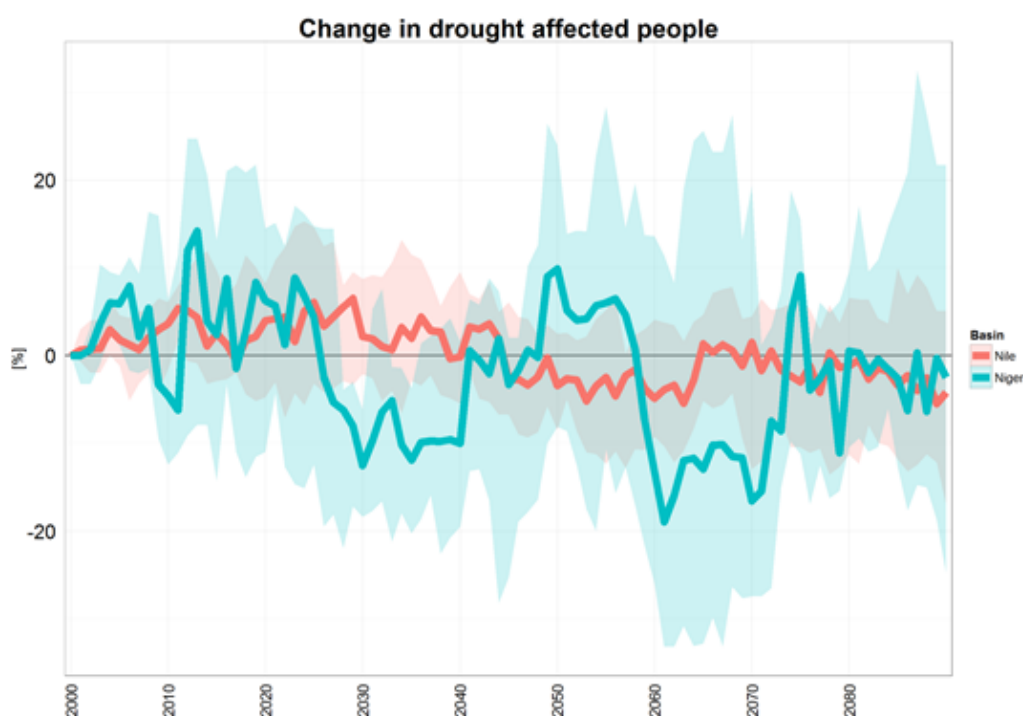
However, a strong finding is that this adaptation needs to take place in an integrated manner, considering disaster risk reduction, poverty eradication and economic growth and development. This can be best advanced by mainstreaming (integrating) climate change into existing development policy and planning,

especially in water and land-use management. Supporting this, stakeholder discussion in these river basins has stressed the need for reliable weather information, seasonal forecast, early warning systems and climate change projections, and the supporting structures and support network to ensure this information can be accessed and understood by governments, civil society and the private sector. These climate services are an early, low-regret adaptation priority.

Finally, a key component of mainstreaming is the need for integrated water resource management (IWRM), to help balance supply and demand (both up- and down-stream) across multiple end-users including for biodiversity and ecosystem services, and to help address water-induced disasters and shocks.

Linked to this, there is the potential for water supply, management and storage infrastructure to help address water variability, as long as this is implemented alongside local climate-smart agriculture and community-based and ecosystem resilience within an IWRM framework.

This issue was explored in the IMPACT2C project with a case study on the impact of climate change on a large dam in East Africa. A key finding was that climate change could have potentially large effects on the performance and safety of this project, given the long life-time (many decades). It is therefore important to include climate change in the design of such projects, rather than relying only on historical climate and hydrological data, to help advance climate-smart development.



**Figure 13.** Change in number of drought affected people under 2°C warming.

**Key messages.** Africa is one of the most vulnerable continents due to its high exposure and low adaptive capacity, and it already suffers major impacts from climate variability and extremes (floods and droughts).

Under 2°C of warming, high flows and flood risks are generally projected to increase for major river basins in the East and West of Africa, though there is uncertainty. For West Africa, agricultural drought events are also projected to become more severe and of longer duration in most locations, increasing the number of drought-affected people.



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## Further information

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