Degrees of Risk

Defining a Risk Management Framework for Climate Security

Nick Mabey, Jay Gulledge, Bernard Finel
and Katherine Silverthorne

February 2011

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Contents

Boxes

Figures

Tables

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Further details about this paper, downloadable resources and news of related activities are available at www.e3g.org.

Executive Summary

> *"What we need is enough mitigation to avoid unmanageable climate change and enough adaptation to manage unavoidable climate change."*
> John Holdren, US Presidential Science Advisor[1]

Climate security threats are not being managed effectively

There is a growing consensus in the security community that climate change presents significant risks to the delivery of national, regional and global security goals. Through sea level rise, shortages of food and water and severe weather events, climate change will have significant impacts on all countries, which in turn could affect their social stability and economic security. In the coming decades such impacts will increase the likelihood of conflict in fragile countries and regions. Peaceful management of even moderate climatic changes will require investment in increased resilience in national and international security and governance systems.

Security analysis has mainly examined the implications of climate change over the coming two decades. These are largely unavoidable under all plausible greenhouse gas emissions reduction scenarios, given the inertia in energy infrastructure and the global climate system. However, if immediate action is not taken to reduce the steady rise in global emissions, there will be a rapid increase in the risk of far more severe impacts, resulting in security challenges that are much more significant than current estimates indicate.

But climate change is not currently well-managed. Agreements at the most recent UN climate negotiations in Cancun in 2010 included a goal of limiting climate change to, at most, a 2°C average global temperature rise. However, the emissions reductions pledged by countries at the same conference would actually result in a 50 percent chance of global temperatures rising by 3-4°C. Fragile areas such as Southern Africa could experience 50 percent more warming than the global rate. If countries failed to deliver on their emissions pledges, or if we have underestimated climate sensitivity, increases of up to 7°C are also possible. But the risks are not symmetrical. There is a 'long tail' on the probability distribution which makes more severe outcomes much more likely than more benign ones. In addition, above 3°C of warming the probability of breaching thresholds for "tipping elements" in the climate system rises sharply. For example, events such as a major die-back of the Amazon rain forest or release of methane from the Arctic tundra would further increase global warming levels.

The implications of current security analysis are clear: unless climate change is limited to levels where its impacts can be managed effectively, and unless successful adaptation

1 Holdren, 2010

programs are implemented, there will be major threats to national and international security.

Current responses to climate change are failing to manage effectively the full range of climate security risks. There is a mismatch between the analysis of the severity of climate security threats and the political, diplomatic, policy and financial effort countries expend to avoid the attendant risks.

The question arises: If the security threat from climate change was analyzed as rigorously as nuclear proliferation, what would an appropriate risk management strategy to deliver climate security look like?

Countries need a comprehensive risk management approach to climate change

Countries are failing to tackle risk effectively because they are not considering the full range of potential scenarios. There are multiple levels of uncertainty involved in addressing and planning for climate change. This includes fundamental questions such as how much average global temperatures will rise, what the impact of more rapid regional climate change will be, and how effective countries will be in agreeing to and implementing adaptation and emissions reduction plans? However, debates on these issues are often over-simplified and uncertainty is often taken as an excuse for inaction.

Uncertainty *per se* cannot be a barrier to action. Uncertainty doesn't mean we know nothing, just that we do not know precisely what the future may hold. Public policy decisions (ranging from military procurement, to interest rates, to financial system regulation) are taken under higher levels of uncertainty than exists over climate change science, impacts or policy choices. In fact the range of uncertainty in climate change is generally smaller than that common in long-term security analysis.

In the face of a serious security threat, and partial information, this report proposes taking some hard won lessons from the security community and adopting a rigorous risk management approach. Absolutes are a rarity in national security and decisions are generally a matter of managing and balancing various forms of risk. Security specialists must balance long-term versus short-term risks. They must make decisions with incomplete information and models that predict divergent outcomes. This approach has underpinned the management of other global security threats, from the Cold War, to nuclear proliferation, to international terrorism.

Risk management endeavors to reduce both the probability of a bad outcome and the potential severity of its consequences. Good risk management requires us to account rigorously for the full range of possible outcomes and understand the deficiencies of our institutional systems in dealing with them. Critically, it requires objective and independent monitoring of the effectiveness of the risk management policies in practice, and updating and revising them as situations change.

Risk management is both an art and a science. It depends on using the best data possible, but also being aware of what we do not know and cannot know. It takes into account the biases in our data and in the way we analyze and use it. It requires complex, and often unquantifiable, trade-offs between different strategies to prevent, reduce and respond to risks. It is both long-term and reactive.

In managing conventional security risks both policy makers and the general public accept that uncertainty is no excuse for inaction. Indeed, it is hard to imagine a politician trying to argue that counter-terrorism measures were unnecessary because the threat of attack was uncertain. But, precisely this argument is often used by opponents of action on climate change to argue against even small measures to mitigate the threat, or build resilience to impacts.

The benefits of a risk management approach

Risk management is a practical process that provides a basis for decision makers to compare different policy choices. It considers the likely human and financial costs and benefits of investing in prevention, adaptation and contingency planning responses. Some risks it is not cost effective to try and reduce, just as there are some potential impacts to which we cannot feasibly adapt to while retaining current levels of development and security.

Risk management approaches do not claim to provide absolute answers but depend on the values, interests and perceptions of specific decision makers. Risk management is as much about who manages a risk as it is about the scientific measurement of a risk itself. The Maldives will have a different risk management strategy to Russia; Indian farmers will see the balance of climate risks differently from the Indian steel industry.

Legitimate differences in risk management strategies will form much of the on-going substance of climate change politics. All societies continually run public debates on similar existential issues: the balance of nuclear deterrence vs. disarmament, civil liberties vs. anti-terrorism legislation, international intervention vs. isolationism. Decisions are constantly made even when significant differences remain over the right balance of action. Political leadership has always been a pre-requisite in the pursuit of national security. We should expect the politics of climate change to follow similar patterns.

Implementing an explicit risk management approach is not a panacea that can eliminate the politics of climate change, either within or between countries. However, it does provide a way to frame these debates around a careful consideration of all the available information, and in a way that helps create greater understanding between different actors.

It has often taken a decade or more of intense debate for robust risk management strategies to emerge to tackle existing national security issues. We do not have the luxury of such time in the case of climate change. Every day we fail to act, the risk becomes incrementally and irreversibly higher. Like the hands of a clock, the risks of climate change can only move forward. The only way to decide what level of risk we want to take, and hence the point at which we need to stop the clock, is to have a frank debate on the full consequences of action and inaction.

A Three-Tier "ABC" Framework

A responsible risk management strategy will aim to reliably achieve a specific objective to limit the overall level of global climate change. It must also include effective adaptation policies and contingency plans which are capable of responding to the full range of possible higher risk scenarios which could result from a failure of mitigation plans and/or the eventuality that climate sensitivity turns out to be at the upper end of current estimates. A prudent risk-management approach should be built on the following three-tier framework:

- Aim to stay below 2°C (3.6°F) of warming
- Build and budget assuming 3-4°C (5.4-7.2°F) of warming
- Contingency plan for 5-7°C (9-12.6°F) of warming

The temperature goals in this framework are not presented as some form of 'optimal' target. Rather they reflect where the majority view of the global political and scientific actors appears to be at this time. Some would argue for tighter mitigation targets and lower adaptation thresholds; others for looser mitigation targets and more emphasis on contingency planning. As countries begin to construct and budget for real national plans and budgets associated with adaptation to various warming trajectories, consensus may emerge to aim at lower emissions trajectories. The UN climate change treaty will review, and potentially revise, its current goal of limiting climate change to below 2°C by 2015.

Ten Recommendations for Launching a Risk Management Approach

Each country will need to develop its own risk management approach, based on the framework above and detailed analysis of national vulnerabilities and interests. However, there are some common areas that are essential to building an overall strategy. *Degrees of Risk* advocates ten key steps toward a comprehensive risk management approach to climate change.

Aim to stay below 2°C	Sufficient mitigation goals
	Increased investment in transformational RD&D
	Resilient and flexible global climate regime
	Independent progress and risk assessment
Build and budget for 3-4°C	Adaptation strategies include 'perfect storms' and interdependent impacts
	Improved cooperation on preventive and humanitarian intervention
	Increased resilience of international resource management frameworks
	Provision of data and tools that decision makers need
Contingency plan for 5-7°C	Contingency 'crash mitigation' planning
	Systematic monitoring of tipping points

Aim to stay below 2°C

1) Sufficient mitigation goals

The most certain way to mitigate security risks associated with climate change is to limit the severity of impacts by lowering the amount of warming. Aggressive mitigation towards lower greenhouse gas concentration targets reduces the probability of extreme outcomes rapidly, and so is a particularly effective hedging strategy against the highest risk scenarios.

The negotiations between Heads of Government at Copenhagen in 2009 suggested that many major countries do not yet have clear and settled view on the global mitigation goal they believe needs to be achieved; despite their agreement on paper to a 2°C goal. There is also little evidence that countries have analyzed the impact of different mitigation scenarios on their core national interests. However, only explicit and detailed national goals can lay the foundation for effective global action to mitigate climate change. Countries must explicitly identify the level of climate risk they consider acceptable, based on assessment of national and international impacts and the risk of extreme scenarios, and act accordingly.

2) Increase investment in transformational technology R&D

Limiting average global temperature increases to below 2°C will require rapidly accelerated innovation and diffusion of clean energy technologies in both developed and developing countries. In addition, higher levels of cooperative investment in RD&D in low carbon energy technologies and solutions would hedge against the risks of under-delivery in key mitigation areas such as energy efficiency and preventing deforestation.

Current national and international innovation programs are not sufficient to effectively manage the risk of policy failure or higher ranges of climate sensitivity. Public sector energy research, development and demonstration (RD&D) in major economies has fallen by up to half over the last 25 years. Nations should look to increase their clean energy RD&D spending by five times by 2020. In addition, they should designate a share – at least 10-20 percent – of increased RD&D spending to cooperative activity with developing countries and develop a range of international cooperation mechanisms to accelerate the development and diffusion of mitigation and adaptation technologies.

3) Resilient and flexible global climate regime

As in arms control, the principle of "trust and verify" is a good foundation for control of greenhouse gas emissions. But if it is not possible to determine whether a nation knowingly missed a target or made a good-faith effort but failed, there is a high potential for misunderstanding and mistrust.

The emerging global climate regime must include the creation of strong rules for reporting, and should promote a high level of transparency. This allows for early identification of problems, and helps outsiders distinguish between intentional freeloading and honest imperfections.

A global climate regime must also provide contingency options that will allow the system to make up for missed reductions.

Reducing global greenhouse gas emissions to safe levels is a marathon, not a sprint. Countries must establish resilient and flexible regimes at national and international levels to avoid failures in the future.

4) Independent national climate security risk assessment

Each country must commission an independent assessment of its progress towards defined goals by an institution outside the usual policymaking chain. A failure to separate policy development and assessment risks biasing the results to justify the initial policy assumptions. Such separation is widely used in other areas of security policy, such as weapons proliferation assessments.

All countries should commit to explicit independent assessments of the effectiveness of national and international polices in achieving strategic climate security outcomes, and critical climate security risks to a country's interests. In addition, explicit processes need to be in place to ensure that objective assessment of threats actually reach senior policymakers and the public. The United Kingdom's independent Committee on Climate Change is one example of a new institution performing part of this role.

Build and budget for 3-4°C

5) Adaptation strategies for "perfect storms" and interdependent impacts

Some impacts of climate change are unavoidable, due to warming *already in the system* from current atmospheric greenhouse gas concentrations. Comprehensive planning for adaptation to expected changes is needed.

A risk management approach to adaptation should include:

- Clear identification of the planning scenarios being used (for example, 2, 3, 4°C or higher)

- Significant investment in measures to increase community and ecosystem resilience to coming changes, and

- Proactive design of adaptation measures to reduce potential for conflict over increasingly scarce resources.

Adaptation planning must not be merely a technical exercise. It must take into account the broader political, economic and social impacts of both climate change and adaptation measures in order to avoid exacerbating rather than reducing the costs of climate change.

When considering adaptation strategies in countries with weak governance structures it is essential to remember that poorly designed adaptation can increase potential for conflict. Adaptation measures can play into local power structures as access to resources can be used to wield power over community members or neighbors, and resource access points, such as wells, can become targets in conflict.

6) Improved cooperation on preventive and humanitarian intervention

The effects of climate change will require larger and more frequent humanitarian and preventive missions by the international community and regional organizations. These will require better coordination, higher levels of civilian capability, and greater investment in preventive approaches to natural disasters.

For example, groups of countries should develop joint regional scenarios based on warming of 3-4°C and use these to drive the development of shared contingency plans and enhanced response capability.

7) Increased resilience of international resource management frameworks

In many cases, society has successfully used legal agreements to reduce conflict over vital resources. Looking ahead, peaceful resolution of resource tensions created by climate change will necessitate updating international management efforts in order to preserve a rule-based global order. These changes could include reforming resource-sharing mechanisms, enhancing international arbitration, and improving scientific cooperation.

The time to strengthen international mechanisms to reduce resource conflict is now, when the impacts of climate change are still at relatively low levels. Failure to actively improve resource management regimes may make them ineffective reconcilers in the future, giving rise to intensification of conflicts and fostering power-based approaches. It may also create climate-related backlash where countries resort to unilateral actions such as retaliatory trade actions, escalating tensions at the international level. This will require action to reform a wide range of international, regional and bilateral agreements.

8) Providing the data and tools that decision-makers need

Specific information gaps – particularly in the likely response of social and economic systems to climate change – are a significant source of uncertainty in managing strategic security risks, including climate risk. As with other security challenges, straightforward investment in identifying and addressing gaps in our knowledge base will help to narrow the range of scenarios that must be addressed in order to adequately manage risk. More focused risk management requires projections that provide actionable information on relevant social and landscape scales.

The IPCC (Intergovernmental Panel on Climate Change) process and other climate-related data collection, analysis and out-year projections rely heavily on academic funding mechanisms and typically adopt conventions and modes of description tailored to the academic community. So it is not surprising that climate data and analyses based on such data are often expressed in ways that, while well suited to academic publications, are not focused on providing informational and analytical support to policymakers and the complex and difficult decisions they face. Decision makers must make clear the data they need for decision support, and researchers and relevant experts need to focus on responding to those needs.

Solutions include:

- Reinterpreting existing data to reflect the time and geographic scales security analysts, planners, and policymakers need.

- Developing new data that incorporates specific characteristics of vulnerable communities and helps determine fragility or resilience in the face of anticipated impacts.

- Providing detailed bottom up monitoring of data identified as relevant to environment, resource and conflict interactions in vulnerable areas and countries.

- Creating well-designed and adequately resourced feedback loops to effectively incorporate new data and advancements in scientific understanding and support continual refinement and validation of analyses, impact projections, and effective response mechanisms.

Additional information is necessary but not sufficient. Analysts need new tools to use this information to provide compelling investment cases for priority preventive actions – especially given current financial constraints.

Contingency plan for 5-7°C

9) Contingency "crash mitigation" planning

A growing body of evidence suggests that vulnerability to catastrophic climate impacts might be higher than expected. As it is not possible to adapt to some of the worst-case scenarios, it is vital to maintain a capability to implement a crash mitigation program should they occur. Examples might include geo-engineering of mechanisms to either absorb carbon dioxide or reflect heat away from Earth's surface, rapid diffusion of nuclear technology, and rapid deployment of clean energy technologies. However nations choose to implement a crash program, one thing is clear, a crash approach, which necessitates precipitous changes in emissions and infrastructure, will be much more economically disruptive than a proactive approach which can be phased in over a longer time horizon.

Some crash mitigation approaches could create additional security problems in their own right, for example leading to nuclear proliferation or low-oxygen 'dead zones' that undermine fisheries. And for any of these strategies, an approach driven solely by one nation's desires to protect itself could create a more challenging security environment for others in the region.

Countries should agree to a management framework for potential contingency programs now, or risk serious side effects of panicked responses to extreme climatic events in the future.

10) Systematic monitoring of climate tipping points

Many assume that climate change will be a slow, linear process toward a moderately warmer future. But scientists agree there are likely to be elements of the climate system that function like light switches – rapidly changing to a qualitatively different state. Scientists believe such 'tipping elements' include the dieback of the Amazon and Northern Hemisphere boreal forests, for the West African and Indian monsoon systems, and for melting of Arctic sea ice and the Greenland ice sheet. Any one of these changes would have dire and widespread consequences, but at present there is little systematic monitoring of such critical elements of the climate system.

There is an urgent need for a comprehensive, long-lived monitoring system that integrates Earth and socioeconomic observations and prioritizes issues of highest potential threat. The current IPCC system relies heavily on existing academic funding systems, which probably cannot provide the support or coordination necessary for such a comprehensive approach.

1 A Clear and Present Danger
How Climate Change Impacts Security

By tackling climate change we can help address the underlying [in]securities that feed and exacerbate conflicts and instability. By ignoring it we resign ourselves to the same crises flaring up again and again. And new ones emerging. So climate change is not an alternative security agenda. It is a broadening and deepening of our understanding as to how we best tackle that existing agenda.
Rt. Hon. Margaret Beckett, United Kingdom Foreign Secretary, 2007[2]

Summary

- Climate change is seen as a significant threat to national security in a growing number of countries. Analyses of climate security risks have been published by the United States, NATO, the European Union, United Kingdom, Germany and Australia. The UN Security Council debate on climate change and security in 2007 saw a wide range of countries outline their views on the security risks posed by climate change, and this concern was confirmed by the UN General Assembly resolution in 2009.

- Military planners in many countries are now exploring the likely impacts of climate change on operations, including:[3]

    - Difficulties in maintaining military capability in extreme environmental conditions.

    - Loss of strategic defense assets owing to sea level rise and extreme weather events.

    - Greater calls for peacetime deployments to provide disaster relief and humanitarian assistance.

    - Instability in strategically important regions, such as Afghanistan, the Nile Basin, Horn of Africa, Peru and the Persian Gulf.

- Security analysis suggests that climate change will impact on a range of issues, from state instability and border conflicts to energy and food security. Peaceful management of even moderate climatic changes will require investment in increased resilience in national and international governance and security systems.

2 Beckett, 2006
3 Abbott, 2008

- Security actors are beginning to respond to some of these threats. Climate change is beginning to shape policy responses to resilience, instability and conflict in areas as diverse as Peru, Afghanistan, the Nile Basin and the Bay of Bengal.

- To date security analysis has generally been focused on understanding the impacts of climate change on economic, political, stability and defense interests. However, given the security consequences of failing to limit global emissions the security community has a strong and legitimate interest in promoting an effective and sustainable global climate change regime that avoids the worst impacts of climate change. Such an approach should be based on best practice approaches to security risk management.

Understanding Climate Security

Regional and global security is inextricably linked to climate change. Climate change will bring about a significantly different strategic security environment, a fact that few countries have yet absorbed and none are fully prepared for. However, there is growing momentum within the security community to tackle the threat of climate change. The reality of climate change will require fundamental readjustments in how international relations are conducted, and will alter much of the focus of international security policy. It will change strategic interests, alliances, borders, threats, economic relationships, comparative advantages and the nature of international cooperation, and will help determine the continued legitimacy of the United Nations in the eyes of much of the world.[4]

Competition for resources has always been a feature of human societies. However, in the coming decades, global populations will endure rising resource scarcity and increasingly disruptive impacts of climate change at levels never before experienced in human history (see Box 1). As then UN Secretary General Kofi Annan told the Security Council in 2007:

> *Environmental degradation has the potential to destabilize already conflict-prone regions, especially when compounded by inequitable access or politicization of access to scarce resources.*[5]

Unless strong action is taken to slow global warming, developed and developing countries alike will experience resource scarcity, rising sea levels, extreme weather events and new health epidemics. This will put significant stress on all countries and may push fragile states over the edge. It will lead to new levels of competition around scarce resources that may result in intra- or interstate conflict. It will also result in mass migration as populations flee land inundated by rising seas and locales that can no longer provide essential resources. This is likely to create serious tensions particularly where there are large, poor populations with high

4 Mabey, 2008
5 Annan, 2007

climate vulnerability adjacent to rich countries; for example, Mexico and the United States, North Africa and Southern Europe, and Southeast Asia and Australia.[6]

Current security assessments are mostly based on mid-range scenarios developed by the Intergovernmental Panel on Climate Change (IPCC). While useful when considering impacts over the next two decades, they do not cover the full range of future climate change risks and do not reflect the most recent research. Because of this, they are not a sound basis for security planning. Failing to consider the full range of probable scenarios is as dangerous for climate change as it is for terrorist attacks.

It is highly unlikely that the current, relatively benign, global security environment – with largely open trade, travel, investment and declining conflict and poverty levels – could be maintained under the pressures of high levels of climate change, whatever security interventions are undertaken. Such levels of climate change would have serious hard security consequences, even for the most powerful countries. Recent analyses show that the security community has a strong and legitimate interest in promoting an effective and sustainable global regime that avoids the worst risks of climate change.

BOX 1: Broad range of security impacts identified in recent analyses

- A 2009 study by United Nations Environment Program (UNEP) concludes that 40 percent of intrastate conflicts over a 60 year period were associated with land and natural resources, and that this link doubles the risk of conflict relapse.[7]

- The World Bank estimates that by 2025 climate change will result in 1.4 billion people across 36 countries facing crop or water scarcities (600 million people in 21 countries are currently impacted by resource scarcities).[8]

- By 2050, 200 million people may be permanently displaced climate migrants, a ten-fold increase over the current total documented refugee and internally displaced populations.[9]

- Regional differences in agricultural production are likely to become more pronounced in developing countries in Sub-Saharan Africa by 2025.[10] The effects of climate change in North Africa are likely to worsen existing water and food

6 Rogers, 2000
7 United Nations Environment Program, 2009
8 National Intelligence Council, 2008
9 Myers, 2002
10 National Intelligence Council, 2008, op. cit.

scarcities, unstable economies, deteriorating urban infrastructure and sociopolitical systems, leading to increased economic migration pressures.

- The impacts of Himalayan melting will be felt across a number of countries, including India, Pakistan, Afghanistan, Burma/Myanmar, Bangladesh, Nepal, Bhutan and China. This could create a geopolitical domino effect that would aggravate the already fragile political, social and economic system. For example, water disputes could arise between India, Bangladesh and Pakistan.[11]

- Increasing sea levels and recurring floods or droughts could lead to a large scale displacement of populations from small island states like the Maldives and Tuvalu and flood prone nations like Bangladesh.

National and International Responses

One of the first climate security initiatives to have a major impact within the security community was a scenario planning paper commissioned by the Pentagon's Office of Net Assessment in 2003. The report, *An Abrupt Climate Change Scenario and its Implications for United States National Security*, identified climate change as a threat that vastly eclipses that of terrorism, and argued that abrupt climate change must be considered a national security issue.[12] However, despite early analysis carried out in the United States and United Kingdom (the UK Cabinet Office and US Ministry of Defense have included climate change in strategic security analysis since 2005[13]), recognition of these links was mainly confined to specialized security analyst circles. The connections between climate change and national and international security – referred to as 'climate security' in this report – really came to the global political foreground in 2007, when the United Kingdom initiated a debate on climate change and national security in the UN Security Council. Although controversial with some countries at the time, this was one of the most widely attended Security Council debates ever held, matching the debate on HIV/AIDS in 2000. The Security Council debate was followed two years later by a UN General Assembly resolution confirming the importance of climate security and urging UN bodies to address the issue. The intervening years saw increasing exploration of climate change by security bodies around the globe.

Such concerns were brought to the attention of a broader United States policy community and the wider public in 2007 by a report from CNA Corporation, *National Security and the Threat of Climate Change*.[14] Published by an advisory board of retired generals and admirals, this report identified climate change as a 'threat multiplier' for existing security risks and

11 IES Military Advisory Council, 2009

12 Schwartz & Randall, 2003

13 UK Cabinet Office, 2005; UK Development, Concepts and Doctrine Centre, 2006

14 The CNA Corporation, 2007

dismissed the notion that remaining uncertainties about climate science should stand in the way of responses. This issue is now well accepted in the United States security community and included in many of the foundational documents that set out United States security doctrine (see Box 2).

BOX 2: Climate change and United States security doctrine

Climate change was further integrated into United States security doctrine in several significant ways during 2010:

- The **Quadrennial Defense Review** notes that climate change may act as an accelerant of instability and conflict and will shape the operating environment, roles and missions that the Department of Defense will undertake.[15]
- The **Annual Threat Assessment** given by the Director of National Intelligence to Congress stated that the intelligence community judges that global climate change will have extensive implications for United States security interests over the next 20 years. Climate change could threaten domestic stability in some states, potentially contributing to intra- or, less likely, interstate conflict, particularly over access to increasingly scarce water resources.[16]
- The **National Security Strategy** refers to climate change as a key global challenge that will lead to conflicts over refugees and resources, suffering from drought and famine, catastrophic natural disasters, and the degradation of land across the globe.[17]
- The **Joint Operating Environment** identified climate change as one of the ten trends most likely to impact the Joint Forces Command.[18]

On the other side of the Atlantic, the European Council has, since 2007, recognized the need to address climate change in order to preserve international security. In spring 2008, the High Representative and the European Commission jointly presented a report to the European Council that concluded:

15 US Department of Defense, 2010
16 Blair, 2010
17 The White House, 2010
18 United States Joint Forces Command, 2010

> *"Unmitigated climate change beyond 2°C will lead to unprecedented security scenarios as it is likely to trigger a number of tipping points that would lead to further accelerated, irreversible and largely unpredictable climate changes. Investment in mitigation to avoid such scenarios, as well as ways to adapt to the unavoidable should go hand in hand with addressing the international security threats created by climate change; both should be viewed as part of preventive security policy."*[19]

NATO has been exploring how climate change will impact its operations. In 2010, NATO parliamentarians issued a press release expressing their support for the notion that climate change must occupy an important place on the Alliance's agenda and be included in the new NATO Strategic Concept.[20] NATO's Secretary General, Anders Fogg Rasmussen, has stated that he feels NATO should have three roles related to climate change: first, it should function as a clearing house for the security-related challenges of climate change; secondly, it should adapt to the security implications of climate change by seeking to reduce the carbon footprint of its forces and finally, it should act as a first responder to address the consequences of climate change directly.[21] Similar analysis has been carried out by security authorities in Sweden, Germany and Australia.[22] There are also an increasing number of think tanks and academic analysts entering this field.[23]

In most countries, the military is the only institution equipped to respond to severe natural disasters and the conflicts that will result if climate change is not slowed. Military planners in many countries are also becoming more aware of the likely impacts of climate change on operations, including:[24]

- Difficulties maintaining military capability in extreme environmental conditions.
- Loss of strategic defense assets due to sea level rise and extreme weather events.
- Greater calls for peacetime deployments to provide disaster relief and humanitarian assistance.
- Instability in strategically important regions, such as Afghanistan, the Nile Basin, Horn of Africa, Peru and the Persian Gulf.

However, **effectively tackling the security challenges posed by climate change will require**

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19 Council of the European Union, 2008
20 NATO Parliamentary Assembly, 2010
21 Rasmussen, 2009
22 See SIDA 2008; WGBU 2008; Lowy Institute 2006
23 For a recent academic review see www.climsec.prio.no/
24 Abbott, op. cit.

more than military operations alone. Coordinated strategies developed by both civilian and military institutions are essential to provide sustainable risk reduction. In this way, climate change has the potential to drive more collaborative approaches among state actors or it could exacerbate tensions between and within countries. A current positive example is the extensive international diplomacy underway to manage tensions over borders, resource access and sea lanes in the Arctic as the sea ice retreats, despite the large economic, sovereignty and security interests at stake.[25] Whether climate change leads to greater stability or a politics of insecurity depends on how effectively it is incorporated into mainstream foreign policy and how completely it is addressed as part of a wide range of security and geopolitical issues.

Facing the Climate Security Threat

The security analysis is clear. Unless climate change is limited to levels where its impacts can be managed effectively, and unless successful adaptation programs are implemented, there will be major threats to national and international security.

This report proposes developing a richer decision-making framework, based on explicit risk management, that allows military and civilian decision makers to take a comprehensive approach to managing the climate security risks. Other than the short summary provided above, this report does not focus on identifying and assessing the security implications of climate change, as this has been done extensively elsewhere.[26] Instead, it explores what is known (and not known) about how climate change will progress and discusses lessons from – and parallels with – examples in the security field that can help provide guidance in addressing decision-making in the face of uncertainty.

The report follows a generic security analysis and risk management approach to 'deconstruct' each aspect of the climate change problem and then draws this analysis together into a set of recommendations for how to implement a risk management response:

Exploring the Threat

- Chapter 2 explores what we know and don't know about the climate change threat. What is the range of risks we face? What are the biases in current risk assessments? What surprises may be around the corner? Will impacts be irreversible? How well can we monitor the emergence of serious threats? More details of the science underpinning these issues are given in Annex 1.

- Chapter 3 examines the biases and misperceptions that occur in analyzing complex uncertain threats such as climate change, based on experience from intelligence and security analysis techniques.

25 Berkman, 2010

26 IES Military Advisory Council, op. cit.

Effectiveness of Existing Responses

- Chapter 4 analyzes how effectively we are currently managing climate risks. What areas of risk are being effectively managed? Where are the big gaps in our actions? What is our *de facto* risk management strategy? What alternative or additional risk management strategies should we employ?

Building a Risk Management Approach

- Chapters 5 and 6 outline the framework for risk management of climate change. What are the critical elements of a risk management approach? What can we learn from the way security policy deals with uncertain but existential threats? How should we incorporate climate science into a risk management approach? Where are critical gaps in the information basis for effective risk management?

- Chapter 7 synthesizes the results of the previous sections to lay out ten priority recommendations for operationalizing a risk management approach to climate security.

This paper does not aim to provide a definitive risk management solution for climate security, but rather to lay out a framework for thinking through what our response should be and propose some of the first critical steps needed to deliver it. The analysis presented below raises many fundamental questions and points to gaps in areas of analysis which we have been unable to tackle given the time and space available. We look forward to continuing to develop and refine this work in collaboration with other researchers, analysts and decision makers in this field.

2 Knowns and Unknowns
Understanding the Climate Change Threat

If the government's leaders understood the gravity of the threat they faced and understood at the same time that their policies to eliminate it were not likely to succeed any time soon, then history's judgment will be harsh. Did they understand the gravity of the threat?
The 9/11 Commission Report, National Commission on Terrorist Attacks upon the United States (also known as '9-11 Commission')[27]

Summary

- The global surface temperature has increased on average by about 0.8°C since the early 20th century. Additionally, ocean heat content has increased, global average sea level has risen, and snow and ice cover have decreased. A wide variety of physical and biological systems have reacted to these climatic changes.

- Multiple lines of scientific analysis demonstrate that the observed global climate warming of recent decades can only be explained by human emissions of greenhouse gases. Though present, natural drivers are too weak or are trending in the wrong direction to explain the observed climatic changes.

- Estimates for projected average global temperature rise in 2100 range from 1.7°C to 7.2°C relative to preindustrial temperatures. Over half this range comes from scientific uncertainty over climate system behavior. But risks are not symmetrical. There is a 'long tail' on the probability distribution which makes severe outcomes much more likely than benign ones. Recent observations show that climate models have been underestimating the rate of important climatic changes - for example the rate of Arctic sea ice melt – suggesting that climate models may be systematically underestimating the rate at which large-scale changes in the climate system will proceed in the future.

- There are several mechanisms that could amplify the scale, pace and impacts of climate change that are incompletely incorporated in, or absent from, models that project future climate change. Moreover, elements of the climate system have changed abruptly and on a large scale in the recent geological past. Available evidence suggests the probability of pushing the climate beyond specific "tipping points" at which abrupt changes are likely occur rises sharply above 3°C warming. Currently there are only patchy monitoring systems in place to provide early warning of whether critical limits are being reached.

27 The National Commission on Terrorist Attacks on the United States, 2004

- Focusing on changes in global average temperatures gives a misleading impression of possible impacts of climate change. Both the level of change and vulnerability to change will vary across regions and latitudes. Higher latitudes will experience far higher temperature changes than the average; tropical areas may experience lower temperature changes but have more climate-vulnerable ecosystems and societies and may be subject to abrupt shifts in precipitation regimes if monsoons fail or intensify.

- The 'worst case scenarios' are not necessarily low probability events, even though analysts tend to assume that they are. Some major tipping points may be inevitable if current momentum economic behavior persists.

The Scientific Basis for Risk Management

Understanding any security threat begins with gathering analysis – or intelligence – on its origins, importance and likelihood. Intelligence is necessarily imperfect – we can never know everything about what threatens us; especially when it depends on future actions and circumstances. The critical issue is the pattern and structure of the evidence; whether it leads us to strong conclusions as to the origin of the threat, or whether alternative hypotheses can possibly explain observed behavior. How has evidence changed over time; what has learning taught us? Is there strong evidence that it will have severe security impacts and are these likely to occur in the absence of positive action to reduce risks?

This chapter briefly examines the evidence around each of these critical areas covering:

- the observed evidence that the climate is changing and that this is attributable to human emissions of greenhouse gases rather than natural variation or other causes;

- the range and causes of uncertainty in projections of future climate change;

- the likely impacts of future climate change and evidence on the potential for highly disruptive changes from uncontrolled emissions.

The conclusion of these sections is that there is strong scientific evidence that climate is likely to change dramatically over the next century compared to any of the changes that modern human society has ever experienced. This evidence is far more reliable than that usually used to underpin long term security capability planning and procurement; for example, the common task of attempting to estimate the level of political threat and military capability in a potential adversary in 2040.

The Climate is Changing and Impacts Have Begun

An overview of observed climate trends and their attribution to human-induced warming is provided in Annex 1 to this report, which also includes an updated review of the key projected patterns of climate change to 2100.

Compelling evidence that global warming is underway led the AR4 to conclude:

> *"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level."*[28]

Moreover, evidence strongly indicates that many biological and physicals systems have already begun to respond to the warming trend:

> *"A global assessment of data since 1970 has shown it is likely that anthropogenic warming has had a discernible influence on many physical and biological systems."*[29]

Attributing Climate Change to Human Activities

The amount of forcing that humanity is exerting on the climate system is greater than has been applied through either natural or anthropogenic forces since humans began building cities and complex societies five to six thousand years ago.

Only a few environmental factors (forcings) could possibly drive a persistent warming of the global climate. Some of these are natural, such as changes in solar radiation or volcanic activity. Other possible climate forcings arise from human activities, including changes in the heat-absorbing characteristics of the land surface (for example, converting forest to cropland or natural land surface to roads and buildings) and the release of greenhouse gases from deforestation and the burning of fossil fuels. Human activities also inject a variety of particle types into the atmosphere that either block sunlight, causing cooling, or absorb it, causing warming.[30] Discovering which of these factors, or combination of them, is primarily responsible for the strong warming trend of the past century has been the focus of intensive research over the past two decades. **Two independent lines of evidence inspire confidence that the warming of recent decades results primarily from the release of greenhouse gases, chiefly carbon dioxide (CO_2), by human activities.**

First, the observed, simultaneous warming of the lower atmosphere (troposphere) and cooling of the upper layers of the atmosphere (stratosphere and higher) in recent decades is a unique 'fingerprint' of enhanced greenhouse warming.[31] For example, warming from an increase in

28 IPCC, 2007 (Synthesis Report, Summary for Policymakers)

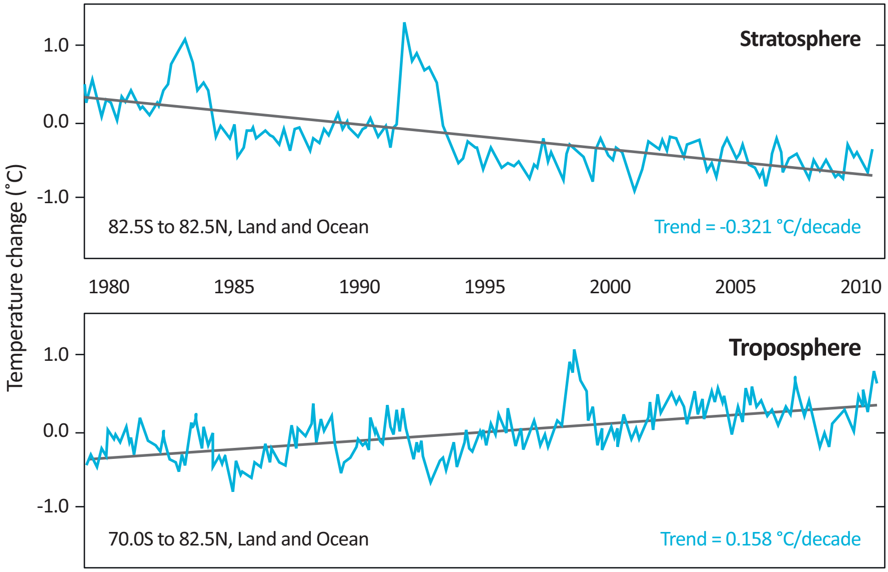
29 Ibid.

30 IPCC, 2007

31 Laštovi ka et al., 2006; Santer et al., 2004

solar intensity would warm all layers of the atmosphere simultaneously. In contrast, CO_2 functions as a positive forcing (warming) in the troposphere but a negative forcing (cooling) in the stratosphere and higher layers. Indeed, over the past 30 years, satellite observations show that the troposphere has been warming while the stratosphere has been cooling simultaneously (see Figure 2.1).

Figure 2.1: Satellite-observed changes in upper and lower atmospheric temperatures from 1979 to 2010.



Trends in upper (stratosphere) and lower (troposphere) atmosphere temperatures over the past three decades. Concurrent cooling in the stratosphere and warming in the troposphere is a signature of the enhanced greenhouse effect, as opposed to solar warming or volcanic activity, both of which would present a different vertical pattern in the atmosphere. ***Source:*** *Remote Sensing Systems, 2009; updated from Mears et al., 2003. Data accessed May 2010.*

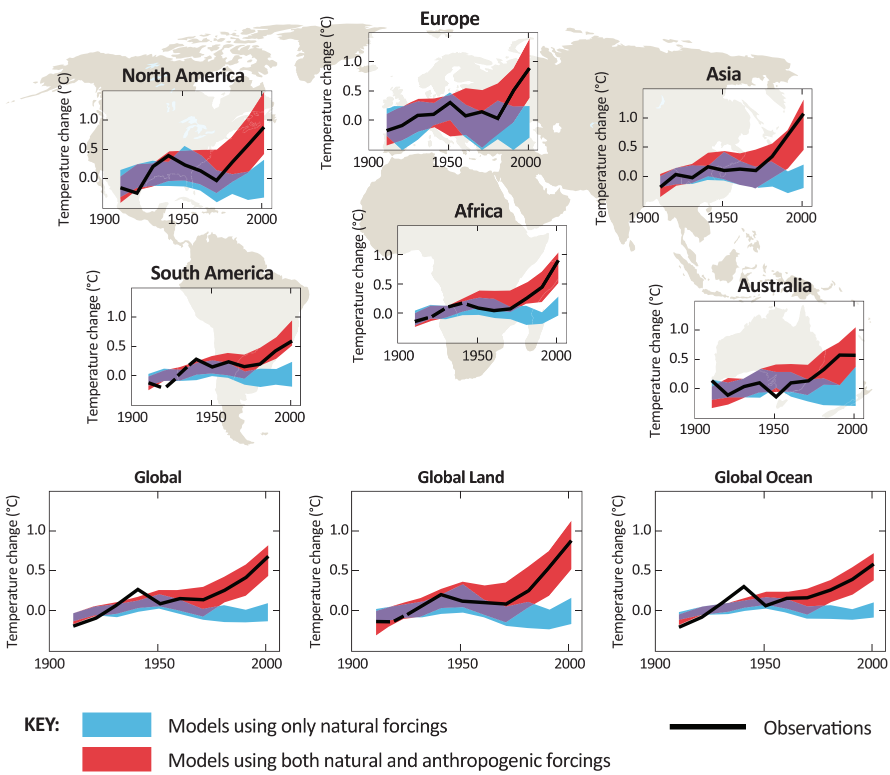
A more detailed, state-of-the-art attribution of various climate trends is possible using *optimal fingerprinting* approaches that match individual forcings (for example, greenhouse gases, solar intensity or airborne particles) to observed climate change patterns using global climate models.[32] This technique has detected human-induced trends in a wide variety of climate variables including land surface warming, vertical warming of the oceans, loss of Arctic sea ice cover, and differential changes in precipitation at different latitudes.

Observations of global land and ocean surface warming and warming of all continents except

32 Pew Center on Global Climate Change, 2008

Antarctica **show that although several forcings are probably involved in producing the detailed pattern of global warming of the past century, no combination of forcings that excludes manmade greenhouse gases can explain the warming trend of the past half-century (Figure A7).** The IPCC concluded with high confidence that that observed temperature rises since the mid-20th century are very likely (>90% chance) due to the human-induced increase in atmospheric greenhouse gas concentrations.[33]

Figure 2.2: Attribution of land, ocean, and global warming to human activities.



Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings. Observed climate change is shown by the black line. The line is dashed where spatial coverage is less than 50 percent. Blue shaded bands show the 5 to 95 percent uncertainty range for nineteen simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5 to 95 percent range for fifty-eight simulations from fourteen climate models using both natural and anthropogenic forcings. ***Source:*** *IPCC, 2007.*

33 IPCC, op. cit.

Scientific Uncertainty

Making decisions about climate change requires a sense of what the future holds under different climate change scenarios. For this purpose, global climate models are used to produce projections of climate variables based on a range of assumed future greenhouse gas emissions scenarios. These models are validated on the basis of their ability to mimic past climate variability and change.[34]

The ability of climate models to reproduce observed 20th century climate has improved steadily over the past few decades. The recent generation of models used by the IPCC in The Fourth Assessment Report (AR4) mimics the magnitude and gross spatial distribution of observed temperature change reasonably well on continental to global scales. However, their performance is not as good for precipitation and degrades for most climate variables as spatial scales become smaller. Large-scale temperature extremes (for example, heat waves) are simulated reasonably well, but light precipitation is overestimated while heavy precipitation is underestimated.[35] Current model projections may also systematically underestimate how quickly other components of the climate system (for example, sea level rise or retreat of glaciers and Arctic sea ice) respond to the warming that has occurred so far.[36]

There are several sources of uncertainty in model projections: future human-induced forcing, natural climate variability, climate response uncertainty, climate sensitivity, and structural uncertainty. These are explored in the following pages.

Future human-induced forcing

When projecting warming, scientists consider various types of forcing (that is, processes that change the relative balance between incoming solar radiation and outgoing infrared radiation resulting in temperature changes).[37] The future emissions of greenhouse gases, sun-shading particles, and soot, as well as future land-surface change by humans, are unknown, as they depend largely on political decisions and socioeconomic behaviors. Analysts have developed socioeconomic scenarios based on plausible alternative futures, but these are essentially elaborate guesses at future societal behavior and it is not possible to ascribe probability to any scenario.[38]

To account for this uncertainty, climate models are driven by a wide range of plausible greenhouse gas emissions scenarios. This accounts for a significant portion of the spread in climate projections. For example, the AR4 employed six marker emissions scenarios that result in a wide range of future emissions. The difference in the projected mean warming from 1990

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34 Randall, et al. 2007

35 Ibid.

36 Rahmstorf et al., 2007a; Gulledge, 2008a

37 US Environmental Protection Agency, 2009

38 Naki enovi & Swart, 2000

to 2100 between the lowest and highest marker scenarios was about 2.5°C.[39] This source of uncertainty is neither natural nor scientific. **In theory, this major source of uncertainty is under the control of decision makers and could be eliminated through policy choices about future emissions and land use.**

Natural variability

Future natural climate variability and change are highly uncertain. External forcings from volcanic eruptions and changes in solar intensity are unpredictable (except for the 11-year solar cycle). Major volcanic eruptions would induce temporary cooling, as did the eruption of Mount Pinatubo in the Philippines in 1991.[40] Change in solar intensity could warm or cool the climate.

Patterns of *internal variability*, such as the El Niño-La Niña cycle in the equatorial Pacific Ocean, are captured in individual models, but their behavior varies from model to model.[41] There is little agreement as to whether and how these patterns will change in the future in response to global warming. For example, the equatorial Pacific becomes more El Niño-like in some models but not in others.[42] How global warming will affect such internal variability remains an important research question.[43]

The best available evidence indicates that the global surface temperature has varied by less than ±1°C over the past 10,000 years.[44] This information suggests that natural variability is unlikely to alter the global climate by an amount comparable to the warming that is projected by the end of this century if human-induced greenhouse gas emissions continue unabated.[45]

Climate response uncertainty

The limited knowledge of how the climate system will react to a given amount of greenhouse gas added to the atmosphere results in disagreement among models, known as the *climate response uncertainty*.[46] The reasons for climate response uncertainty are multiple and not fully understood, as the models are individually very complex and differ from each other in various ways.

39 Meehl et al., 2007

40 Forster et al., 2007

41 El Niño is unusually warm sea surface temperature in the equatorial Pacific Ocean; La Niña is unusually cool temperatures in the equatorial Pacific. They are statistically linked to abnormal patterns of temperature and precipitation around the world.

42 Meehl et al., op. cit.

43 Trenberth et al., 2007

44 Jansen et al., 2007

45 Meehl et al., op. cit.

46 Ibid.

The AR4 employed approximately twenty different global climate models in its projections of future climate. For a given emissions scenario, the inter-model spread among projections is large. For example, the uncertainty range for projected global warming from 1990 to 2100 for any given emissions scenario is on the order of 2°C; the range is narrower for the lowest marker scenario and wider for the highest marker scenario.[47] Given that the Cancun Agreements recognize a goal of stabilizing the increase in global average temperature below 2°C, an uncertainty range of approximately 2°C is a major risk factor.

The quantified uncertainty range for model projections is based on the spread among different climate models across a range of emissions scenarios. Combining emissions uncertainty and response uncertainty, the AR4's *full uncertainty range* for projected warming in 2100 relative to 1990 is 1.1-6.4°C, with a *likely* (>66%) range of 1.8–5.4°C. The 2°C goal in the Cancun Agreements is in relation to preindustrial climate. Relative to preindustrial temperatures, the AR4's full uncertainty range is 1.7-7.2°C and the likely range is 2.4–6.0°C.[48]

Climate sensitivity

Climate response uncertainty is not fully quantified (the phrase "full uncertainty range" is therefore a misnomer). A major factor is the *equilibrium climate sensitivity*, which is defined as the amount of warming that would result from a doubling of the concentration of CO_2 in the atmosphere.

Global climate models estimate the climate sensitivity internally based on their own physical calculations. The average of these model-generated estimates in the AR4 is 3.2 ± 0.7°C. However, there are other ways of estimating climate sensitivity and the full range of estimates in the broader peer-reviewed literature is about 1-11°C. These extremes are highly improbable but cannot be ruled out. The AR4 judges that the true climate sensitivity likely falls within the range of 2-4.5°C but the uncertainty is much greater on the upper end, with a 5 to 17 percent chance that the true sensitivity is greater than 4.5°C.[49]

This skewed uncertainty creates a long tail on the severe end of the probability distribution that represents an elevated risk factor because it is more likely that the climate sensitivity is underestimated than that it is overestimated (Figure 2.3).[50] The AR4 climate projections partially address this issue by estimating future warming using a suite of simplified models with an effective sensitivity range of 1.9-5.9°C.[51] This range is broader than the likely range, but it does not represent the full range of uncertainty. More importantly, it is not a systematic assessment of the risk that climate sensitivity uncertainty entails. A systematic assessment

47 Ibid.

48 Ibid.

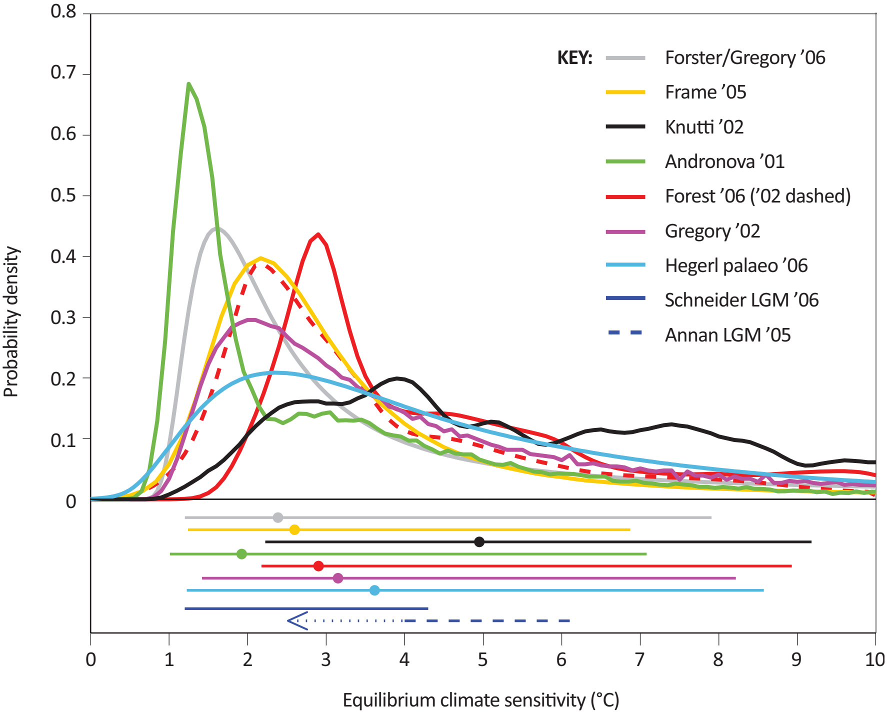
49 Hegerl et al., 2007, p. 664-745; Hegerl et al., 2006; Schneider et al., 2007

50 Gulledge, op. cit.

51 Meehl et al., op. cit.

would hold all other factors constant and vary the climate sensitivity within each model rather than across different models. However, that analysis has not been carried out and complex climate models are not designed to perform such an analysis.

Figure 2.3: Probability distributions for equilibrium climate sensitivity.



Estimated probability distributions for the equilibrium climate sensitivity from several studies using a variety of approaches. Horizontal bars show the 5 to 95 percent uncertainty ranges and the dots show the median estimate for each distribution. ***Source:*** *Hegerl et al., 2007.*

Structural uncertainty

Another form of uncertainty in climate models that has not been systematically assessed is *structural uncertainty*, which covers a host of processes that may be missing from or incorrectly implemented in the models. Among these structural uncertainties are potential positive (amplifying) or negative (dampening) feedbacks that are too poorly understood to be included in models. Cloud processes, for example, are not fully represented in models, and are the primary source of inter-model discrepancies in the calculated climate sensitivity.[52] Cloud processes could result in either positive or negative feedbacks.

52 Randall et al., op. cit.

Climate scientists have long recognized the potential for climate change to be underestimated because of a lack of understanding of positive feedbacks in the climate system. Although negative feedbacks exist, the Earth's climate system appears to be endowed disproportionately with positive feedbacks.[53] One example is the potential release of billions of tons of CO_2 and methane from permafrost (frozen soil) and peat deposits in the north.[54] As the planet warms, these soils are beginning to thaw. How much and how quickly they will release their stores of greenhouse gases into the atmosphere is presently unpredictable and is totally absent from climate models. Another positive feedback that is not completely integrated into models is the potential for plants and oceans to take up less CO_2 from the atmosphere in a warmer world, resulting in a more rapid accumulation in the atmosphere as anthropogenic emissions continue to warm the planet.[55]

Rate of Change and Timing of Impacts

Recent observations indicate that climate models have been underestimating the rates of change of several key aspects of the climate system, including:

- Ice loss from the Greenland and Antarctic ice sheets.[56]
- Ice loss from mountain ice caps and glaciers.[57]
- Arctic sea ice decline.[58]
- Global sea level rise.[59]
- Global precipitation increase.[60]
- Latitudinal widening of the tropical belt.[61]

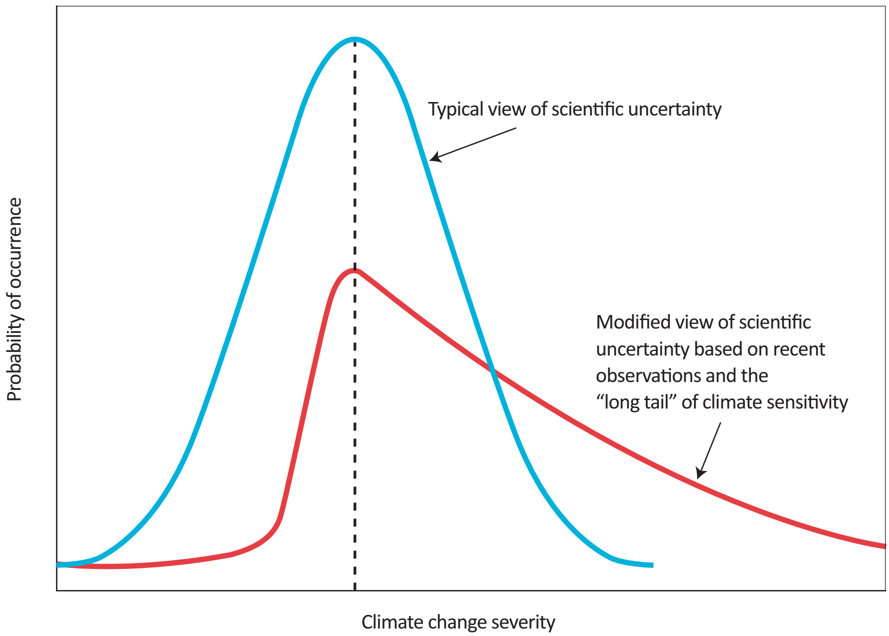
All of these changes were predicted before they were detected, but they are occurring sooner or more rapidly than expected.[62] Observed rates of temperature change and increases in atmospheric CO_2 concentrations are closer to model projections, but are near the upper limits of those projections.[63]

53 Spencer et al., 2007; Hansen, 2007.
54 Walter et al., 2007; Schuur et al., 2008; Dorrepaal et al., 2009
55 Pittock, 2006; Meehl et al., op cit.
56 Lemke et al., 2007, p 337-383; Shepherd & Wingham, 2007
57 Meier et al., 2007
58 Stroeve et al., 2007
59 Rahmstorf et al., op. cit.
60 Wentz et al., 2007
61 Seidel et al., 2008
62 Engelhaupt, 2007
63 Rahmstorf et al., op. cit.

The reasons for underestimating change are not understood at this time. Inadequately treated positive feedbacks and natural climate variability that is not captured in models are possible explanations.

Since observed climate change seems to be systematically outpacing model projections, the uncertainty regarding future climate impacts appears to be skewed toward more severe outcomes compared to expectations from models (Figure 2.4). **This situation implies that the probability of underestimating change is currently greater than the probability of overestimating, and that the upper end of the risk distribution is difficult or impossible to constrain based on current understanding.**

Figure 2.4: The long tail of scientific uncertainty for future climate impacts



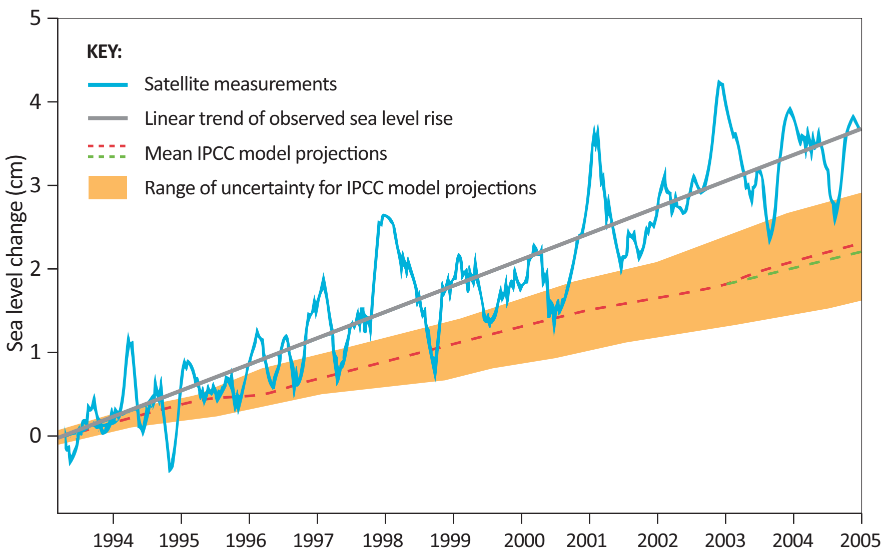
Based on recent observations compared to climate model projections, the probability distribution of climate change outcomes appears to be biased systematically toward more severe outcomes. ***Source:*** *Adapted from Gulledge, 2008a.*

Sea level rise and Arctic sea ice decline

Rates of sea level rise and Arctic sea ice decline are of particular concern because of the potential effects on so many people and natural systems around the world. Rapid sea level rise would directly impact hundreds of millions of people who live in coastal zones and indirectly impact billions through negative effects on ports and centers of commerce, damage to fisheries and crop producing deltas, human migration from coastal to inland areas, and migration across borders. Loss of Arctic sea ice is a direct amplifier of global climate change and could stimulate the rapid melting of permafrost, which, as already mentioned, could in turn release billions of tons of additional CO_2 and methane into the atmosphere, further amplifying warming. Access to the Arctic is also of strategic and commercial interest.

The global climate models used in the AR4 underestimate current rates of sea level rise by about 50 percent on average (Figure 2.5), calling their projections of future sea level rise into question.[64] Projections published after the AR4 generally indicate 0.5 to two meters of sea level rise by the end of the current century, but the estimates are preliminary.[65] It may not be possible to have confidence in any projections until ice sheet behavior can be modeled more accurately. However, there is strong evidence of rapid sea level rise the last time the Earth's climate was similar to today's climate, during the last interglacial about 125,000 years ago. At that time the Earth's average surface temperature was 1-2°C warmer than at present, and sea level likely peaked seven to nine meters higher than the present sea level.[66] The average rate of sea level rise leading up to the peak was 1.6 meters per century.[67] Such rates appear plausible later in this century and the next.

Figure 2.5: Observed sea level rise compared to model projections.



Observed sea level rise compared to modeled sea level rise. ***Source:*** *Schubert et al., 2006*

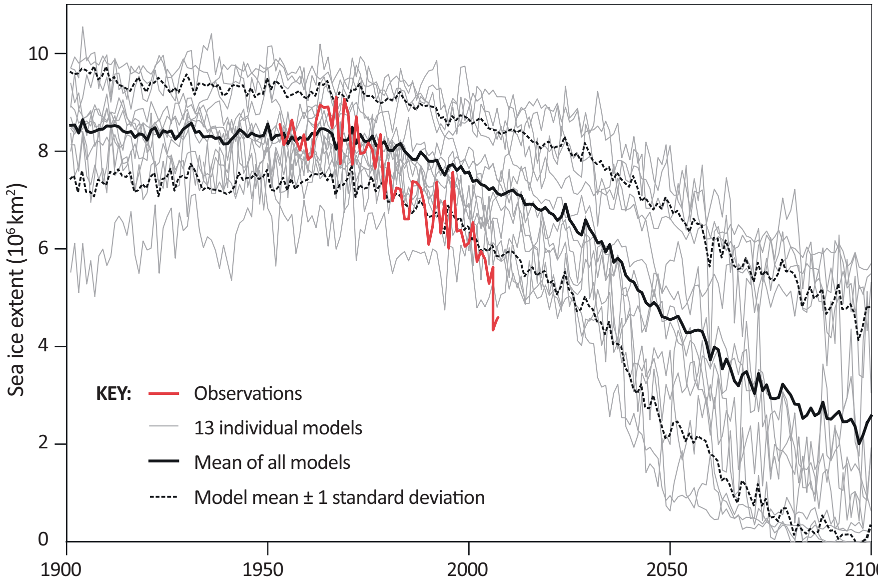
64 Rahmstorf et al., op. cit.

65 Pfeffer et al, 2008; Vermeer and Rahmstorf, 2009

66 Kopp et al., 2009

67 Rohling et al., 2007

Figure 2.6: Observed Arctic sea ice loss compared to model projections.



Observed trend in summer Arctic sea ice decline compared to model projections. ***Source:*** *Stroeve et al., 2007.*

Similarly, the AR4 models underestimate Arctic sea ice loss by about 300 percent on average (Figure 2.6).[68] Even at the slower simulated rates, some models project a seasonally ice-free Arctic by the end of this century. However, the observed rates of ice loss, including the record-breaking low summer Arctic sea ice extent in 2007, has led to speculation that the Arctic could open up decades earlier, with recent projections in the peer-reviewed literature ranging from the 2030s to the 2080s.[69] The great concern is that the larger area of open water during each summer is allowing the Arctic Ocean to absorb more summer solar radiation (it would be reflected back to space if the ice were still there), warming the water more over the winter and preventing thick ice from forming. Consequently, not only is the area of the sea ice declining, the thickness may be declining even faster, potentially leading to an irreversible acceleration of ice loss that could result in an unexpected, abrupt transition to summer ice-free conditions much earlier than expected.[70]

Much of the discussion about the opening of the Arctic has focused on new economic benefits – mineral and energy resources, fisheries, transport, and tourism. However, the risks have

68 Stroeve et al., op. cit.

69 Boé et al., 2009; Wang & Overland, 2009

70 Maslanik et al., 2007

received less attention, in part because much of the science remains uncertain. Nonetheless, enough is known to identify a variety of potentially risky outcomes with global implications:[71]

- An ice-free Arctic Ocean will absorb more sunlight and convert it to heat, thus amplifying warming.
- The Arctic currently removes CO_2 from the atmosphere, but sea ice loss would likely cause it to switch to releasing CO_2 and methane (a very potent greenhouse gas) to the atmosphere, further amplifying global warming.
- Atmospheric circulation and therefore precipitation and storm patterns may be altered by a warming Arctic and changes in how the ocean interacts with the atmosphere in the northern hemisphere.
- A warmer, ice-free Arctic Ocean with more freshwater from snow and ice melt may slow the Atlantic thermohaline circulation, thus cooling Europe and further warming other parts of the world. These changes would alter marine ecosystems (i.e. fisheries) patterns of precipitation and storms on a broad scale.
- Amplified warming will accelerate melting of land-based glaciers, thus accelerating sea level rise. The Greenland Ice Sheet could become destabilized, leading to abrupt and massive sea level rise beyond the 21st century.
- Countries have already begun to compete for access to untapped natural resources in the Arctic. Unlike other international arenas, such as Antarctica, coastal waterways, and space, there are limited agreed international rules to govern how different countries will access and utilize the Arctic.

Because the potential economic benefits of the opening of the Arctic are large, there is a substantial need for more concerted effort to resolve the risks so that effective risk management decisions can be made. At this stage, however, it is not safe to assume that the opening of the Arctic will yield net benefits.

Abrupt Change, Thresholds and Nonlinearity

The widespread perception that climate change will be a smooth and gradual process is a barrier to perceiving the full breadth of risks that climate change entails. Well-established evidence indicates that the climate has changed abruptly and on a large scale in the recent geological past.[72] The rapid rise in sea level during the last interglacial period described above is a documented example of an abrupt global-scale change that would be of grave concern if

71 Schiermeier, 2006; Sommerkorn and Hassol, 2009; Kraska, 2010

72 Alley et al., 2003; National Research Council, 2002

repeated today. But abrupt changes may be a common feature of climatic changes and their impacts, especially on local scales. This is because impacts may occur suddenly when certain thresholds of warming are exceeded, causing a system to shift from one major state to another.

Moreover, the complexity and multiple interactions amongst systems in the climate may lead to nonlinear behavior, where a small change in one system may lead to a large and unpredictable change in a responding system.[73] Nonlinear behavior makes predictions more difficult and causes risks to increase nonlinearly with rising atmospheric greenhouse gas concentrations.[74] Abrupt climate change is therefore difficult to forecast. However, estimates of the probability of abrupt changes suggest that large ice sheets are susceptible to nonlinear behavior change during this century.

The earliest abrupt changes are likely to be associated with extreme weather, especially heat wave frequency and intensity, heavy precipitation and flooding, and drought severity and duration. The dry subtropics are the most susceptible to switching into a permanent drought-like state; there are signs of such changes already in Australia, the Mediterranean region, and the Southwestern United States, for example.[75] Poorly understood – but potentially very rapid and dangerous – is the potential for the sudden reorganization of atmospheric circulation patterns that could strongly alter large-scale precipitation patterns.[76]

Tipping elements

Major climatic subsystems that might exhibit nonlinear threshold responses to warming are described as *tipping elements*. These are sub-continental elements of the Earth's systems that can be switched into a qualitatively different state by small disruptions.[77] Several large-scale tipping elements that are potentially relevant to decision makers are depicted in Figure 2.7. These are not the only tipping elements of potential importance to policy makers: the list focuses on large-scale Earth systems potentially relevant to international security and foreign policy, but there are likely to be many local tipping elements.

73 Rial et al., 2004.

74 Schneider et al., op. cit.

75 Shindell, 2007; Seager et al, 2007; Lenton, et al., 2008

76 Steffensen, 2008

77 Lenton et al., op. cit.

BOX 3: (In?)Stability of the Atlantic Thermohaline Circulation

The U.S. Department of Defense has released a report that considers the potential national security implications of a collapse in the Atlantic thermohaline circulation (THC).[78] The THC is "one of the most important large-scale ocean current systems for Earth's climate."[79]

The THC plays a major role in global climate by transporting huge amount of heat from the tropics into the North Atlantic Ocean. The main reason for concern is that the THC appears to be a tipping element (see reference to Atlantic Deep Water Formation in Figure 2.7) capable of shutting down suddenly "from global warming due to increased river discharge and Greenland meltwater influx."[80] Consequences of a dramatic slowing or collapse of the THC could include strong cooling in northwestern Europe; an additional meter of sea level rise in the North Atlantic; hotter, drier conditions in North Africa, the Middle East, Central America, the Caribbean, and Amazonia; and more droughts in some grain exporting regions, including North America and South Asia. Although uncertainties around specific consequences are large, there is potential for the impacts to be abrupt, global, and difficult to manage.[81]

The THC captured the public imagination about a decade after scientists extracted an ice core from the Greenland ice sheet that revealed, for the first time, that the climate around Greenland – and possibly over a much larger area – had warmed dramatically within a single decade as the last major ice age was ending.[82] Until that time, scientists had assumed that the climate was much more stable than that. Already known as an important factor in distributing heat and water around the globe, the THC was an obvious suspect for causing this abrupt change: perhaps the flow of the THC was unstable and might stop under certain conditions. A leading hypothesis held that if polar ice melted because of global warming, the resulting freshwater, which is lighter than salty water, might form a cap over the North Atlantic and stop the sinking of cold, salty water that was thought to drive the THC.[83]

When the Pentagon released its report on abrupt climate change, the stability of the THC was simply unknown, making it impossible to say whether the THC should really be a concern or not, except that its consequences could be severe. Then, in

78 Schwartz and Randall, op. cit.
79 Hofmann and Rahmstorf, 2009
80 Ibid.
81 Gulledge, 2008b
82 Grootes, et al., 1993
83 Hofmann and Rahmstorf, op. cit.

2005 a peer-reviewed study was published that claimed to have detected a 30 percent slowdown of the THC between1957 and 2004, a period of rapid global warming.[84]

Again, the potential perils of the THC were in the news.[85]

The apparent slowdown was inferred from samples taken over four time points spanning five decades, which many scientists considered inadequate to draw any conclusions. Meanwhile, a team of scientists interested in abrupt climate change strung a set of instrumented cables from West Africa to the Bahamas to take continuous measurements of the THC. Within just a year, the instruments detected up and down variations in the strength of THC currents that were just as large as the change detected between 1957 and 2004.[86] These results demonstrated that the variability of portions of the THC is large and much more thorough and systematic long-term monitoring would be required before any conclusions could be drawn about the stability – or instability – of the THC. Unfortunately, much of the press coverage read as though scientists had determined that there was no slowdown of the THC and that the circulation was more stable than previously thought, a serious misreading of the science.

In 2007, the IPCC AR4 report added to the confusion when it reported that there was less than a 10 percent chance that the THC would collapse during the 21st century. The conclusion was consistent with the results of climate models, but more recent observational evidence suggests that the models might be unrealistically stable:

> *"[T]here is evidence suggesting that our current generation of models … maybe far too stable with respect to perturbations like those resulting from global warming [such as] increased river discharge and Greenland meltwater influx."*[87]

At the time the AR4 was released there were indications that the THC could be at greater risk of collapse than models indicated. A survey of climate scientists published the same year as the AR4 found:

> *"Many processes and factors deemed important are assessed [by the experts] as poorly known and insufficiently represented in state-of-the-art climate models."*

84 Bryden, et al. 2005

85 Carey, with Shapiro, 2004; Leahy, 2004

86 Kerr, 2006

87 Hofmann and Rahmstorf, op. cit.

"Assuming a global mean temperature increase in the year 2100 of 4 [°C], eight experts assess the probability of triggering an AMOC collapse as significantly different from zero, three of them as larger than 40 percent."[88]

One would be remiss, therefore, to conclude (or report) that the apparent risk of THC collapse is less than scientists believed in earlier years. From a risk management perspective, this misunderstanding is perilous because it artificially removes a potentially serious risk from the decision maker's table.

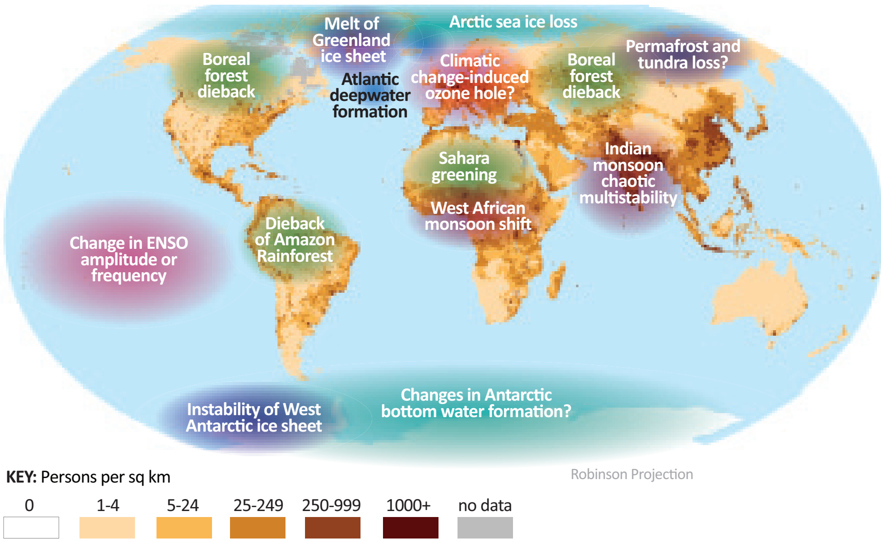
The great uncertainty surrounding the future of the THC calls for at least two risk management responses. First, it is clear that better scientific understanding is needed. Second, early warning and advance preparations for a potential collapse would help moderate the impacts of a THC collapse. For both responses, the most important resource is an adequate operational monitoring system supported by governments as a permanent international security program. Scientific measurement programs, which typically run for a few years and focus on the minimum measurements necessary to serve immediate scientific needs, are inadequate for this purpose: "Scientific honesty would require records for decades… How do you go about doing science when you need decades of record?"[89]

All of these tipping elements hold broader significance to society or for unique or threatened natural systems. Any massive sea level rise, whether abrupt or gradual, will originate from large-scale mass loss from the large polar ice sheets. El Niño and the tropical monsoons will impact food production and weather extremes in much of the world, including South and Southeast Asia and West Africa. Widespread melting of Arctic permafrost may act as a positive feedback by releasing tons of CO_2 and methane to the atmosphere. All of these tipping elements are very uncertain, but based on current understanding the most sensitive are the loss of Arctic sea ice over a few decades and the collapse of the Greenland ice sheet over a few centuries, ultimately leading to two to seven meters of sea level rise. **There is a high risk of triggering these tipping elements even if society manages to limit warming to 2°C. Most of the other tipping elements identified here become much more likely if global average temperature rises by more than 3°C.**

88 Zickfeld, 2007

89 K. Wunsch of Massachusetts Institute of Technology, as quoted by Kerr, 2006

Figure 2.7: Map of large-scale tipping elements in the global climate system.



Map of potential policy-relevant large-scale tipping elements in the climate system overlain on global population density. ***Source:*** *Lenton et al., 2008.*

Monitoring Climate Change

From the description above it can be seen that "worst case scenarios" are not low probability events, but may be inevitable under current momentum economic behavior. Current emissions trajectories and foreseeable growth in the absence of climate policy could easily put us on a path to warming of 5°C or more by the end of the century. With such warming, there is little uncertainty over whether extreme impacts will occur, only when they will happen, and to what extent they will affect specific locales. We do not know precisely where particular tipping points lie; we know they exist. Like a ship navigating through the fog we need to make a judgment about how close we go towards the rocks in order to shorten the route to our destination.

In the absence of completely accurate forecasting capability on when critical impacts may occur, it is vital to continually monitor impacts in order to quickly observe rapid changes and recalibrate models to improve estimates of future damage. As explained above, many observations suggest that models are underestimating critical climate change impacts and processes. We lack sufficient monitoring of many basic climate variables to provide the validation and correction of climate models needed to hone their forecasting skill.

However, currently there is only patchy and non-systematic monitoring of most major climate system tipping elements such as Arctic methane emissions. The IPCC system does not have a dedicated observing system; instead, it relies heavily on existing academic funding systems that are not driven by decision support needs. **There is an urgent need for greater investment in specific monitoring systems to give policy makers early warning of dangerous climate impacts.**[90]

Regional Projections and Regional Sensitivity to Change

For security planners, regional projections and sensitivity analysis are essential to projecting future security scenarios.[91] The capacity to generate a detailed outlook at the scale and with the time-specificity desired is still limited. However, there has been some substantial work on projecting regional impacts at a larger scale. Some examples of projected regional changes from the AR4 are provided in Table 2.2.

Table 2.1. Examples of projected regional impacts. ***Source:*** *IPCC, 2007.*

Africa	By 2020, between 75 and 250 million people are projected to be exposed to increased water stress due to climate change. By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50 percent. Agricultural production in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition. Towards the end of the 21st century, projected sea level rise will affect low-lying coastal areas with large populations. The cost of adaptation could amount to at least 5 to 10 percent of Gross Domestic Product (GDP). By 2080, an increase of 5 to 8 percent of arid and semi-arid land in Africa is projected under a range of climate scenarios.
Asia	By the 2050s, freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is projected to decrease. Coastal areas, especially heavily populated mega delta regions in South, East and South-East Asia, will be at greatest risk due to increased flooding from the sea and, in some mega deltas, flooding from the rivers. Climate change is projected to compound the pressures on natural resources and the environment associated with rapid urbanization, industrialization and economic development. Endemic morbidity and mortality due to diarrheal disease primarily associated with floods and droughts are expected to rise in East, South and South-East Asia due to projected changes in the hydrological cycle.

90 GCOS, 2009.

91 A thorough examination of projected impacts of climate change can be found in Annex 1.

Australia and New Zealand	By 2020, significant loss of biodiversity is projected to occur in some ecologically rich sites, including the Great Barrier Reef and Queensland Wet Tropics. By 2030, water security problems are projected to intensify in southern and eastern Australia and, in New Zealand, in Northland and some eastern regions. By 2030, production from agriculture and forestry is projected to decline over much of southern and eastern Australia, and over parts of eastern New Zealand, due to increased drought and fire. However, in New Zealand, initial benefits are projected in some other regions. By 2050, ongoing coastal development and population growth in some areas of Australia and New Zealand are projected to exacerbate risks from sea level rise and increases in the severity and frequency of storms and coastal flooding.
Europe	Climate change is expected to magnify regional differences in Europe's natural resources and assets. Negative impacts will include increased risk of inland flash floods and more frequent coastal flooding and increased erosion (due to storminess and sea level rise). Mountainous areas will face glacier retreat, reduced snow cover and winter tourism, and extensive species losses (in some areas up to 60 percent under high emissions scenarios by 2080). In southern Europe, climate change is projected to worsen conditions (high temperatures and drought) in a region already vulnerable to climate variability, and to reduce water availability, hydropower potential, summer tourism and, in general, crop productivity. Climate change is also projected to increase the health risks due to heat waves and the frequency of wildfires.
Latin America	By mid-century, increases in temperature and associated decreases in soil water are projected to lead to gradual replacement of tropical forest by savanna in eastern Amazonia. Semi-arid vegetation will tend to be replaced by arid-land vegetation. There is a risk of significant biodiversity loss through species extinction in many areas of tropical Latin America. Productivity of some important crops is projected to decrease and livestock productivity to decline, with adverse consequences for food security. In temperate zones, soybean yields are projected to increase. Overall, the number of people at risk of hunger is projected to increase. Changes in precipitation patterns and the disappearance of glaciers are projected to significantly affect water availability for human consumption, agriculture and energy generation.

North America	Warming in western mountains is projected to cause decreased snowpack, more winter flooding and reduced summer flows, exacerbating competition for over-allocated water resources. In the early decades of the century, moderate climate change is projected to increase aggregate yields of rain-fed agriculture by 5-20 percent, but with important variability among regions. Major challenges are projected for crops that are near the warm end of their suitable range or which depend on highly utilized water resources. Cities that currently experience heat waves are expected to be further challenged by an increased number, intensity and duration of heat waves during the course of the century, with potential for adverse health impacts. Coastal communities and habitats will be increasingly stressed by climate change impacts interacting with development and pollution.
Polar regions	The main projected biophysical effects are reductions in thickness and extent of glaciers, ice sheets and sea ice, and changes in natural ecosystems with detrimental effects on many organisms including migratory birds, mammals and higher predators. For human communities in the Arctic, impacts, particularly those resulting from changing snow and ice conditions, are projected to be mixed. Detrimental impacts would include those on infrastructure and traditional indigenous ways of life. In both Polar Regions, specific ecosystems and habitats are projected to be vulnerable, as climatic barriers to species invasions are lowered.
Small islands	Sea level rise is expected to exacerbate inundation, storm surge, erosion and other coastal hazards, thus threatening vital infrastructure, settlements and facilities that support the livelihood of island communities. Deterioration in coastal conditions, for example through erosion of beaches and coral bleaching, is expected to affect local resources. By mid-century, climate change is expected to reduce water resources in many small islands, for example in the Caribbean and Pacific, to the point where they become insufficient to meet demand during low-rainfall periods. With higher temperatures, increased invasion by non-native species is expected to occur, particularly on mid- and high-latitude islands.

It is important to place these changes into the context of the regional climates to which local systems and societies have adapted over time. For example, a given change in climate such as a degree of warming or a 10 percent change in precipitation does not affect all regions the same way. It will be necessary, therefore, to examine how sensitive different regions might be to changes in temperature or precipitation. From a security perspective it would then be useful to compare regional sensitivity to the distribution of global population density and to regions that are important for crop production and export and regions where increased water stress and food insecurity could lead to instability, migration and conflict.

There is a striking correspondence between the global distributions of human population density and land that is currently suitable for producing rain-fed crops (see Figure 2.8a and 2.8b). This pattern holds for developed countries like the United States even though extensive irrigation augments precipitation to increase crop yields, implying that historical rainfall patterns remain the primary determinants of regional agricultural production and population density.

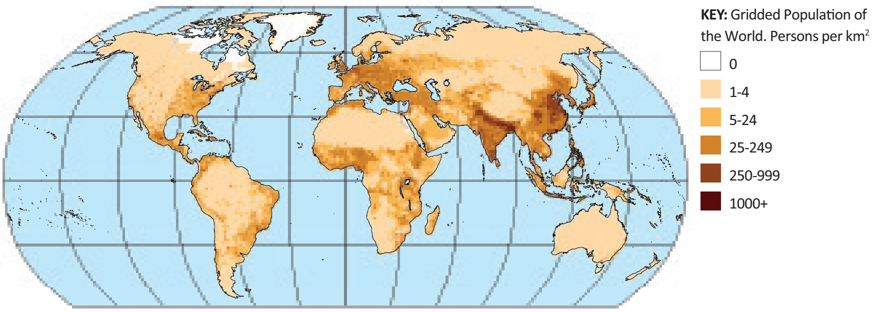
Some regions experience a very stable climate, and natural and human systems have developed around this stability. Even a small change may generate significant impacts in such regions. For instance, moderate decreases in precipitation may lead to the collapse of productive rainforests in wet tropical systems. Alternatively, settlements and infrastructure in these regions may be damaged by increased flooding from small increases in precipitation during the rainy season. Semi-arid regions that are already marginal for supporting natural and human systems may be rendered uninhabitable by small decreases in precipitation or stream flow. In contrast, regions with historically large climate variability require larger changes of future climate to move natural and human systems beyond the bounds of the climate extremes to which they have adapted. For instance, in spite of great natural climate variability, the Arctic is expected to be heavily impacted by climate change because the degree of warming is projected to be large compared to the global average and much larger than in the tropics.

A regional climate change index mapping physical sensitivity to changes from current climate regimes is shown in Figure 2.8c.[92] **The areas most sensitive to a combination of projected temperature and precipitation change relative to natural historical variability are in tropical Central and South America, tropical and southern Africa, Southeast Asia, and the polar regions.** The Mediterranean region, China and the western United States show intermediate levels of sensitivity. Marginal agricultural lands generally show intermediate to high climate sensitivity, including in the southwestern United States, Central America, sub-Saharan Africa, southern Europe, Central Asia, including the Middle East, and eastern China. Most of these regions also bear large human populations. Also of note, the most affected region of South America completely covers the Amazon rainforest, which is projected to become relatively drier. Reduced productivity of this forest would have strong feedbacks on global climate by releasing carbon to the atmosphere and would result in massive loss of biodiversity, including economically important species.

92 Baettig et al., 2007

Figure 2.8 Distributions of human population density, rain-fed agriculture, and regional sensitivity to climate change.

Figure 2.7A



Robinson Projection. Based on 2.5 arc minute resolution data.

Figure 2.7B

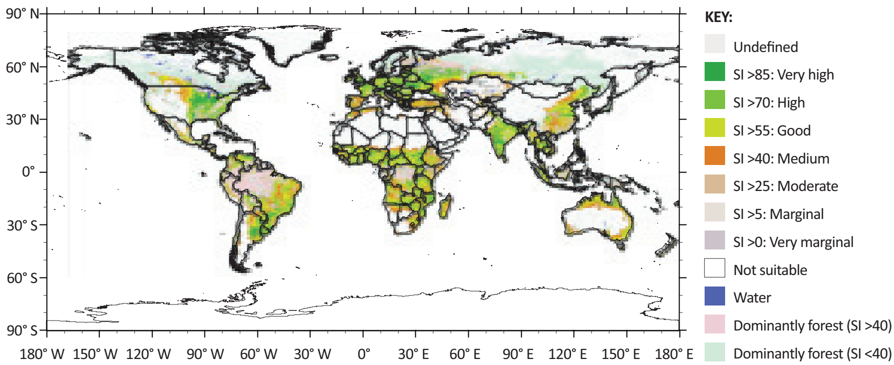
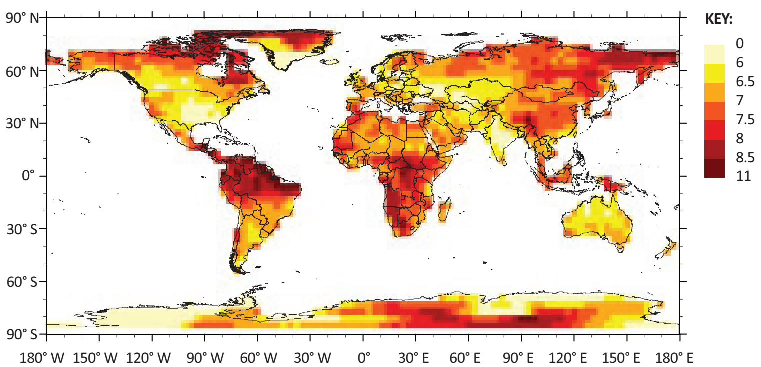


Figure 2.7C



(a) *Distribution of current global population density.* ***Source:*** *CIESIN and CIAT, 2005* ***(b)*** *Current suitability of land for rain-fed crop production, excluding current forests.* ***Source:*** *Fig. 5.1A in Easterling et al., 2007* ***(c)*** *The aggregated climate change index indicates expected future changes in temperature and precipitation relative to current climate variability; higher numbers indicate greater relative change.* ***Source:*** *Baettig et al., 2007*

3 The Role of Risk Perception in Risk Management

"Intelligence analysts should be self-conscious about their reasoning processes. They should think about how they make judgments and reach conclusions, not just about the judgments and conclusions themselves."
Richards Heuer, Centre for the Study of Intelligence, Central Intelligence Agency[93]

Summary

- Managing analytical and perceptual biases is a central and familiar task of intelligence analysis. Effective decision support for climate security must incorporate these insights if the threat is to be faced effectively. A range of misperceptions currently exists which undermines action to manage the risks posed by climate change.

- Uncertainty about climate change science and policy options is often used as an excuse for inaction or ignored to simplify policy debates. Both tendencies undermine effective risk management because inaction cannot reduce risk and ignoring uncertainty conceals risk.

- Several common misconceptions present barriers to accurate risk perception. The presumption that the climate system will only change slowly and gradually belies ample scientific evidence that both global and regional climates tend to change suddenly and at times dramatically when forced. Extreme climate related events of the past decade have overturned the misperception that rich countries will be only lightly affected by climate impacts. The assertion that poor countries' development needs trump the management of climate risks belies the great likelihood that climate change will undermine efforts to reduce poverty and improve social and economic conditions in the developing world.

- Insufficient integration across disciplines and a philosophical aversion to perceived outlier scenarios can lead to inadvertent expert bias that works against developing an adequate understanding of risk. Moreover, overconfidence or ideology may lead individual experts to intentionally provide an overly narrow view of risk. Decision makers should identify risk management as the operational framework for making decisions about climate change and ensure that experts provide information tailored to that framework while avoiding inadvertent or intentional biases.

- Compared to a decade ago, recent upward adjustments of risk estimates suggest the need for continuous learning and updating our formal perceptions of risk. When

93 Heuer, 1999

planning against future climate scenarios, decision makers should bear in mind the tendency for experts to underestimate impacts when information is limited.

From Analysis to Decisions

The analytical definition of risk is the probability of an outcome multiplied by the severity of its consequences.[94] In this formulation, two factors determine whether a risk is high or low: likelihood and severity. A high probability of an outcome with minor consequences causes only moderate concern. On the other hand, a low probability of an outcome with grave consequences may cause significant concern. At its most basic, **risk management endeavors to reduce the probability of an outcome, the potential severity of its consequences, or both,** depending on the nature of the problem and the management opportunities it presents.

Nuclear weapons are a familiar case study in security risk management where nations have endeavored to reduce both the probability and the potential severity of a nuclear attack. Within this framework, the probability of an attack is reduced through the principle of assured mutual destruction as a deterrent, and mechanisms to prevent the proliferation of nuclear weapons to additional actors. In principle, arms reduction agreements should lower the potential consequences of a nuclear war by reducing the maximum potential firepower. Indeed, the current global arsenal possesses less than one-third of its peak explosive power of past decades.[95] Unfortunately, even a fraction of the current arsenal may be powerful enough to cause a devastating, decade-long nuclear winter that would collapse agricultural production worldwide and starve most of the human population.[96] Nonetheless, disarmament remains a key component of the risk management portfolio, with further arms reduction efforts in process.[97] Even though new risks are emerging (for example, non-treaty states and non-state actors exhibiting nuclear ambitions), the lack of a nuclear attack since the end of World War II suggests that this risk management framework has succeeded, so far.

Climate change presents a similar problem in which both the probability and potential severity of outcomes need to be reduced to manage the associated risks. In 2007, a group of distinguished scientists, including President Obama's current science advisor, John Holdren, wrote that "confronting climate change [means] avoiding the unmanageable and managing the unavoidable."[98] The IPCC's AR4 articulates the point further:

94 Yohe, 2010

95 Robock et al., 2007

96 Ibid.

97 Kellerhals Jr, 2010

98 Bierbaum et al., 2007

> *Responding to climate change involves an iterative risk management process that includes both adaptation and mitigation and takes into account climate change damages, co-benefits, sustainability, equity and attitudes to risk.*[99]

In climate change policy, **mitigation** refers to steps taken to minimize the extent of climate change – "avoiding the unmanageable" – principally through reductions in greenhouse gas emissions. **Adaptation** refers to steps taken to cope with the impacts of climate change that cannot be avoided – "managing the unavoidable." The last part of the AR4 statement lists factors to consider in determining socially appropriate policy measures. How society and decision makers perceive the risks of climate change, and how much they value reducing uncertainty about future damages (i.e. risk reduction), is crucial to weighing the costs and benefits of action.

The first step to constructing a risk management system is to understand systematic issues in translating the huge body of primary scientific evidence into meaningful data for decision makers. This process is termed 'intelligence assessment' in security policy and is well known to be subject to a range of perceptual, methodological and structural biases.[100] Intelligence failure is a constant subject of public debate; for example, the flawed assessments of Iraq's weapons of mass destruction were subject to extensive public – and secret – reviews in the United States and United Kingdom. The translation of climate change science for use in decision-making is highly susceptible to these failures; no matter how complex or inaccessible the concepts of climate science and the data may be, in the end they must be synthesized by non-specialists and communicated to policy makers.[101] In the process of assessment and evaluation a range of problems can interfere with effective translation of risk:

- **Perceptual barriers** caused by 'fuzzy' consideration of uncertainty, deliberate exaggeration/understatement of uncertainty, overestimation of stability in the climate system, and overestimation of resilience to climate impacts.

- **Expert bias** in that the way uncertainty is handled inside the scientific community is not appropriate for effective use by decision makers.

- **Learning barriers** in that the information gained on underlying biases in analysis and modeling from improved observation is poorly transmitted to decision makers.

Barriers to Perception

There is an important distinction between nuclear weapons and climate change: public and decision maker perception of the associated risks. From a risk management perspective, the diffi-

99 Yohe, op. cit.

100 US Government, 2009

101 Rogers and Gulledge, 2010

culty with climate change is that it will not result in instant annihilation. The effects of climate change are more akin to the risk of nuclear winter: potentially an existential threat but not instantaneous, nor generally understood. Without a basic recognition of the likelihood and potential severity of climate change impacts, it is not possible to manage the associated risks rationally.

Such barriers to accurate perception of the risks of climate change fall into four categories: uncertainty, the assumption of ample time to act, the assumptions of low risk for the rich and low priority for the poor, and expert bias.

'Fuzzy' Uncertainty

There is a common human tendency to dismiss uncertain consequences as not urgent, even if the consequences are potentially severe. In the United States, uncertainty has often been cited as reason to delay national policies to reduce greenhouse gas emissions. Typically, the stated rationale is to allow time for science to reduce uncertainties before sinking financial resources into solutions that may prove unnecessary.[102] Alternatively, uncertainty around climate science and climate change policy is often ignored or downplayed to avoid 'complicating' policy debates.[103] Additionally the media have reported uncertainty in a 'fuzzy' manner, implying that all aspects of climate science are highly uncertain, or over-representing eccentric scientific views as part of the mainstream debate in pursuit of journalistic 'balance'.[104] It is also well documented that some powerful groups and individuals who are ideologically or economically opposed to action on climate change have intentionally exaggerated scientific uncertainty to bolster the argument for inaction.[105] This has made proponents of urgent action less willing to acknowledge uncertainty, which then makes it harder to consider the more extreme risks from climate change and biases risk assessments towards conservative estimates of potential damages.

The prospects for resolving uncertainty vary across different parts of the climate system, but few of the most important questions (such as the true equilibrium climate sensitivity, discussed in the previous chapter) are likely to be resolved within the next decade.[106] Waiting another 10 years to implement mitigation policies would lock in additional climate security risk through additional greenhouse gas emissions and would eliminate the option of stabilizing the climate at more ambitious levels should it prove necessary or desirable.[107] While learning will play a key role in iterative decision-making over time, the prospect of learning should not imply that waiting to enact policies to reduce greenhouse gas emissions, or to begin adapting to unavoidable changes is economically efficient.[108] **Formal analyses designed to test the**

102 Lomborg, 2007

103 Boykoff et al., 2010.

104 Boykoff, 2010

105 Oreskes and Conway, 2010

106 Webster et al., 2007; Roe and Baker, 2007; Newbold and Daigneault, 2009

107 den Elzen and Höhne, 2008; Mignone et al., 2008

108 Yohe, op. cit.; O'Neill, 2008

optimal timing of climate policy under uncertainty never find that when future learning is taken into consideration inaction now is still the best response.[109]

In any case, scientific understanding of climate change has reached a point where it is clear that it is happening, that human activities are very likely causing it, and that if it continues unabated it is likely to have predominantly negative impacts on most people and the natural systems that people depend on for their well-being. Moreover, the real risks and vulnerabilities to climate extremes in both developed and developing countries are repeatedly being demonstrated: such as the devastation of New Orleans and Burma/Myanmar by Hurricane Katrina and Cyclone Nargis, respectively; the heat wave that caused 35,000 premature deaths across Europe in 2003; and the devastating floods in Pakistan in 2010.[110]

Given this scientific foundation, economist Gary Yohe has said:

> *This knowledge alone is sufficient to establish the serious risks of climate change and the need to respond in the near-term in ways that will reduce future emissions and thereby ameliorate the pace and extent of future change.* ***Indeed, looking at uncertainty through a risk management lens makes the case for near-term action through hedging against all sorts of climate risk. It then follows from simple economics that action should begin immediately in order to minimize the expected cost of meeting any long-term objective.***[111]

The Stable-Climate Myth

The widely held idea that society has plenty of time to decide how to respond to climate change before taking meaningful policy actions is a significant barrier to accurate risk perception. Several misconceptions may contribute to this notion. One is that the climate system will only change gradually and smoothly, offering ample time for society to develop policy responses as changes develop and new technologies permit. In reality, the climate tends to change in fits and starts, especially when forced to change rapidly:

> *Abrupt climate changes were especially common when the climate system was being forced to change most rapidly. Thus, greenhouse warming and other human alterations of the earth system may increase the possibility of large, abrupt, and unwelcome regional or global climatic events.*[112]

109 O'Neill, 2009

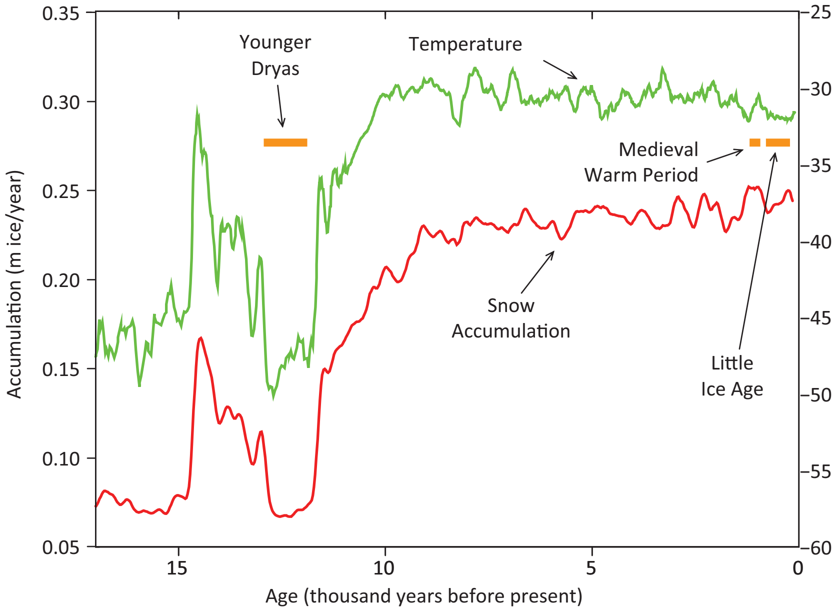
110 Confalonieri et al. 2007; Smith et al., 2009

111 Yohe, op. cit.

112 National Research Council, 2002

The misperception of a stable climate conflicts with abundant scientific evidence that the climate has changed abruptly and dramatically during periods of past climate change. About 11,500 years ago, at the end of a period known as the Younger Dryas, the annual average temperature in central Greenland jumped by about 15°C in a decade and average annual snow fall increased dramatically in just a few years (Figure 3.1). The Younger Dryas was global and caused temperature and precipitation to change significantly in many places around the world.[113] This and many similar events in the paleoclimate record send a clear message: abrupt change is a normal feature of the climate system during times of forced climate change. During the Younger Dryas, the forcing on the climate system was natural, but today humans are exerting a very strong forcing on the climate through greenhouse gas emissions to the atmosphere.

Figure 3.1: Abrupt climate change as revealed in a Greenland ice core.



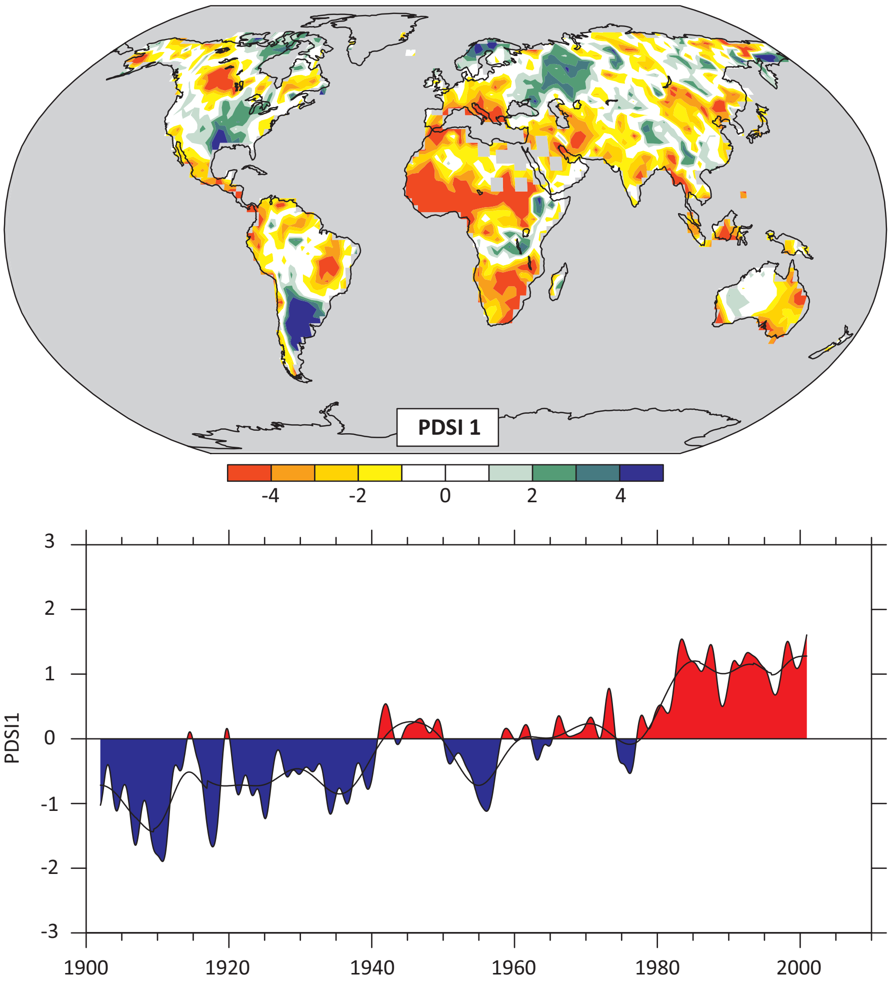
Abrupt climate change in Central Greenland. Isotope data from an ice core reveal changes in the local average annual temperature and snow accumulation rate. Abrupt, large increases in both variables occurred within a decade about 11,500 years ago. ***Source:*** *National Research Council, 2002.*

Abrupt changes are not limited to prehistoric climates: "Severe droughts and other regional climate events during the current warm period have shown similar tendencies of abrupt onset and great persistence, often with adverse effects on societies."[114] Throughout the 20th century there was a persistent trend toward drier conditions globally, but in the early 1980s

113 Ibid.
114 Ibid.

there was a sudden and sustained uptick in the amount of land worldwide that was in drought conditions (Figure 3.2). The causes of this sudden change are not well understood, but the fact that it occurred tells us that the climate is not a stable, benign system.

Figure 3.2: Global increase in drought severity during the 20th century.

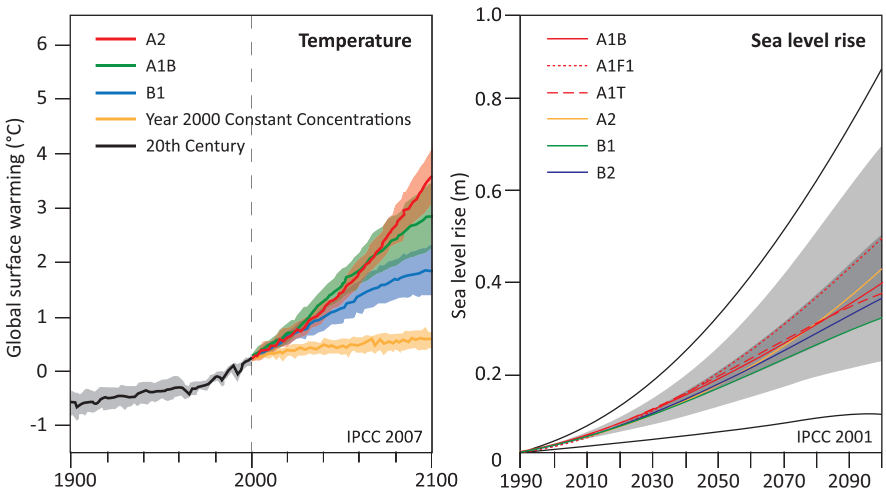


Change in drought severity from 1900 to 2002. The Palmer Drought Severity Index (PDSI) is a measure of relative drought conditions maintained by the U.S. National Climatic Data Center. The map at the top shows how the PDSI changed geographically from the early 20thcentury to the early 21stcentury. The graph below shows how the PDSI changed over time as a global average. ***Source:*** *Trenberth et al., 2007.*

Climate change impacts vary over both place and time; they are experienced locally, not globally. On local and regional scales, components of the climate system are more chaotic than they appear in global or continental averages; for example, places that experience more droughts may appear to cancel out additional rainfall in places that experience more flooding. As atmospheric circulation patterns or ocean currents reorganize, regional climates may change suddenly with unpredictable consequences.[115] Even sea level rise varies regionally.[116] Recent studies have found, for example, that the east and west coasts of the United States are likely to experience significantly more sea level rise than the global average as the world continues to warm. **Compared to the smooth, gradual, predictable changes that many people expect, the sudden, unpredictable changes that may be a common feature of regional climates will be more difficult to plan and prepare for.**[117]

The misconception of a stable climate may stem in part from computer model-generated projections of future climate change that graphically depict very smooth and gradual changes over the span of the 21st century (Figure 3.3). Such projections average model output over very large areas – often the entire globe – and over long periods of time – typically 5 to 30 years, thus smoothing over temporal and geographical differences and giving the false impression of gradual, predictable change everywhere all the time. While useful to scientists studying the basic physics of the global climate system, this type of projection is of very limited use for informing societal risk.

Figure 3.3: Climate model projections giving a false impression of smooth climate change.



Examples of climate projections. Projected change in global average temperature (left) and sea level rise (right) through the 21st century. The smooth, monotonic rise results from averaging over the entire globe and over many years. ***Source:*** *(Left) Meehl et al., 2007; (Right) Church et al, 2001.*

115 Hare & Mantua, 2000; National Research Council, 2002

116 Bindoff et al., 2007

117 Gulledge, 2008a and 2008b

Another feature of the climate system that narrows the window for action is a 20 to 30 year delay between the time that a quantity of greenhouse gas is emitted to the atmosphere and when its warming effect is realized in the near-surface atmosphere.[118] This delay means that the opportunity to reduce global warming 20 to 30 years from now has essentially passed. Another way to think of this phenomenon is that **the greenhouse gases already emitted to the atmosphere will drive the warming of the next two to three decades.** That warming, expected to be about 0.2-0.3°C per decade, is now unstoppable unless we could immediately stop emitting all greenhouse gases, which is not feasible.[119] Continued greenhouse gas emissions would lock in further warming with a 20 to 30 year sliding window.[120]

Low risk for the rich and low priority for the poor

There is a common misconception that the risks of climate change are small for the wealthy (developed countries or rich populations within a country) and that a plethora of other problems are more immediate, dire and important for developing countries. However, recent events demonstrate that wealthy countries and populations are much more vulnerable to climate impacts than previously realized. As for the more demanding problems of the developing world, climate change will interact with many of these, making their solutions even more challenging.

In 2005, Hurricane Katrina killed approximately 1,500 people and caused economic losses equivalent to a third of the gross domestic product of Louisiana and Mississippi combined.[121] Although this single event cannot be linked directly to climate change, it starkly illustrates the United States's vulnerability to climate-related disasters. There is evidence that category 4 and 5 hurricanes have become more frequent already.[122] More importantly, both theory and climate model projections indicate that category 4 and 5 hurricanes will become more frequent in the future as a result of human-induced global warming, even if there is an overall decrease in the total number of tropical cyclones (i.e. the decrease in frequency may come from a smaller number of weak storms).[123]

Sea level rise and higher storm surges resulting from climate change also present significant human security and economic risks to developed countries.[124] Analysis conducted for the OECD has found that:

118 IPCC, op. cit

119 Ibid.

120 Ibid.

121 Ebi, 2010

122 Elsner et al., 2008; Knutson et al., 2010

123 Knutson et al., ibid.

124 Examples of climate change impacts in North America, Europe, Australia and New Zealand can be found in Chapters 11, 12 and 14 of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry et al., 2007.

> *The most affected port cities are found not only in rapidly growing developing countries (e.g. Kolkata, Shanghai, Guangzhou) but also in some of the most wealthy of countries worldwide, including the United States (e.g. Miami, New York City), the Netherlands (e.g. Rotterdam, Amsterdam) and Japan (e.g. Tokyo, Osaka).*[125]

The United States suffers from severe droughts, heat waves, flash floods, heavy snowfall, intense mid-latitude storms (thunderstorms and nor'easters) and wildfires. Major events in all of these categories have occurred recently and are expected to become more intense and/or frequent because of climate change.[126] For example, since the mid-1980s, large wildfires in the western United States have quadrupled in frequency and have burned more than six times the area that was typical in the 1970s and early 1980s.[127] Moreover, large wildfires burn an average of a month longer before being brought under control than they did in the 1970s. The Midwestern United States experienced two 'once-in-500-year floods' in 1993 and 2008.[128] These floods were very costly: agricultural losses and property damage stemming from the June 2008 Midwest flood amounted to over $15 billion in damage costs and resulted in 24 deaths; severe flooding in the summer of 1993 caused $30.2 billion in damage with 48 lives lost.[129]

As mentioned previously, in 2003 a series of historic heat waves caused 35,000 premature deaths in central and southern Europe. Nearly half the deaths occurred in France, one of the world's richest countries.[130] Climate simulations suggest that the accumulation of anthropogenic greenhouse gases in the atmosphere has already more than doubled the probability of such events and future projections indicate that similar summer temperatures will be common in the region by the middle of this century.[131] Also in recent years, large, uncontrollable wildfires have ravaged economically valuable Canadian forests and priceless Greek monuments.[132] In 2007, widespread flash floods struck the United Kingdom, a result of heavy rainfall that persisted for months and broke records dating back to the beginning of the data archive in 1766.[133] The flooding was described by the UK Environment Agency as a 'national catastrophe', and insured losses were estimated at £3.2 billion.[134] In contrast, California, Australia and large portions of southern Europe have been locked in severe droughts for the past decade, damaging crops and straining water resources.[135]

125 Corfee-Morlot et al., 2009, p.19-20
126 IPCC, op. cit.; Eilperin, 2006; Zabarenko, 2008; US News, 2009; Drye, 2010
127 Westerling et al., 2006
128 Holmes, 2008
129 Lott et al., 2008
130 Confalonieri et al., op. cit.
131 Stott et al., 2004
132 Hill, 2009; Ross, 2007
133 Met Office, 2007
134 Smith, 2010
135 Wahlquist, 2008; Kirby, 2003; Blake, 2009

Given recent events around the world and climate model projections that indicate more severe impacts in the future, it is not appropriate to assume that rich countries or communities are invulnerable to serious impacts from climate change. That is not to say that rich countries are as vulnerable to climate impacts as developing countries. There is clear evidence that a combination of wealth and good governance makes developed countries more resistant and resilient to natural disasters.[136] However, the distinction is one of degree of vulnerability, rather than classification as vulnerable or not.

Additionally, if developed countries divert resources to adapting to the effects of climate change at home, they may find it necessary to reduce investments in developing countries, further increasing the vulnerability of developing countries and generating additional pressure for people to try to migrate from poor countries to rich ones.[137]

Some advocates of poverty reduction and aid to developing countries argue that climate change is a problem for the distant future and is less important than many of the problems that plague the developing world today.[138] However, the majority of development organizations are beginning to incorporate climate change into their work.[139] Climate change may already be challenging development goals by interacting with and amplifying the problems that development is intended to ameliorate, and this interaction will grow stronger.[140] Various factors combine to make societies in Africa, for example, highly vulnerable to continued and future climate change:

- Weak governments and institutions.
- Rapid population growth.
- Widespread water stress.
- Prevalence of malaria and diarrheal diseases.
- Reliance on rain-fed agriculture.
- A large fraction of economic productivity occurring in climate-sensitive sectors.
- The climate change that has already occurred there.

Since many development problems are sensitive to climate (e.g., food security and disease),

136 United Nations International Strategy for Disaster Reduction Secretariat, 2009
137 Gulledge, 2008b
138 Lomborg, 2007
139 OECD DAC, 2009
140 Parry et al., 2007

experienced poverty reduction and development aid organizations have identified climate change as a serious risk to development goals.[141] For example, Christian Aid, which has worked in many least-developed countries for more than five decades, says:

> *[M]itigation – the cutting of harmful greenhouse gas emissions – must be viewed as the primary endeavor in climate change negotiations. It must also be seen as the most honestly pro-poor climate policy. Above 2°C of warming, any notion of development rather than merely a process of damage limitation will be lost... The twin aims of tackling poverty and climate change – for one cannot be achieved without the other – must be brought closer together.*[142]

While there may be a real danger of diverting sorely needed resources away from acute development issues in the name of climate change, the fact that climate change will exacerbate other problems means that it cannot be ignored in favor of dealing with those problems. An effective risk management framework would ensure that the basic problems of developing countries are the focal point of climate risk reduction goals.

Understanding Expert Bias

In spite of their deeper knowledge of climate change and/or security matters, experts may be susceptible to risk-misperception for a variety of reasons.

Within the climate science community, the culture and methodology of science may result in underestimates of projected change, unease with dire forecasts due to a lack of statistical rigor in the analysis, or a general sense that outlier results should not be entertained, even if no specific reason is known to reject them.[143] Some scientists may also fear losing credibility by appearing alarmist.

To avoid contaminating the knowledge pool with falsehoods, the scientific method places a premium on avoiding false positives – formally called *type I error* – and is quite permissive, at least in practice, of false negatives, or *type II error*. To guard against type I error, scientists typically apply a statistical significance rule (when applicable) that requires less than a 1-in-20 (5 percent) chance that a result has occurred purely by random chance. In cases where statistical power is very low (that is, when too few samples are available to inspire confidence about calculated outcomes), the bias against type I error increases the chances of committing a type II error. This intellectual bias makes sense in the context of the scientific process as a precaution against contaminating evidence with undetected falsehoods; however, it is not a sensible approach to managing the risk of extreme hazards.

141 OECD DAC, op. cit.

142 Christian Aid, 2007

143 Engelhaupt, 2007

This aversion to type I error stands in juxtaposition to the logic of risk avoidance, which may be more averse to type II error if the consequences of a false negative finding could be severe.[144] For example, current projections of sea level rise are very uncertain, but range as high as two meters by the end of this century (and much more beyond this century).[145] Since so many large cities, heavily populated coasts, crop-producing mega deltas and fishery-supporting coastal wetlands would be severely damaged or completely destroyed by this much sea level rise, the consequences of ignoring this upper-end estimate if it proved to be correct (a type II error) would be highly regrettable, to say the least.[146]

A closely related issue is the way scientists handle incomplete information, or *structural uncertainty*. An instructive case study of this problem lies in how the IPCC AR4 handled its sea level rise projections.[147] The AR4 projected sea level rise from 1990 to 2095 in the range of 18 to 59cm.[148] These numbers are based on computer models that estimated the expansion of seawater as it absorbs heat and the melting of ice on the surface of glaciers as the atmosphere warms. There was also a small add-on for the observed rate at which the ice streams in the Greenland and Antarctic ice sheets flowed into the oceans between 1993 and 2003. However, these models did not include a major source of future sea level rise: future changes in the rate of ice stream flow in the large ice sheets, a phenomenon scientists call *ice dynamics*. Therefore, the AR4 concludes:

> *Because understanding of some important effects driving sea level rise is too limited, this report does not assess the likelihood, nor provide a best estimate or an upper bound for sea level rise… The projections do not include uncertainties in climate-carbon cycle feedbacks nor the full effects of changes in ice sheet flow, therefore the upper values of the ranges are not to be considered upper bounds for sea level rise.*[149]

Changes in ice dynamics were omitted because scientists simply do not know yet how to calculate them, but they are the largest potential source of future sea level rise.[150] A true risk assessment would therefore need to consider an uncertainty range that was substantially larger than 18 to 59cm.[151]

This omission is related to the type I vs. type II error problem. Scientists are confident in their ability to model thermal expansion of seawater and surface melt on glaciers. On the other

144 Schneider & Mastrandrea, 2010

145 Overpeck and Weiss, 2009

146 Gulledge, 2008b, op.cit.

147 For a detailed discussion see Gulledge, ibid.

148 IPCC, 2007 (Synthesis Report, Summary for Policymakers), op. cit.

149 Ibid.

150 Alley et al., 2005

151 Rahmstorf, 2007b

hand, speculating on how changes in ice dynamics might alter future sea level rise is risky business for a community averse to type I error. But decision makers might choose to be more averse to type II error if they were informed of how much it could mean in terms of consequences. Indeed, some IPCC authors argued that alternative methods could have been used to paint a more complete picture of the risk. These methods would take advantage of information about sea levels in the geological past, when the Earth's temperature was a few degrees warmer than it is today. For example, as mentioned in the previous chapter, paleoclimate research indicates that sea level likely peaked seven to nine meters higher than at present about 125,000 years ago, the last time the Earth was between ice ages and at a time the global temperature was 1-2°C higher than it is now.[152] This could be very relevant to decisions about managing the risks of future climate change.[153] But in the AR4, future climate change and past climate change are described in different chapters with different authors, and the decision was to keep them separated.[154] This decision seems to be organized around scientific specialties rather than around informing decision makers about the risks of climate change.[155]

Working in silos and unconstrained type I-error aversion can lead to inadvertent expert bias that works against providing decision makers with the most useful and complete picture of the risks surrounding climate change.

On the other hand, an intentional form of bias occurs when experts openly dismiss uncertainty, driven by overconfidence in their individual understanding of relevant systems or by personal ideologies. In other words, some experts may be unwilling to embrace the full range of uncertainty because they lack objectivity. A small number of bona fide climate experts fall into this category, but their views often attract more attention from the media and decision makers relative to the vastly larger number of scientists that embrace the broader range of uncertainty embodied in the peer-reviewed literature and integrated assessment reports (see Box 4).[156] These stylized views may understate or overstate the risks, but when decision makers give special weight to these unique views, they choose to ignore the bulk of the scientific evidence that can inform risk.

In a risk management framework for climate change, the role of science is two-fold: it must fulfill its traditional role of making progress in understanding climate change processes and outcomes, and it must also work diligently and thoughtfully to circumscribe uncertainties with the express purpose of assessing risk. In the context of the culture and normal practice of academic science, these two roles are somewhat antithetical, although not fundamentally so. Informing decision makers about risk entails a balanced approach to describing both type I (false

152 Kopp et al., 2009, op. cit.

153 Jansen et al., 2007, op. cit.

154 This narrative of events was pieced together by one of the authors (J.G.) based on separate conversations with several IPCC Lead Authors from different sections of the IPCC Fourth Assessment Report.

155 The judgments expressed here are those of the author and are not necessarily shared by any of the IPCC authors.

156 Boykoff, 2010., op. cit.

positive) and type II (false negative) errors and their potential consequences, so that decision makers can make clear judgments about their own level of aversion to each type of error based on the *consequences* of being wrong and not just the statistical reliability of the information.[157]

To facilitate and better define the role of science in describing climate change risks, it is incumbent on the policy community to clearly identify risk management as the framework for making decisions about climate change and to ensure that scientists provide all types of information needed to underpin a balanced risk management strategy. This includes being vigilant against emphasizing singular opinions and attempts to dismiss the majority of the uncertainty (and therefore risk) resulting from individual overconfidence or ideology.

BOX 4: Expert bias on climate sensitivity

A recent hearing in the U.S. Congress aired a debate between scientists arguing for use of a low climate sensitivity (LCS) and scientists representing the mainstream view that a wide range of uncertainty exists with an overall best estimate that is significantly higher than LCS supporters contend.[158]

The LCS argument was presented by Dr. Patrick Michaels (Cato Institute):

"My tentative hypothesis would be that the sensitivity [of temperature to carbon dioxide] has been overestimated, in agreement with Lindzen, Spencer and a whole host of other scientists."[159]

The mainstream view was represented by Dr. Richard Alley (Pennsylvania State University):

"You have now had … a debate here between people who are giving you the [central estimate] and people giving you the [low-end estimate]. This is certainly not both sides. If you want both sides we have to have somebody in here who is [having a] panicked conniption fit on the [high] end, because you're hearing one very optimistic side – we wish Dr. Michaels and Dr. Lindzen were correct – against the assessed central value."[160]

157 Schneider & Mastrandrea, 2010, op. cit.

158 Hearing on "A Rational Discussion of Climate Change: the Science, the Evidence, the Response" before the House Science and Technology Committee, Subcommittee on Energy and Environment, November 17, 2010. Written testimonies and video recording of witness remarks: http://democrats.science.house.gov/publications/hearings_markups_details.aspx?NewsID=2947.

159 See video record of witness remarks at ibid.

160 Ibid.

This exchange illustrates intentional and inadvertent forms of expert bias: Dr. Michaels exhorts policymakers to heed his anomalously optimistic view that the true climate sensitivity is likely to be low – a classical example of expert overconfidence. In contrast, Dr. Alley points out that the debate in this Congressional hearing had centered on an optimistic view versus a central value, while neglecting the pessimistic end of the uncertainty range; such neglect is a common result of type I error aversion among mainstream experts.

Choosing to rely on improbably low values rather than following the central value would clearly be a high-risk approach. Alternatively, choosing to solely use a central value approach without considering high and low extremes would also remove from consideration by decision makers options for addressing all levels of potential harm. Only a structured risk management framework can allow decision makers to effectively challenge all forms of expert and disciplinary bias and construct a firm understanding of the evidence base for, and consequences of, particular decisions.

Learning and Risk Perception

Accurate risk perception underpins rational risk management. Since risk perception is based on understanding of potential consequences, it must be updated regularly as new lessons about consequences are learned.

The recent update of the IPCC's 'reasons for concern' (RFC) illustrates this concept. In its Third Assessment Report, published in 2001, the IPCC outlined five RFCs aimed at helping decision makers organize their thoughts around the concept of "prevent[ing] dangerous anthropogenic interference with the climate system", which is the agreed aim of the whole international community contained in the objectives of the UNFCCC.[161] What constitutes "dangerous" interference requires values judgments that are beyond science, but science can describe potential consequences of various levels or types of interference, which decision makers can then use to gauge danger.[162] The IPCC identified five categories of potential climate change impacts that they thought decision makers might care about in this context (see Box 5).

161 Smith et al., 2001; United Nations Framework Convention on Climate change, 1992

162 Parry et al., op. cit.

BOX 5: IPCC "reasons for concern"

The relationship between global mean temperature increase and damage to or irreparable loss of unique and threatened systems. Some unique and threatened systems may be irreparably harmed by changes in climate beyond certain thresholds.

The relationship between global mean temperature increase and the distribution of impacts. Some regions, countries, islands and cultures may be adversely affected by climate change, whereas others could benefit, at least up to a point. For example, in some sectors, adverse effects may be experienced in some parts of the world while other parts may have net gains. Within countries, some regions or groups of people could be harmed while others benefit or experience less harm.

The relationship between global mean temperature increase and global aggregated impacts. Using a consistent method of measurement and aggregation of climate change impacts, we address how aggregate impacts change as global mean temperature increases, whether aggregate impacts are positive at some levels of temperature increase and negative at others, whether change will occur smoothly or in a more complex dynamic pattern, and whether aggregate impacts mask unequal distribution of impacts.

The relationship between global mean temperature increase and the probability of extreme weather events. As mean climate changes, so too will the probability of extreme weather events such as days with very high or very low temperatures, extreme floods, droughts, tropical cyclones, and storms.

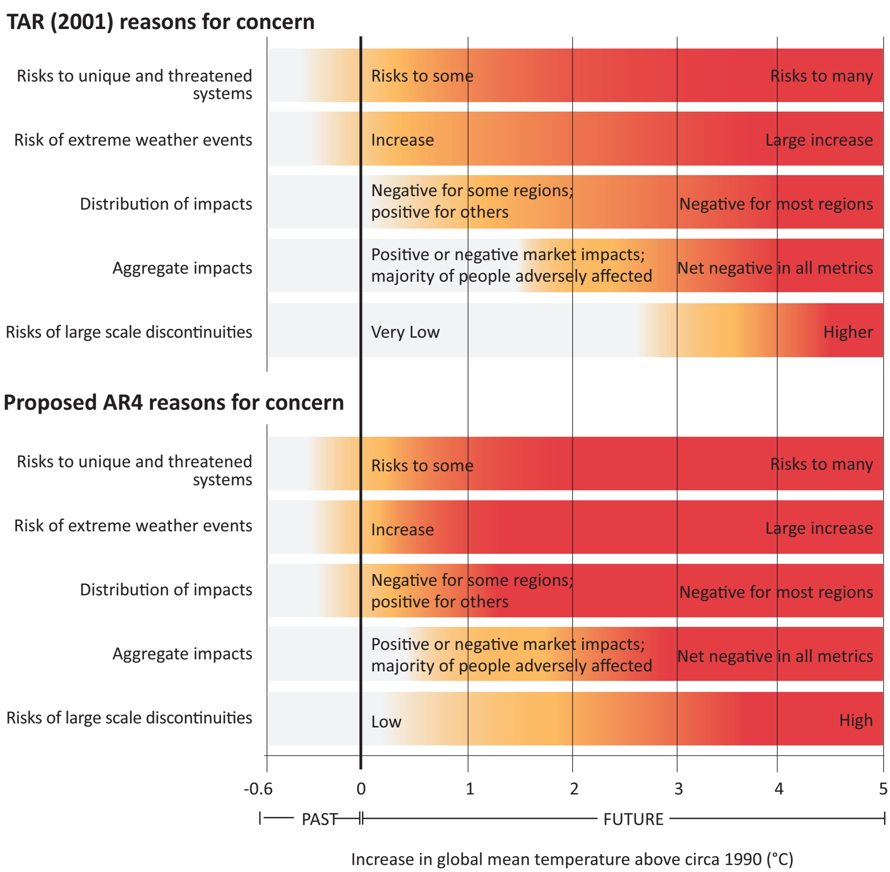
The relationship between global mean temperature increase and the probability of large-scale singular events, such as collapse of the West Antarctic ice sheet or shutdown of the North Atlantic thermohaline circulation.

Source: *Excerpts from Smith et al., 2001*

The intent was to give decision makers a sense of what level of global average warming might be tolerable before risks become very large for each of the five RFCs. Judgments were based on the expert group's perception of the risks, derived from the information available at the time (around 2000). The results are shown in the top panel of Figure 3.4. This figure became known colloquially as the "flaming embers chart" because of its color scheme.

Nearly a decade later, many of the original RFC authors and other experts updated the flaming embers chart to reflect new information gathered in the years since the original chart was produced.[163] For example, Hurricane Katrina's social impacts in the United States and the 2003 European heat wave revealed greater vulnerability in developed countries than previously realized. Much more data became available on the rate of observed climate change (for example, sea level rise, loss of Arctic sea ice and accelerating ice loss from the Greenland Ice Sheet), and the condition and vulnerability of unique ecosystems to warming and ocean acidification (for example, coral reefs, coastal wetlands, and alpine and Arctic species). More information was available about the number of people already experiencing damaging impacts (for example, coastal erosion and water stress). Some newer analyses of aggregate economic impacts found the potential for very large global economic damage. Almost all of the new information regarding all five RFCs pointed to greater risk at any given level of warming than the experts had judged to be the case in the previous assessment (bottom panel in Figure 3.4).

Figure 3.4: Recent update to the IPCC's "reasons for concern."



163 Smith et al., 2009

The risks of climate change at different levels of warming (°C) relative to the global average temperature in 1990, as depicted in the 2001 IPCC Third Assessment Report (top) and in the updated version published in 2009 (bottom). Increasing color intensity represents increasing risk with greater levels of warming. Coloring begins at the minimum temperature at which risk is estimated to become significant. White indicates "neutral or low impacts or risks", yellow indicates "negative impacts for some systems or more significant risks" and red indicates "substantial negative impacts or risks that are more widespread and/or severe". ***Source:*** *Smith et al, 2009.*

When the original burning embers chart was developed around 2000, relatively little information on observed impacts of climate change was available. Evaluating a decade of new information prompted the expert panel to lower the temperatures at which they perceived significant impacts or risks for all five RFCs. **This comprehensive shift toward greater risk estimates suggests a tendency for experts to underestimate impacts when information is limited and decision makers should bear this tendency in mind when planning against future climate scenarios.** The top to bottom comparison of the old and new burning embers charts also illustrates the need for continuous learning and updating our formal perceptions of risk. A risk management framework is the ideal vehicle for organizing and sustaining such an effort through time.

4 Evaluating the Current Response
No Effective Management Plan in Place

"Further recognizes *that deep cuts in global greenhouse gas emissions are required according to science, and as documented in the Fourth Assessment Report of the Inter-governmental Panel on Climate Change, with a view to reducing global greenhouse gas emissions so as to hold the increase in global average temperature below 2°C above pre-industrial levels, and that Parties should take urgent action to meet this long-term goal, consistent with science and on the basis of equity."*
Conclusion of the United Nations Framework Convention on Climate Change, Cancun, Mexico, December 2010[164]

Summary

- Both, the mitigation of greenhouse gas emissions and adaptation to unavoidable impacts are crucial to managing the risks of climate change. Adaptation cannot succeed unless climate change is limited to manageable levels through mitigation. On the other hand, mitigation cannot avoid all climate damages and adaptation will be required to manage the security consequences of those unavoidable changes.

- In modeling analyses, mitigation pathways that aim for a 50:50 chance of keeping global average temperatures below 2°C have global emissions of greenhouse gases peaking within a decade and declining to near zero before the end of the century. In these pathways, developed countries achieve nearly carbon neutral energy systems by 2050 and emerging economies follow within a few decades. If global temperature is more sensitive to greenhouse gas concentrations than currently estimated, or if greater impacts are observed at lower temperatures than expected, then deeper emissions cuts (and possibly net removal of CO_2 from the atmosphere) would be needed to preserve climate security.

- Adaptation has recently become a significant focus of the international climate change regime. While many countries consider adaptation to have equal importance to mitigation, there has been little real action on implementing adaptation strategies and deploying relevant resilience-enhancing policies and technologies. In addition, there is significant resistance in some quarters to explicitly considering climate impacts on stability and conflict when selecting appropriate adaptation measures.

- The Cancun Agreements, struck at UN climate negotiations in 2010, contain a goal of holding the increase in global average temperature below 2°C above preindustrial levels.

164 UNFCCC, 2010

However, countries did not agree to binding emissions reductions consistent with this target. Current best estimates suggest that if all emissions reduction efforts registered under the Copenhagen Accord and subsequently captured in the Cancun Agreements are fully delivered, global average temperature is likely to rise by 3-4°C; well into the range where damage becomes very severe and climate tipping points are likely to be breached. There is yet to be agreement on the details of a robust international climate regime that could monitor and enforce even these relatively weak commitments.

- International action on climate change is analogous to the current situation on nuclear proliferation. All countries formally acknowledge the risks of nuclear proliferation but are collectively failing to enforce a sufficiently robust counter-proliferation regime. However, in the case of the nuclear threat, the United States and other major countries are expending significant political capital to build and sustain an effective international control regime. **If the security threat from climate change was analyzed as rigorously as nuclear proliferation the question arises: what would an appropriate risk management strategy to deliver climate security look like?**

- **Current responses to climate change are failing to effectively manage climate security risks. There is a mismatch between analysis of the severity of climate security threats and the political, diplomatic, policy and financial effort being expended to avoid these risks.**

Elements of a strategy to keep warming below 2°C

The phrase "avoid the unmanageable and manage the unavoidable" captures the dual nature of the risk management response to climate change: both mitigation of greenhouse gas emissions – aimed at avoiding the most damaging impacts of climate change – and adaptation to those impacts that are already unavoidable because of emissions to date, are essential. Since climate change is already underway, it is not possible to avoid all damages. Adaptation will be required to manage the security and other social implications of those unavoidable impacts. On the other hand, adaptation alone is not viable because the consequences of unmitigated climate change are likely to be unmanageable on too many fronts. Adaptation cannot succeed unless climate change is limited to manageable levels. **The value of mitigation should be readily apparent to security analysts, who know well that the most successful battle is the one we don't have to fight.**

In order to stay within low to medium warming scenarios, significant greenhouse emissions reductions are needed by 2020 leading to very deep reductions in global emissions by 2050.[165] Keeping temperature rise below 2°C, would require stabilizing greenhouse gas levels in the atmosphere at around 450 parts per million of CO_2 equivalent (ppm CO_2-e).[166] Current

165 Gupta et al., 2007

166 Hare and Meinshausen, 2006

modeling estimates that this would give a 50 percent chance of remaining below a 2°C increase, not accounting for any positive climate system feedbacks. This implies that the world can emit another 500 billion tons of carbon before reaching the 2°C limit, roughly the same amount emitted since the beginning of the industrial revolution. At current emissions rates, this allotment would be exhausted by around 2050; since emissions are accelerating, however, the allotment would likely be exhausted much sooner without mitigation.[167] To achieve this goal, two thirds of current known fossil fuel reserves must remain in the ground; equivalent to stopping all further coal exploitation.[168]

In principle, it is possible in the future that we could learn that less stringent mitigation can avoid dangerous human interference with the climate system. However, since current observations of actual climate change suggest that climate models may be conservative in their projections, it appears more likely that more stringent mitigation measures could be needed. If we learn in the future that circumstances are less dire than previously perceived, the option to relax stringency will always be available. On the other hand, delayed action eliminates more stringent options with the passage of time and continued growth of atmospheric greenhouse gas concentrations.[169] Hence, the prudent response and the most economically efficient one, is to implement mitigation policies as early as is feasible.[170]

Even stabilizing emissions at 450ppm would require radical shifts in global energy systems over the next decades. Global emissions of greenhouse gases would need to peak within about a decade, and then start declining. Before the financial crash, they were rising at a rate consistent with the most damaging scenario modeled by the International Panel on Climate Change.[171] Recognizing that richer countries agreed to act first, the IPCC's most recent assessment report indicates that an effective approach would see developed countries cutting their emissions 25-40 percent by 2020, and 80-95 percent below 1990 levels by 2050. Under this scenario, developing countries would need to achieve a substantial deviation from baseline in key regions by 2020 and globally by 2050.[172] Emerging economies such as China would need to start delivering absolute emissions reductions by 2020-2030, when their per capita GDP levels will still be a fraction of developed country levels. In 2006, Chinese per capita CO_2 emissions were around half of European emissions; American per capita emissions are double European levels. But by 2020 Chinese per capita emissions could exceed European per capita levels.

These numbers lead to a simple conclusion: an even chance of staying below the 2°C threshold requires the developed world to have moved to a carbon neutral energy system by the middle of the century and major emerging economies to follow within the next few decades. Any remaining carbon 'space' will be used to cover emissions in agriculture, defense

167 Raupach, et al., 2007

168 Allen et al., 2009

169 Mignone et al., 2008, op. cit.; O'Neill et al., 2010

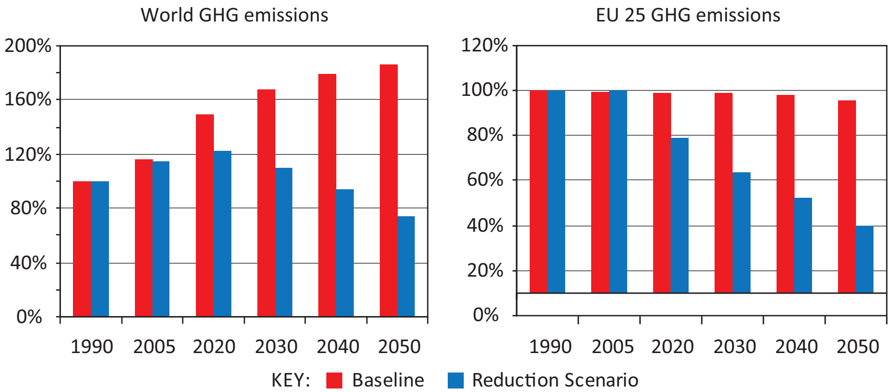
170 O'Neill, 2009, op. cit.; Yohe, 2010, op. cit.

171 Raupach, op. cit.

172 Gupta et al., 2007, op. cit. Box 13.7, p.776.

and perhaps some international air travel, though some models suggest all emissions will need to decline to zero in order to maintain temperatures below 2°C. If more stringent mitigation turns out to be necessary because impacts have been underestimated, negative emissions (i.e. net removal of carbon from the atmosphere) could be required.

Figure 4.1: 2°C Compatible Emissions Pathways for Developed and Developing Countries to 2050



Source: *European Commission, 2007*

Forming an Adaptation Strategy

Assisting developing countries in their efforts to adapt to climate change impacts has been a central tenet of the global climate regime since the drafting of the Framework Convention on Climate Change in the early 1990's. However, very little has actually been done over the intervening 20 years to explore key adaptation needs, identify sources of funding and technologies required, or undertake on the ground efforts to improve resilience.

Estimates of future adaptation investment needed to preserve critical infrastructure, security and economic output under different climate change scenarios include an additional level of uncertainty as they depend on regional and local climate change impacts. Many countries already spend large amounts of national resources managing and responding to impacts of the current climate; India estimates it spends up to 2 percent of GDP on these areas. The World Bank has estimated annual additional costs of $78 – $100 billion would be needed by 2050 to adapt to a 2°C scenario in developing countries.[173] Under a business-as-usual scenario, where temperature increase is not limited to less that 2°C, these costs could rise significantly.[174] These costs do not reflect the damage – and human costs – of a changing climate but an estimate of the cost of achieving greater resilience to climate change. The poorer developing countries expect a significant proportion of these funds to come from

173 World Bank, 2010
174 Ibid.

developed countries that have been responsible for the majority of emissions currently in the atmosphere but current total overseas development aid is only approximately $120 billion per annum; resulting in huge gap in potential investment needs.[175]

Successful adaptation and improved resilience requires more than just financial resources, it requires revisiting even the most effective international resource regimes. Climate change and growing resource scarcity will put great strain on international agreements to manage water, food trade, borders and other climate sensitive resources. These international agreements underpin the open global economy our prosperity depends on but there are clear trends showing major countries are hedging against the collapse of this order by securing bilateral access to vital strategic resources. While implementing such hedging strategies is understandable from each individual country's point of view, the collective result could undermine overall trust in the sustainability of the international rules based system for delivering fair access to critical resources. Most medium and small countries also have no recourse to such "great power" tactics. It is in the interest of global stability to counter-act these trends with targeted interventions to improve the resilience and effectiveness of critical international agreements to the impacts of climate change and resource scarcity, and thus increase the perception that the international rules-based system will continue to deliver reliable security and fair access to critical resources.

Despite intensive analysis it is clear that information on the regional and local impacts of climate change is still very weak, and this is hampering the development of effective strategies to increase resilience in all countries. State fragility and the existing communal and international disputes of climate sensitive resources such as rivers, maritime borders and fisheries will further complicate the design of adaptation strategies. Improving societal resilience will not be a politically neutral act in many of the most vulnerable countries of Africa, Asia and the Middle East. It is critical that these conflict issues are factored into international cooperation.

Current action to manage climate security risks

There are currently very few national climate policies in place which are consistent with a 2°C trajectory, and even fewer that are firmly incorporated into national legal commitments. Furthermore, the UN climate negotiations process has yet to yield a global agreement that will prevent dangerous climate change, which is the objective of the 1992 UN Framework Convention on Climate Change.[176] A review of recent UN climate negotiations reflects the political challenges of agreeing an effective international climate regime.

The Copenhagen Accord of 2009 was little more than a political "letter of intent"[177] cobbled together by a limited number of Parties during the final hours of highly anticipated UN

175 OECD, 2009

176 UNFCCC, 1992

177 UNFCCC, 2009

climate negotiations. The Cancun Agreements,[178] on the other hand were welcomed by numerous standing ovations by virtually all Parties to 2010 UN climate negotiations, giving a good indication of the outlines of a global climate regime can be agreed under current political conditions. The Cancun Agreements include several important elements that impact climate security concerns.

The Agreements also made some progress on operational issues that will have significant implications for climate security.

Adaptation – In recognition of all countries' need to implement adaptation measures, and to accelerate international cooperation to reduce vulnerability and increase resilience, countries established the Cancun Adaptation Framework and an associated Adaptation Committee. This effort is meant to promote effective adaptation including impact, vulnerability and adaptation assessments and disaster risk reduction strategies. It also calls for measures to enhance understanding, coordination and cooperation with regard to climate change induced displacement, migration and planned relocation and for improving climate related research, observation, and data collection in order to provide decision makers with better information.

Technology – Countries established a Technology Mechanism to accelerate deployment and transfer of mitigation and adaptation technologies. The major attributes of the system include a Technology Executive Committee and a Technology Centre and Network. The Parties agreed an accelerated work plan for the Technology Mechanism with a goal of taking decisions at climate negotiations in 2011 that make it fully operational by 2012.

Finance – Countries formalized commitments made in the Copenhagen Accord regarding pledges of international finance to assist developing countries to adapt to climate impacts and mitigate carbon emissions. Developed countries agreed to provide new and additional resources approaching $30 billion between 2010 and 2012, and longer-term finance flows rising to $100 billion per year by 2020. In order to facilitate these financial flows countries established a new Green Climate Fund.

Transparency – To facilitate access to information on how successful countries' carbon reduction measures are, all major economies will report on progress made toward meeting their mitigation targets and actions. In addition, developed countries agreed to use a common reporting format to facilitate transparency regarding whether they are meeting their commitments to provide financial support for developing country efforts. In return, developing countries have agreed to strengthen reporting on their mitigation activities including anticipated effects, domestic provisions and timelines for implementation.

Mitigation – They contain a goal of holding the increase in global average temperature

178 UNFCCC, 2010

below 2°C above preindustrial levels and require a review of the adequacy of this long term goal, based on the best available science, to be completed between 2013 and 2015. This review is explicitly to consider a 1.5°C goal and the Parties have agreed that they "shall take appropriate action based on the review".

Participation – In a departure from the Kyoto Protocol, which limited mitigation commitments to countries representing 35 percent of global emissions, the Cancun Agreements include a registry for mitigation targets and actions from developed and developing countries representing nearly 80 percent of global industrial emissions.[179]

Limitations of the International Climate Regime

Despite advances, the Cancun Agreements cannot be relied upon to deliver a path to climate security. The overarching vulnerability is that the Agreements are not legally binding in their current form and lack clarity around a timeline for establishing a legally binding regime. The Kyoto Protocol, which was drafted with the clear intent of legally binding developed countries to their mitigation commitments now stands in limbo, with Cancun decisions leaving an open question as to whether countries will agree keep the Protocol alive with a new set of reduction targets in the future. The Cancun Agreements specifically state that they do not prejudge the prospects for, or content of, a legally binding agreement in the future.[180]

The Cancun Agreements also lack a clear pathway to keep warming below dangerous levels. While the Agreements contain a goal to limit increases in global temperature to below 2°C, calculations of the commitments that countries have registered find that total reductions are actually more consistent with warming of 3-4°C. Specifically, the pledges fall short of the IPCC range of emissions reductions necessary for stabilizing concentrations of carbon dioxide equivalent (CO_2-e) at 450ppm), a level associated with a 26-78 percent risk of overshooting a 2°C goal.[181] Current pledges are likely to lead to a world with global emissions of 47.9 gigatonnes to 53.6 gigatonnes of CO_2-e per year by 2020. **This is about 10-20 percent higher than today's levels and would result in a greater than 50 percent chance that warming will exceed 3°C by 2100.**[182]

A further complicating factor in projecting the impacts of mitigation efforts is the fact that a number of parties registered emissions ranges rather than a specific goal. Many countries have indicated that working towards the stronger end of their target ranges is conditional on a global and comprehensive agreement, which is currently not in place. This means that countries will most likely default back to their lower-end pledges which would result in a 50:50 chance of a global temperature increase of nearer to 4°C.[183]

179 Rogelj et al., 2010

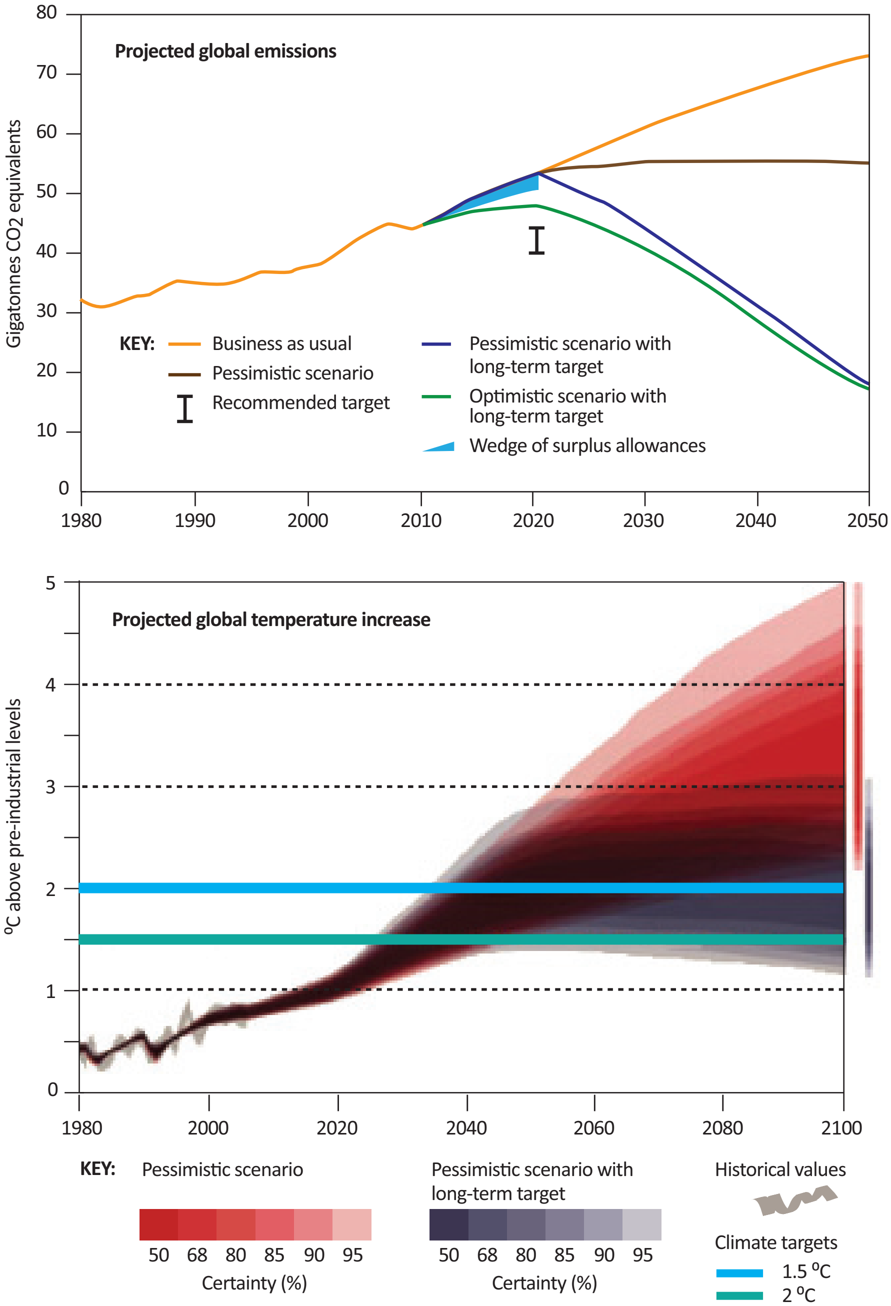
180 UNFCCC, 2010, op. cit.

181 Meinshausen, 2005

182 Rogelj et al., 2010

183 Ibid.

Figure 4.2: Effects of national emissions pledges in the Copenhagen Accord.



Source: *Regolj et al, 2010.*

Measures on finance face similar hurdles to achieving stated goals. For instance, though there is specific reference to providing $100 billion per year, and a new fund has been established, there is no specificity about how such funds are to be mobilized. The UN Secretary General established a High-Level Advisory Group, under the leadership of heads of state from developed and developing nations, for the purpose of making recommendations about how to mobilize such funds.[184] Yet the Parties in Cancun did not adopt any recommendations from this group, instead merely "taking note" of the report as one relevant source of information. Thus, while the agreements reflect a serious intent to implement a comprehensive response to the problem, political conditions have prevented securing legally binding commitments that would provide certainty about constraining risk.

In some respects, international action on climate change is analogous to the current situation on nuclear proliferation. All countries formally acknowledge the risks of nuclear proliferation but are collectively failing to enforce a sufficiently robust counter-proliferation regime. However, in the case of the nuclear threat, the United States and other major countries are expending significant diplomatic, economic and intelligence efforts to convince other countries of the importance of tackling the threat, and cooperating to build and sustain an effective international control regime. In the face of existential threats, countries do not wait for the political conditions to change in favour of an agreement to materially reduce risks, but construct pro-active strategies to change the range of the politically possible in order to advance their national interests. **If the security threat from climate change was analyzed as rigorously as nuclear proliferation, the question arises: what would an appropriate strategy to deliver climate security look like?**

184 UN Secretary General, 2010

5 Responding to the Threat
Learning from Security Sector Risk Management

"We never have 100percent certainty. If you wait until you have 100 percent certainty, something bad is going to happen on the battlefield. That's something we know."
General Gordon R. Sullivan, former Chief of Staff US Army; Chair CNA Military Advisory Board on National Security and the Threat of Climate Change[185]

Summary

- Uncertainty *per se* should never be a barrier to action. Policy decisions with tremendous economic impacts – from military procurement to financial system regulation – are taken under much greater uncertainty than exists over climate change science, impacts or policy choices. In the face of a serious security threat and partial information, climate change policy makers should learn some hard won lessons from the security community by adopting a rigorous risk management approach.

- Climate change shares central features with more traditional threats such as nuclear proliferation and terrorism. They all have high degrees of uncertainty over the sensitivity, range, scale, speed and the discontinuous nature of the threats, and significant uncertainty over the effectiveness and reliability of response strategies. They present hard security consequences that would require serious military responses if unmanaged, but need mainly civilian action to preventively reduce long-term security risks. There is one key difference that makes climate change much more certain than traditional security threats. Decision makers can rest assured that the climate system will follow the laws of physics.

- The security arena is full of lessons of effective and ineffective risk management strategies. In the Cold War NATO invested in massive nuclear and conventional deterrence to prevent the worst scenarios of future conflict, although the need for such "over-kill" is still disputed and blamed on vested industrial interests. In World War II, the inability of the French high command to adapt their strategy of passive defense – exemplified by the Maginot line – in the face of mobile armored warfare shows how incumbents can prevent responses to emergent risks. They allowed sunk costs, political divides, and uncertainty to paralyze action. Strategies against bioterrorism have taken a different approach, eschewing the possibility of comprehensive prevention and focusing on effective rapid response and early detection.

185 CNA Corporation, 2007, op. cit.

- Decision makers are used to thinking in terms of low-probability but high-impact events, and those that are high-probability but low-impact. However, the clear existence of climate system tipping points means that – unless global emissions are dramatically reduced - high impact events will have high probability. This unfamiliar scenario often seems hard for decision makers to absorb.

- Good risk management requires us to rigorously account for the full range of possible outcomes, and to understand the deficiencies of our institutional systems in dealing with them. Critically it requires objective and independent monitoring of how effective risk management policies actually are in practice, with updates and revision as these situations change.

- Implementing an explicit risk management approach is not a panacea which can eliminate the politics of climate change; either within or between countries. However, it does provide tools to make the consequences of choices clearer to decision makers, and can help create common understanding between different actors which itself should help promote agreement and greater cooperation.

Understanding Security Risk Management

Uncertainty *per se* should never be a barrier to action. Uncertainty doesn't mean we know nothing; rather, it is a description of how well we know something. If we know something within prescribed limits, then uncertainty can inform decisions. Public policy decisions with significant economic impacts – from military procurement to interest rates to financial system regulation – are taken under much greater uncertainty than exists over climate change science, impacts or policy choices.

In the face of a serious security threat and partial information, the climate change community could learn some hard won lessons from the security community and adopt a rigorous risk management approach to climate change. This is the kind of approach that has been taken with other global security threats – from the Cold War to nuclear proliferation to international terrorism – which the security community has decades of experience in practical implementation.

The leap from security policy methods to climate change is not as extreme as it may first appear. Climate change shares a core central feature with these more traditional threats. They all present hard security consequences which would require serious military responses if left unmanaged, but need mainly civilian action to reduce long-term risks. For example civilian authorities are mainly responsible for controlling civilian nuclear materials, reducing the influence of radical Islamic ideologies leading to violent extremism and building effective governance in unstable states to prevent future conflict. Successful management of these problems therefore requires cooperation and common approaches across the full range of security sector and civilian authorities.

Viewing climate change through the lens of national security provides an opportunity to utilize decision-support tools common to the security community. Security planners are frequently called upon to make strategic decisions in the face of uncertainty. Absolutes are a rarity in national security and decisions are generally a matter of managing and balancing various forms of risk. Security specialists must balance long-term versus short-term risks. They must balance between unlikely but potentially catastrophic scenarios and probable but manageable alternatives. They must make decisions with incomplete information and models that predict divergent outcomes. In short, security planners, on a daily basis, are confronted with greater uncertainty than policy makers dealing with climate change, which is ultimately pushed in a certain direction by the laws of physics.

In the security field there is always some, often extremely high, degree of uncertainty over threats and how to successfully counter them. Yet both policy makers and the general public accept that uncertainty is no excuse for inaction. Indeed, it is hard to imagine an American politician trying to argue that counter-terrorism measures were unnecessary because the threat of attack from al Qaeda was uncertain. But precisely this argument is often used by opponents of action on climate change to argue against even small measures to mitigate the threat.[186]

This report draws on the empirical and theoretical security literature to build upon a time-tested model for making national security decisions under conditions of uncertainty. By placing the climate change challenge into an appropriate conceptual space it is possible to develop concrete recommendations, structuring a risk management approach to policy and process. The principles explored are flexible enough to comfortably accommodate varied assessments of the threat, while recognizing that even the most optimistic projections of limited climate warming yield an imperative for action.

There is no off-the-shelf risk management approach to address national security threats, and indeed relying on past approaches would remove much of the value of the risk management process. However, the lessons of the past show that all effective responses rest on clear objectives, a willingness to address worst case scenarios and a process for explicitly managing the uncertainties that inevitably occur in large scale complex problems.

It has often taken a decade or more of intense debate for robust risk management strategies to emerge to tackle existing national security issues. We do not have the luxury of such time in the case of climate change as everyday we fail to act the risk becomes incrementally and irreversibly higher. Like the hands of a clock, the risks of climate change can only move forward.

186 http://republicans.globalwarming.house.gov/press/PRArticle.aspx?NewsID=2773

The Ubiquity of Strategic Uncertainty

The range of uncertainty in climate change is not dissimilar to the range of uncertainty common in security analysis. Uncertainty forms part of the strategic context of both areas; in that an understanding of uncertainty is vital in shaping the most important decisions. In fact, there are at least five major sources of uncertainty commonly encountered by security planners that are also present when addressing climate change.

1. Uncertainty about the likelihood of adverse effects. Uncertainties about when, where and what degree of impacts of climate change will be experienced are actually much smaller than the uncertainties often confronted by security planners. The United States, for instance, actively considers the possibility of a future conflict with China,[187] yet the likelihood of such conflict is at least an order of magnitude less likely than future realization of projections of climate change. Similarly, concern over the unlikely possibility of the development of Iranian nuclear weapons and ballistic missiles capable of striking Europe is prompting greater cooperation between European countries and the United States on missile defense.[188]

2. Uncertainty over the consequences of change. There is continued uncertainty around how existing infrastructure and human responses will affect climate change impacts on the ground. Security analogues for this sort of uncertainty include the significant debate about the likely consequences of the use of biological weapons by terrorists.[189] Some models suggest crippling effects, while others argue that such consequences are only likely to occur in cases of optimal deployment. Security analysts cannot rely on precision in estimates, and must instead work with wide ranges of possible consequences. Uncertainty is not seen as a justification for inaction, but rather is seen as a structural condition that must be addressed in crafting effective policy response (see box).

BOX 6: Managing the risk of bioterrorism

Shortly after 9/11, the United States was struck by a series of biological attacks that killed five people and infected seventeen more. The FBI eventually concluded that they were the sole work of disgruntled US Army microbiologist Dr Bruce Ivins, not al Qaeda as originally feared. As such, the anthrax attacks served as a shocking reminder of the risk of both domestic terrorism and biological terrorism.

Mass casualty bioterrorism attacks require a combination of factors: a highly contagious agent, a long incubation period, high levels of host mobility, and effective

187 Minnick, 2010

188 Illmer, 2009

189 National Research Council, 2008

weaponization and deployment. It is a difficult issue to address because the range from low- to high-end casualty estimates encompasses several orders of magnitude, from the single digits to tens of millions.[190] This is a function of the wide variation in transmission rates of various pathogens and the varying success terrorists may have in manufacturing and spreading the disease. In short, there is massive uncertainty about whether such an event is likely to occur and, even more so, about the consequences of an attack.

The obvious responses include early detection and the ability to isolate those infected. For treatable diseases, the challenge is one of logistics: the production, storing, and distribution of sufficient antibiotics and vaccine doses to treat all those infected or at risk. But in the final analysis, the best way to reduce risk is to develop the ability to respond quickly. Time is the crucial factor: being able to quickly recognize a bioterror attack is the most significant factor in preventing mass casualties. This conclusion emerged only after careful study and a rigorous assessment of the nature of the risks. As a consequence, bioterrorism preparedness has focused heavily on first responders.

3. Uncertainty over the speed of changes. The speed of climate change depends on unknowable future human choices[191] and as yet unknowable parameters of climate sensitivity. Similarly, a great deal of security planning must be based on long-term trend analysis inherently subject to uncertainty. Analysts working in the non-proliferation field, for example, have long had to deal with this challenge. At the micro level, there is tremendous uncertainty surrounding the nuclear ambitions of individual states, for example Iran. At the macro level, since the 1960s policy makers have been responding to inaccurate predictions of widespread proliferation of nuclear weapons to perhaps as many as thirty countries by the year 2000.[192]

4. Uncertainty about discontinuities. Discontinuous outcomes (moving from one threshold state to another) are possible – and indeed likely – in any complex system, including the global climate system and the international security system. The history of warfare is replete with examples of such discontinuities, including the rise of the Hittite Empire due to the harnessing of iron, and Alexander the Great's mastery of combined arms.[193] Even today, strategists must deal with the possibility of technological developments (such as cyber warfare) and societal developments (including globalization and religious fundamentalism) overturning embedded security calculations.

5. Uncertainty over the effectiveness of policy instruments. There is considerable uncertainty in the ability to predict the success of policy responses to climate change, a process well

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190 Zubay, 2008
191 Briscoe, 2004
192 Cirincione, 2008, p. 33
193 Krepinevich, 1994

reflected in the security literature – from questions over sanctions to democratization. However, skeptics of climate change draw the wrong conclusions: inaction is not an appropriate response to uncertainty. Rather, effective policy under uncertainty involves explicitly and carefully weighing the various sources of risk, and applying an effective risk management framework to analyze these risks and adopt appropriate strategies in response.

Risk Management: A Framework for Embracing Uncertainty

A risk management approach can provide a basis for sound decision-making even under high uncertainty. Good decision-making requires us to rigorously take into account the full range of the known and unknown aspects of a problem, understand the biases and limits in our information systems as well as our responses to uncertainty, systematically analyze threats and vulnerabilities, and put in place strategies to effective manage risks. Critically it requires objective and independent monitoring of how effective risk management policies actually are in practice, and updating and revision of these as situations change.

Risk management is a practical process that provides a basis for decision makers to compare different policy choices whilst considering the likely human and financial costs and benefits of investing in prevention, adaptation and contingency planning responses. There are risks that are not cost-effective to try and reduce, just as there are impacts we cannot feasibly adapt to and others that could undermine fundamental aspects of societies. In the Cold War, NATO invested in massive nuclear and conventional deterrence to respond to the worst scenarios of future conflict, and there are still arguments over whether the high costs – and overkill – of deterrence were fully justified. Strategies against bioterrorism have taken a different approach, eschewing the possibility of comprehensive prevention and focusing on building capability for effective rapid response and early detection and containment.

The key to good policy is to systematically assess all of these issues, using all of the information we have now or can obtain in the future, rather than ignoring inconvenient or 'extreme' risks. A core lesson of the regulatory failures that led to the global financial crisis in 2008 is that seeing the world through the prism of a single theoretical model can result in policy makers ignoring vital evidence of fundamental threats.

Risk management is both an art and a science. It depends on using the best data possible, but also being aware of what we don't know and cannot know. It takes into account the biases in our data and in the way we analyze and use it. It requires complex – and often unquantifiable – trade-offs between different strategies to prevent, reduce and respond to risks. It is both long term and reactive.

There are a large number of potential responses to risk. These include hedging, insurance, mitigation, adaptation and redundancy. Each of these distinct approaches plays a role in balancing risk. The goal can be either to equalize risk across a number of policy options or pursue an appropriate strategy that seeks to improve the worst possible case. In either case, the framework functions by forcing decision makers to make explicit choices. The enunciation of these choices is crucial because it forces decision makers to confront the consequences of their decisions, but it is also significant because it serves an important role in shaping and structuring a responsible public debate over crucial policy issues.

A risk management framework is more complex than the usual process of plotting dangers against a probability/consequences matrix. Nonetheless, that serves as a useful starting point and helps explain some of the reasons decision makers seem to have such difficulty grappling with the climate change challenge.

Deconstructing risk management responses to different types of uncertainty

Decision makers are used to thinking in terms of two types of problems: those that are low-probability but high-impact, and those that are high-probability but low-impact. Balancing risk between those two is notoriously difficult, but in security affairs analysts often conceive of policy responses that blend a steady state capacity to deal with regular outbreaks of high-probability, low-impact events, while maintaining a surge capacity to deal with the low-probability, high-impact events. The advantage in this case is that if policy responses exist that can meet both sets of challenges, then it is relatively easy to balance requirements since in the event that the high-impact challenge manifests itself, resources can be stripped from the low-impact events to deal with the more dangerous challenge. Under these conditions, the high-probability, low-impact events take on characteristics of *lesser included contingencies.*[194]

As a practical matter, policy responses can rarely be optimized for both sets of challenges. However, policy responses can be developed that are reasonably adequate for both sets of challenges and sufficiently interchangeable to allow for re-purposing relatively quickly. An obvious example is the trade-off between developing military capacity to wage conventional military operations and those required for a peacekeeping function. Conventional forces can be used in a peacekeeping role, though they may not fulfill these functions as effectively as would a dedicated peacekeeping force. But given the cost of each, it is difficult to justify the creation of what are effectively redundant forces. Instead, a dual-use capability can be developed.

Climate change does not fit into this dichotomy, however. The threat of climate change is high-impact and high-probability. Unfortunately, many decision makers, conditioned by years of the trade-off between those two, have trouble grasping this. **The tendency to conceive high-consequence events as low-probability is so dominant it creates difficulties conceptualizing a catastrophe that seems both likely and imminent.** The response in policy circles has often been either denial or resignation.

If the risk management framework is broadened to encompass greater varieties of risk, a

194 This approach has been explained as the management of hybrid threats, or 'high-low' combinations of capabilities and methods – that is, violent irregular forces that possess advanced military capabilities or regular forces who combine conventional and unconventional warfare. See Freier, 2009

number of strategies can be identified that effectively manage risk and that can define a set of solutions to focus policymaker's attention. In this way, each of the five sets of uncertainty outlined above lends itself to appropriate policy response (see Table 5.1 for a summary).

Uncertainty about the likelihood of adverse effects

The standard response to this sort of uncertainty involves risk mitigation, hedging and insurance. The goal of risk mitigation would be to invest resources in trying to prevent the adverse consequence from manifesting itself in the first place. Risk mitigation is most useful when there is significant chance of the adverse event occurring. Historic examples include the adoption of a policy of containment by the United States in the face of what was seen as a high-probability risk of Soviet aggression. Today, the United States continues to invest significant resources in various environment shaping strategies, such as security engagement and presence designed to reduce the overall chance of adverse outcomes occurring.[195] Indeed, in the security field, risk mitigation is the prime source of risk management, and on a day-to-day basis is often the single most common activity. When considering lower-probability risks, hedging and insurance schemes come into play. Insurance usually requires a third party willing to cover risks, and indeed private interests are increasingly seeking methods to insure against the risks of climate change – just as they do against national security risks; but this is not an option, usually, for governments. The non-diversifiable nature of climate risk makes insurance a less viable option in the climate change arena as many believe that overall climate change is uninsurable; there is no third party capable of making good on even a small percentage of the costs, and given the high likelihood, the fees would be exorbitant.[196]

Hedging, however, remains a possible response. The classic case of hedging in the security field is the secret alliance. Public alliances involve some hedging as well, but also serve a deterrence/shaping function. Secret alliances, by contrast, are designed largely to manage risk by giving a country increased capability to draw upon in the case of conflict. States negotiate secret alliances in advance for two reasons. First, it serves to reduce the threat a nation faces by reducing the negative consequences of a conflict in the future. This allows a state to balance resource allocations to face a wider array of challenges. Second, they are negotiated in advance because seeking an alliance once a conflict has begun is likely to face a higher chance of failure, and is also likely to be more costly. Hedging strategies in the present are designed to make adaptation strategies in the future less costly and more likely to succeed. In other words, the best chance of adapting effectively later is built on hedging now.

In the case of climate change, local government and voluntary initiatives are emerging as hedging strategies in the absence of clear guidance from national and international authorities. The Regional Greenhouse Gas Initiative and the Western Climate Action Initiative in United States, both centered on cap-and-trade mechanisms in the utilities sector are a case in point. In Canada and Mexico, sub-national authorities are also forming policies

195 Discussed in depth in the 2010 Quadrennial Defense Review. US Department of Defense, op. cit.

196 US Government Accountability Office, 2007

and agreements.[197] Worldwide, a multitude of companies have launched pre-emptive policies and initiatives toward, for example, adoption of cleaner technologies or emissions reduction from production processes.

Security policy makers routinely manage uncertain threats in precisely these ways. They try to shape the environment. They build up deterrence capabilities. They hedge against future risks through alliances. None of these require certainty. Indeed, they only make sense as responses to uncertainty.

BOX 7: The defeat of France in 1940

By the mid-1930s, all the great powers were experimenting with armored warfare and there was a fairly significant body of evidence that new technology would transform the nature of warfare.[198] The demands of the mechanized warfare that was emerging required a more professional military with smaller numbers of individuals serving longer enlistments to gain technical proficiency. This requirement was a source of political unease in France at the time because of tension between the political left, which favored a more populist military structure, featuring widespread service but short enlistments, and the right that preferred the reverse. Furthermore, having invested heavily in static frontier defenses – the Maginot Line – the French defense establishment was reluctant to embrace a form of warfare that might negate the utility of this capital investment.

What is striking is not so much that France failed to embrace the potential of armored warfare, but that they did not seek to mitigate the risks of Germany adopting such an operational concept. France could have reduced its military risk dramatically through a variety of relatively low-cost mitigation and hedging strategies. For example, they could have created a strong reserve force to counter-attack a potential German breakthrough. Instead, the French were unable to demonstrate resilience and an ability to respond to an initial breakthrough, and as a consequence their risks escalated dramatically once the Germans were able to develop a plan that solved the technical challenges of overcoming frontier defenses.

The French approach lacked resilience and redundancy. They allowed sunk costs, political divides, and uncertainty to paralyze action. And as a consequence their risks spiraled as their security became increasingly dependent on the hope that the German military would not be able to solve what was essentially an engineering challenge – namely how to neutralize or bypass French forward defenses. In a

197 Jones & Levy, 2009
198 Paret et al., 1986, p. 527-676

parallel with some of today's debates over climate change, the French focused wholly on the risks of policy changes and ignored the risks of inaction. The result was a substantial and unmitigated escalation of risk that ultimately manifested itself in military defeat.

Uncertainty over the consequences of change

In the security field there is a continuous challenge with managing worst case possibilities. Outside critics often assert that security analysts and policy makers over-inflate worst case risks, which can become self-fulfilling prophecies because of the dynamics of security competition.[199] Nevertheless, considering worst case risks is an important element of any security analysis. Interestingly, there is compelling evidence – detailed in Chapter 2 – that in the climate change field, policy makers are systematically underestimating not only worse case scenarios, but even likely scenarios.

The breaking point on decisions regarding worst case risks is the point at which the outcome becomes literally intolerable. Policy makers often focus particularly on this issue before deciding on a course of action. Implicitly, they are here applying a *maximin* strategy, where the goal is not to manage the whole range of risks, but rather to remove the single greatest danger from the table.[200] This was, for example, the decision-making logic behind the Israeli attack on Iraq's Osirak reactor.[201] Regardless of whether the Israelis considered a future nuclear attack by Iraq likely or unlikely, they were simply unwilling to live with the possibility of it occurring at all.

This is an important line of analysis in climate change debates. When we examine outcomes that are likely to occur with a greater than 4°C change in global temperature – certainly not a worst case scenario – they reveal consequences that are intolerable for many and which would have second-order consequences that would likely be intolerable for all.[202] Security analysts looking at this sort of a challenge should develop maximin strategies to ensure that, regardless of anything else, these outcomes do not occur. Based on the physics of the climate system, this approach would necessitate limiting the concentration of CO_2 in the atmosphere, which is the only viable option to limit worst-case impacts of climate change.[203]

199 This is the logic of the 'security dilemma'. See Jervis, 1978.

200 This strategy of minimising the maximum expected costs (minimax) or maximising the minimum expected outcome (maximin) is considered one of the key principles of game theory.

201 Feldman, 1982

202 The warming range that defines the intolerable rests below this range for many countries for whom 4°C of warming would already put them beyond existential boundaries.

203 Orr et al., 2005

BOX 8: The development of US nuclear force structure

By the late 1950s, the Soviet Union had developed nuclear weapons and a significant delivery capability. At this point American strategists began work to transform an incipient form of nuclear deterrence into a clear doctrine. The ends were clear: the United States hoped to deter the Soviet Union from using nuclear weapons against the United States or its allies. The means to achieve this was the establishment of nuclear deterrence built on the threat of US nuclear retaliation.

The problem was that there was significant uncertainty about the effectiveness of this policy instrument. On the one hand, policy makers were aware of the fact that they would themselves be deterred by the credible thought of even a single warhead exploding in an American city.[204] So there were some who argued for a minimal deterrence posture, with a small force sufficient to ensure freedom from attack. On the other hand, other analysts believed that the Soviet leaders were fanatics, perfectly willing to sacrifice a significant percentage of their population in order to achieve world domination. They argued that effective deterrence required building a capacity to wholly devastate the Soviet Union, even if this involved massive construction, maintenance and deployment costs, and would also risk provoking a dangerous arms race.[205]

The challenge was that the risk of nuclear attack represented a wholly intolerable outcome that had to be removed from the table. As a result, the United States gravitated toward a massively redundant nuclear arsenal: a triad of land-, sea- and bomber-based nuclear forces, each of which had the capability to devastate the Soviet Union. This approach may have resulted in over-kill, but it came out of a coherent risk management framework. The main problem with the nuclear decisions of the late-1950s and early-1960s was the failure to mitigate the risks associated with this kind of build-up. The United States did not embrace a nuclear arms control agenda to stabilize the arms race until the late 1960s, and periodic technological advances – such as the development of multiple warheads and a rudimentary missile defense capability – chipped away at the foundation of these force-planning decisions.[206] Though Cold War nuclear deterrence was costly and redundant, it never failed. Deterrence held and the Cold War was able to wind down in response to political developments rather than culminating in military conflict.

204 Bundy, 1988
205 Freedman, 2003
206 Newhouse, 1973

Uncertainty over the speed of changes

Security analysts regularly deal with uncertainty over the speed of change, though in practice this is clearly the least well-managed problem. The issue is that relatively small mistakes in calculating the slope of threat over time can yield massive under- or over-estimations of the threat. For instance, the United States over-estimated Soviet economic growth for years. In the 1970s, analysts began to project a future where the Soviet Union might actually overtake the United States in economic might. The reverse, of course, can also occur as negative trends are systematically under-estimated, giving rise to the possibility of disruptive surprises.

Appropriate responses to this sort of uncertainty involve the development of more robust tracking mechanisms. There is an entire sub-discipline of the arms control field devoted to developing and honing verification mechanisms precisely for the purpose of assuring that assessments of trends – such as the amount of enriched uranium produced – are indeed accurate.[207] Again, this is a source of uncertainty and risk in the security field. This uncertainty is not seen as a justification for inaction, but is instead a justification for increased attention. In the climate change area, this would require a greater emphasis on monitoring, particularly in the context of thresholds for climate system tipping points. As discussed previously, there is compelling evidence that the speed of climate change has been underestimated, and yet the public debate has largely failed to acknowledge the likelihood that uncertainty over the speed of change is a much larger source of elevated risk than of positive opportunities.

Uncertainty about discontinuities

Security analysts are poor at dealing with the possibility of massive discontinuities. However, this can serve as a cautionary tale about failures to understand how quickly risks can develop and manifest themselves.

Discontinuities are an inherent element of complex systems. There is an important distinction between 'complicated' systems and 'complex' systems. The former are ultimately closed systems, and can be fully analyzed. An airplane is a complicated system, made of thousands (or even millions) of parts. But their interaction can be fully modeled. When planes crash due to mechanical failure, it is usually possible to trace back the problem to the single source that caused the sequence of events that brought down the aircraft. It can be hard to understand a complicated system, but with sufficient diligence they can be fully modeled, and as a result managing risk in complicated systems is fundamentally an engineering challenge. Complex systems, by contrast, are characterized by the existence of multiple and rarely fully understood feedback loops and mechanisms. While complex systems are fully deterministic they are not fully predictable; no matter how great the resources devoted to analyzing their component parts.[208]

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207 A useful primer on verification issues and resources is available at NuclearFiles.org (n.d.). There was a significant emphasis on verification measures at Copenhagen, see Reuters, 2010.

208 Kurtz and Snowden, 2003

Complex systems resist simple predictions about the future. The essence of managing complexity is to apply multiple lenses to the same issue or challenge in order to gain insights. Some of the techniques to understand complexity involve consensus mapping across various domains to identify both areas of analytic confluence and areas of unexpected disagreement. Working through complexity also requires open-ended analysis, for example through free-play war-gaming. It also requires sensitivity to variations across multiple levels of analysis.

Consider the discontinuous development of American military dominance in the 1990s. Prominent analysts – using linear methods – had estimated that the United States might take as many as 30,000 casualties in dislodging Iraq from Kuwait in 1991. Instead, the number was less than 1,000, with fewer than 200 combat fatalities.[209] This represented an increase in combat effectiveness of nearly two orders of magnitude. It occurred by a confluence of self-reinforcing, though largely unplanned, dynamics. Although these dynamics were ultimately brought together in a single system, they were initially engineered as autonomous developments. This included:

- The development of a Cold War operational concept of isolating the battlefield in the face of Soviet numerical superiority in Europe.
- The spread of precision munitions due to specific battlefield requirements in Vietnam, as well as the lessons from the 1973 Arab-Israeli conflict.
- The increase in computing power and communication throughput developed by private industry.
- A set of unique insights that led to the development of stealth technology to defeat radar systems.[210]

Climate change is the ultimate complex system. The global climate itself is so complex that it is extremely challenging to model conclusively. There are likely to be a vast number of 'unknown unknowns' in the system. Indeed, some opponents of tackling climate change mitigation rely on this to bolster their arguments, positing the existence of some sort of undiscovered homeostatic mechanism to keep the system in balance. But the unknown unknowns also cut in the other direction, as evidence from thawing permafrost and the unexpectedly rapid collapse of massive polar ice shelves demonstrates. The fact that there are many debates in climate science points to the significant uncertainty in the models. Worse, because human action is changing the climate, human behavior must be incorporated into climate models. This generates an additional source of uncertainty, albeit one that security analysts face in many other contexts as well.

209 For a discussion of the challenge of estimating combat loses see O'Hanlon, 2003.

210 Shimko, 2010

The climate is a complex system and most forms of human interaction exist in the realm of complexity. Managing climate security requires a robust strategy that can shape outcomes created by the interactions of both human and climate systems. Ultimately, complexity itself is a significant risk factor that needs to be addressed explicitly. Many of the most significant military disasters in history have been a consequence of a failure to grasp the possibility of sudden and massive discontinuities. The attacks on 9/11 were an archetypal example of such a discontinuity. While there was significant evidence in advance of the attacks, their discontinuous nature put anticipation outside of the realm of predictability for most security analysts.

The 9/11 Commission criticized analysts and decision makers for a failure of imagination when considering the nature of likely terrorist attacks on the United States.[211] Not considering and preparing for the full potential impacts of climate change would constitute a similar failure of national security systems.

Uncertainty over the effectiveness of policy instruments

A fundamental challenge in security analysis regards uncertainty over policy instruments. Consider contemporary debates about Iran. Can Iran be deterred? Will sanctions change the regime's desire to acquire nuclear weapons? Does confronting the regime bolster its legitimacy or undermine its public support? Every security issue faces these sorts of challenges.

Part of the problem revolves around the challenge of affecting complex systems, but there are at least three more significant problems. First, policy responses are often indirect. Iranian preferences, for instance, cannot be directly altered. All that can be done is to calibrate a series of incentives and disincentives and hope that the right balance is found. Second, it is often difficult to control second-order consequences, and of course difficult to predict unintended consequences. Third, policy choices are constrained by political consequences. This means that even optimal policy options are often implemented in a sub-optimal way. Indeed, it is often the case that adjustments due to political considerations render policy choices not just sub-optimal, but actually counter-productive.

Uncertainty over policy effectiveness encourages security policy makers to adopt redundancy in their recommendations (that is, duplication of elements to provide alternatives in case of failure). In fact, redundancy in security analysis is so deeply rooted – lodged in the maintenance of reserves on the battlefield since antiquity – that it is rarely commented on any longer.

The contrast to climate change policy could not be starker. While the behavior of the climate system – and the different socio-economic scenarios which partly drive it – are modeled in sophisticated probabilistic scenarios, plans to reduce emissions are generally generated by deterministic least-cost optimization models.[212] These models tend to have no analysis of

211 See National Commission on Terrorist Attacks Upon the United States, 2004., op. cit.

212 For example, see International Energy Agency, 2009 or McKinsey&Co, 2009.

policy failure despite the highly uncertain nature of some mitigation options, such as wide spread energy efficiency implementation, reducing tropical deforestation, availability of biofuels, and agreement on an effective global emissions reduction regime. Some work has been done on the impact of critical low carbon technologies (for example, carbon capture and storage) not being available as soon as expected,[213] but very little on the probability or risk management of innovation and technology diffusion. This is beginning to change at the national level in some countries, where policy failures in existing climate mitigation programs are all too apparent and the need to keep a portfolio of technology options open is seen as crucially important for delivering a reliable, least cost emissions reductions roadmap.[214]

Discussion of climate change responses is mostly concerned with their adequacy if fully implemented, direct costs, impact on existing industries and non-climate impacts (for example, nuclear waste, biofuels displacement of food crops or reliability of renewable energy). Discussion of potential policy and technological failures is mostly missing, or drowned out by the voices of special interests and technology champions. This has resulted in little rational discussion of risk management strategies and even fewer proposals for building in redundancy and/or contingency plans for managing failures when they occur.

Key Principles in Implementing Risk Management Frameworks

Table 5.1 summarizes the generic responses to the types of uncertainty described above. In practice policies embodying these approaches must emerge from a specific risk management framework. These should be designed based on the three key principles: decision maker focus, managing information, and systematic analysis of policy alternatives.

Table 5.1. Summary of generic risk management responses to uncertainty.

Type of uncertainty	Risk management response
Uncertainty about the likelihood of adverse effects	Mitigation and adaptation enabled through hedging strategies.
Uncertainty over the consequences of change	Define worst cases and specify maximin strategy.
Uncertainty over the speed of changes	Development of robust monitoring using bench-marks and explicit hypothesis testing.
Uncertainty about discontinuities	Increased learning and monitoring using levels-of-analysis consensus mapping and free-play wargaming.
Uncertainty over the effectiveness of policy instruments	Redundancy and contingency strategies.

213 See International Energy Agency, 2008 and International Energy Agency, 2010.

214 See UK HM Government, 2010 and Committee on Climate Change, 2010 for examples of this in the United Kingdom.

Decision maker focus

Risk management needs to be fundamentally decision maker focused. It serves as a tool to guide decisions and promote productive exchanges among empowered stakeholders. It provides the basis for comparison between different policy choices, allowing decision makers to compare likely human and financial costs and benefits of investing in prevention, adaptation and contingency responses. While risk management responses must be tailored to fit national (and sub-national) circumstances, having a common risk management framework can promote alliances and partnerships based on common interests and shared vulnerabilities, and reflect complementary strengths and role specialization.

One basic challenge with climate policy is that decision-making is diffuse. Among major public policy issues, climate policy is perhaps the issue with the largest number of crucial decision points. Not only is this an issue requiring international cooperation to produce effective policy, but any strategy will also require significant cooperation from sub-national government actors as well as a myriad of private sector concerns. Some of the most effective tools of mitigating climate change require broad-based cooperation from millions of individual citizens, for example, in energy conservation and efficiency measures.

An effective risk management framework requires first identifying the risk managers and the environments that shape their risk management response. Confusing environments, perverse incentives and insufficient public oversight can lead to poor or non-existent risk management strategies, with disastrous consequences. For example, the way in which the financial sector was bailed out after the poor investment choices that created the 2008 financial crisis essentially socialized losses while privatizing gains, giving risk managers in that sector little incentive to employ more effective risk management in the future. Similarly, the companies involved in the 2010 Deep Horizon oil spill were responding to an environment where liability was capped at a level that was not significant when compared to expected returns, and government oversight entities were ineffective. While adjustments are underway, the existing policy environment provided little incentive for rigorous internal oversight or disaster response planning.

Risk management approaches do not provide absolute answers but depend on the values, vulnerabilities, interests, perceptions and risk appetites of specific decision makers. Risk management is as much about who manages a risk as what a risk is, and must always consider who is best placed to actually influence outcomes. For example, The Maldives will have a different risk management strategy to Russia; in India subsistence farmers will balance risks differently from the steel industry. Legitimate differences in risk management strategies will form much of the on-going substance of climate change politics at national and international levels. All societies continually run public debates on similar existential issues such as the balance of nuclear deterrence vs. disarmament, or civil liberties vs. anti-terrorism legislation. Decisions are constantly made even when significant societal differences remain over the right balance of action.

Decision makers will generally tend to act rationally, but they can only do so if they are, in fact, receiving accurate risk and reward signals. Often they do not receive these signals. They are subject to organizational bias, work with incomplete information, run up against institutional limitations, and/or have immediate political and institutional imperatives which bias against responding to information. Fundamentally, the complexity of the world must be addressed with imprecise tools and institutions that are ill equipped to deal with complex systems. These institutional limitations are significant in the field of climate change. The author Upton Sinclair famously noted in the 1930s, "It is difficult to get a man to understand something when his salary depends upon his not understanding it."[215] Machiavelli also noted that:

> *"[I]t ought to be remembered that there is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things. Because the innovator has for enemies all those who have done well under the old conditions, and lukewarm defenders in those who may do well under the new."*[216]

These quotes define the institutional challenge to realizing climate security. Existing institutions are not well designed to implement policies in response to complex systems and uncertain risks. **In general, established interests tend to capture government institutions and use them to defend the existing order of things.**[217] **It is only the long history of military disasters that has, over time, conditioned military institutions to be more aware of uncertainty and heedful of managing risks.**

Not all actors are equally vulnerable to externalities. Many operate under different time horizons. Indeed, for political actors, this is a crucial problem. That is, the negative consequences of climate change occur in the future, the adjustment costs for effective mitigation occur *now*. Even for political actors concerned about the future, their ability to influence the future depends on their ability to remain in power in the present. So their policy risk and political risk assessments point them in different directions, but it is not simply a choice to focus on policy risk. No matter how brave they are, taking action that puts them in political jeopardy also eliminates their ability to affect policy down the road.

While entities with a bias against action can deflect progress away from effective climate policy, self-identified champions of climate policy can also undermine effective risk management by failing to inform themselves about the full spectrum of risk. Indeed, one of the great challenges is that once a political leader acknowledges the reality of climate change – and pledges action – they may resist the need to readjust their policies when additional data is developed. This is a consequence of the unfortunate tendency to dichotomize political actors into 'supporters' of climate action and 'opponents'. **A supporter of action to combat**

215 Sinclair, 1935, p. 109

216 Machiavelli, 1532

217 Olson, 1984

climate change, who nonetheless dramatically underestimates the risks, is nearly as great a hurdle to effective risk management as an outright climate change denier.

In the security field, the most common technique for building consensus on risk assessments is putting decision makers through either structured or free-play wargames and simulations. But this common practice in security affairs is used only sporadically in managing other public policy issues. This is unfortunate because it is a useful tool, particularly to bring together senior stakeholders from various communities that have little exposure to each other. The logic of wargaming is that it allows decision makers to explore alternative policy directions with rapid feedback, and the opportunity for systematic debriefing. It allows decision-makers to tweak initial assumptions and explore alternative futures. They also produce a fast 'gut' understanding of the dynamics, risk and constraints of complex situations which would be unobtainable no matter how many presentations and briefings they received. These strategic games are useful for considering long-term decisions, but rely on many assumptions about the functioning of feedback loops. Wargames themselves do not reduce uncertainty, but they allow decision-makers to gain a more sophisticated understanding of the nature of uncertainty and to reach shared judgments about the nature of the challenges they face.

Implementing an explicit risk management framework is not a panacea that can eliminate the politics of climate change, either within or between countries. However, it does provide tools to make the consequences of choices clearer to decision makers, and can help create a common framework of understanding between different actors which itself should help promote agreement and greater cooperation.

Managing information

Effective risk management relies on access to good information. The joint scientific process of the IPCC, now in its third decade, has generated more information on climate change than just about any other public policy issue under consideration today. However, as discussed in Chapter 2, the complexity of the climate system means that there are many remaining questions about key impacts, and there are certain to be additional unknown unknowns with serious implications.

It is reasonably clear that most actors are underestimating the risks of climate change. They are doing so, at least in part, because they are not conversant in the latest scientific information. As discussed in Chapter 2, informational surprises over the past decade indicate that the downside risk of climate change is likely to be much greater than is generally understood. Almost every time new information is gathered, it turns out that the observed data is worse than had been expected. There have been essentially no positive major surprises.

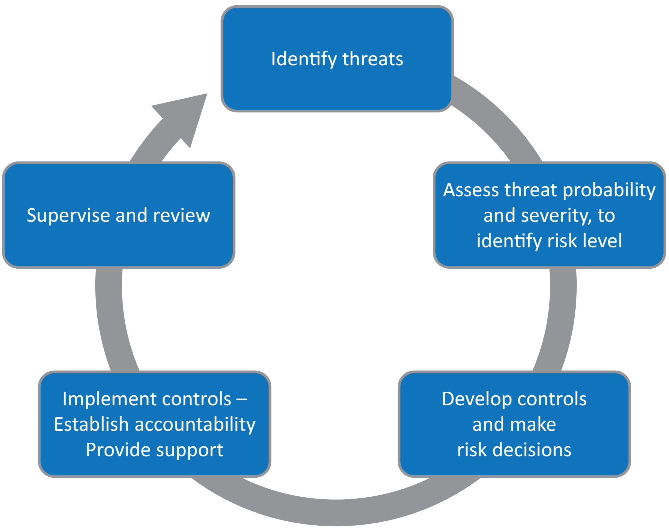
Better integration of scientific data is an essential part of the solution.[218] But there also needs to be robust effort focused explicitly on trying to identify the types of unknowns that may

218 Rogers and Gulledge, 2010, op. cit.

be faced. Some of these are already apparent. There needs to be better exploration of potential tipping points and discontinuities. There also needs to be a more explicit integration of assumptions about state behavior. Finally, additional work is needed on the second-order consequences of various adaptation strategies. The risk of poorly coordinated responses may be as significant as the risk of inaction. Risk management is fundamentally a learning system. Learning requires the ability to incorporate and make sense of new data. This can occur in an *ad hoc* fashion, but effective learning is most likely when repeated evaluation is incorporated into the process.

One effective way to promote learning is to establish benchmarks that clarify expectations. Bad news is then more than a challenge to a broad orientation, but instead can be measured against a series of expectations. A climate regime based on assumed slow changes in the stability of ice sheets, for example, could have built in mechanisms requiring reassessment if those explicit benchmarks were established and then triggers were met. This assessment in turn should trigger a new response to risk if necessary. Figure 5.1 is adapted from a consolidated multiservice reference for the US military on deploying risk management. The guide explicitly instructs that the risk management approach should be applied as a cycle, so that if control measures are identified as ineffective, or a new threat is identified, the entire risk management process is repeated.

Figure 5.1: Continuous Risk Management Cycle



According to a publication on risk management for the US Army, Marine Corps, Navy and Air Force, the benefits of practicing risk management include enhanced mission accomplishment, enhanced decision-making skills based on reasonable and repeatable processes, provision of a clearer picture of readiness, avoidance of unnecessary risk and identification of feasible and effective control measures. ***Source:*** *Adapted from Air Land Sea Application Center, 2001.*

Systematic analysis of policy alternatives

Ideally a risk management system considers the full range of possible alternatives. In reality, policy alternatives are unfortunately almost always incompletely explored. Information deficits are largely to blame. All the second-order consequences of action in a complex system are simply not understood. A risk management system must account not just for what *ought* to be done, but what *can* be done given the existence of a specific set of actors. Indeed, an understanding of institutional limitations is crucial not just to define the range of the possible in the short-run, but also to specify the desirability of constructing new institutions. Again, consider an example from the security field, where an organization like NATO was created precisely in order to develop new capacity to manage long-term alliance relationships.

Alternative policies are often difficult to compare because their costs and benefits operate on different axis. The climate change field requires risk assessments that are able to handle comparisons across multiple domains. Again, this is a common problem in the security literature. Consider the issue of humanitarian intervention, which essentially requires potential interveners to ask, "how many of our people should we put at risk for one of theirs?" But it also exists for any of a large number of value trade-offs. How much should civil liberties be sacrificed to enhance counter-terrorism efforts? What is the optimal 'guns vs. butter' ratio?

There is no simple solution to these value trade-offs, other than to guard against the tendency to simplify the debate out of existence. It is indeed legitimate to ask how much economic growth ought to be sacrificed in order to combat climate change. It is also legitimate to prioritize economic growth. But too many decision-makers go from the point of view that economic growth is more important, to the argument that *any* sacrifice of economic growth is too much. More fundamentally, too many decision-makers ignore the legitimate threat that unmitigated climate change presents to continued economic growth. The costs of policy are weighed without considering the economic benefits.

There are, however, some clear benefits to a more rigorous analysis of alternatives. These include assessing conditions under which policy alternatives can be productively combined – how climate security can be maximized and benefits for prosperity outcomes achieved – and also the reverse situation when policy alternatives are mutually exclusive or counter-productive. The latter analysis is particularly crucial because, given the nature of differing risk pools, it is perfectly possible for actors to pursue risk mitigation strategies that are individually rational and yet collectively counter-productive.

Good risk management requires us to rigorously take into account the full range of the known and unknown aspects of a problem, understand the biases and limits in our information systems and our responses to uncertainty, systematically analyze threats and vulnerabilities as well as consider possible alternatives when putting in place strategies to effectively manage risks. Critically it requires objective and independent monitoring of how effective risk management policies actually are in practice, and updating and revising these as situations change.

6 Exploring Options

Tailoring the Risk Management Approach to Climate Change

"Pacific island countries are likely to face massive dislocations of people, similar to population flows sparked by conflict. The impact on identity and social cohesion are likely to cause as much resentment, hatred and alienation as any refugee crisis…The Security Council, charged with protecting human rights and the integrity and security of States, is the paramount international forum available to us... the Council should review sensitive issues, such as implications for sovereignty and international legal rights from the loss of land, resources and people."
Delegate of Papua New Guinea, UN Security Council Debate on Climate Change, April 2007[219]

Summary

- Good risk management always requires balance. The risk of extreme climate change and 'tipping points' should move this balance towards a more aggressive mitigation approach. The balance between limiting climate change and adapting to its impacts also requires a detailed understanding of the vulnerability of human systems and the opportunities and limitations of strategies to respond to extreme climate change.

- By design the climate of the past two centuries is the ideal climate for our modern society. Many megacities are at sea level, most of our food is produced in a few, rain-fed regions, and our built environment is designed to weather familiar extremes. Industrial civilization has been built on the assumption of a stable climate but this assumption no longer holds. Sudden, unpredictable changes that may be a common feature of regional climate changes will be difficult to plan and prepare for. In the face of such uncertainty, flexible adaptation approaches that include a range of social policy measures and resilience are probably more useful than 'hard' engineering responses alone, particularly in preventing conflict over scarce resources.

- Climate change will raise the risk of the type of 'perfect storm' events seen in 2008 when food prices rocketed due to drought, high oil prices and trade restrictions. Uncertainty over future climate impacts will be a source of tensions inside and between countries as different groups argue for interventions to protect against scenarios damaging to their core interests. At the extreme, disputes of management of increasingly scarce and volatile resources may result in violence and instability.

219 UN Security Council, 2007

- Climate change and growing resource scarcity will put great strain on international agreements to manage water, food, trade, borders and other climate sensitive resources. It is in the interest of all countries to agree to targeted interventions in the next decade to improve the resilience and effectiveness of these international agreements.

- Though most attention to date has been focused on uncertainty in climate science and regional impacts, understanding risks to the successful implementation of mitigation programs is at a similar scale of importance in effectively managing climate security. A number of hedging strategies including stronger international coordination on R&D in critical technologies are available to manage these risks.

Risk Management Analysis of Climate Change

Systematic application of a risk management approach to climate change requires examination of the uncertainties surrounding climate science, climate impacts, mitigation and adaptation policies on a range of interrelated questions. Annex 2 outlines the analytical process used in the preparation of this report to tackle the following key questions:

- What is the range of risks we face?

- What are the biases in current risk assessments? Are the risks likely to be over or underestimated?

- What surprises may exist?

- How irreversible will impacts be once they have occurred?

- How well could we monitor the emergence of serious threats? How well are we currently monitoring threats?

- How effectively are we currently managing these risks?

- What are alternative or additional risk management strategies we should employ?

As with any syncretic exercise, this process involved many judgments about the relative importance of different areas and actions. The structured analysis around the risk factors described in Annex 2 shows how a comprehensive and comparable analytical framework can be used to base these conclusions. A framework is important in order to make the basis of judgments transparent – thus open to revision and challenge – and to guard against disciplinary bias by giving equal weight to all areas of analysis.

A balanced risk management policy comes from the overall synthesis of all these factors. The complexity and multidisciplinary nature of the climate change problem makes such holistic analysis very challenging. However, core risk management conclusions can be drawn from the type of overview analysis outlined in this report. This analysis can be used to guide deeper investigation into particular areas, which in turn inform further holistic analysis. This iterative approach moving between analysis and synthesis is critical for robust risk assessment, but is often missing in time bound policy processes.

In many ways the focus on deepening understanding of individual components of climate change should be contrasted with the lack of specialist attention and resources devoted to the systematic process of synthesizing these results into a coherent strategy.[220] As any intelligence collection agency will testify, there is no point spending huge amounts of resources in collecting critical data if the intelligence assessment and policy making machinery is incapable of using this information to make good decisions. A decision support system is only as good as the weakest link in the analytical, assessment and strategy development chain.

For example, the United Kingdom spends billions of pounds annually on collecting intelligence on global threats,[221] but funnels much of this through an Assessment System of just over 20 Cabinet Office analysts and an even more under-resourced foreign policy decision-making system, especially around the risk of state failure and internal conflict. Despite several reports over the past decade cataloguing these decision support failures systematic reforms to improve strategic decision-making have still to be fully implemented.[222] The establishment of the UK National Security Council in 2010, including explicit threat assessment inputs on climate change and resource scarcity, may begin to fill some of these gaps.

Risk management frameworks are specific to particular groups of decision makers – there is no 'right' answer. The analysis outlined in this report is aimed at national level decision makers across the full spectrum of government departments, and with a particular emphasis on areas where enhanced international cooperation can help manage climate security risks. However, this basic process can be tailored to any group of decision makers and the analytic content deepened to provide specific recommendations, for example, to guide sub-national adaptation planning.

Critical Elements Driving the Risk Management of Climate Change

Analysis carried out in preparing this report highlighted the following areas as critical inputs to designing an overall risk management framework:

- **Climate change is effectively irreversible** such that global surface temperatures and associated changes in precipitation will not return to their 20th century state for more than a thousand years after CO_2 concentrations are stabilized in the atmosphere.

220 Rogers and Gulledge, 2010, op. cit.

221 Represented by the joint budgets of the United Kingdom's overseas intelligence agency, Foreign Office and related defence intelligence assets (HMT, 2010).

222 UK Cabinet Office, 2005., op. cit.

- **Stationarity is dead.** Unlike during the past two centuries of urbanization and industrialization, climate can no longer be considered a constant when analyzing infrastructure resilience and the first presumption should be that systems will be vulnerable to future climate change without adaptive measures.

- **Consider best, worst and median case scenarios of adaptation and mitigation together** inside a risk management framework, rather than simply planning for a successful delivery of a 2°C mitigation scenario.

- **Compound vulnerability is as determinative as exposure.** The complex vulnerabilities of ecological and socioeconomic systems to multiple climatic changes will determine the real impacts of climate change as much as regional levels of warming.

- **Adaptation is a complex, uncertain and political activity.** The design of adaptation interventions will face politically driven assessments of future scenarios which benefit specific groups, exacerbating the vulnerability of other groups and raising the risk of political conflict.

- **Changes in climate extremes are more important than changes in averages**. The frequency and intensity of heat waves, droughts, and heavy precipitation increase more rapidly than climatological averages. Projections of climatological averages, such as the 2°C goal, are a poor index of risk and not a sufficient basis for policy-making.

- **Beware of the long tail** where the upper bound on the severity of outcomes is more difficult to identify than the lower bound, leading to a greater probability that expected impacts have been underestimated than overestimated.

- **Aggressive mitigation can lop off the long tail of uncertainty**, effectively removing worst possible outcomes from the table and leading to higher benefits than would be estimated from an analysis that ignored the long tail.

- **Risks relating to the success of mitigation policies are as important as climate uncertainty.** Decisions to mitigate greenhouse gas emissions could lead to underinvestment in adaptation, while several likely modes of mitigation failure could result in 3-4°C of warming, despite aiming to stay below 2°C.

Climate change is effectively irreversible

It appears that climate change is essentially irreversible on time scales of relevance to humans. There are two basic reasons. First, the CO_2 that humans emit into the atmosphere remains there for a very long time, as described by one paleoclimatologist "300 years, plus 25% that lasts forever."[223] Second, because the exchange of heat between the ocean and the atmos-

223 Archer, 2005

phere is slow, the ocean will continue to release absorbed heat to the atmosphere long after the greenhouse gas concentration in the atmosphere has declined. Consequently, both warming and associated changes in precipitation are likely to persist for more than 1,000 years.[224] The implications of this irreversibility are profound for the future climate.

In addition to the climate itself, many effects of warming could be *wholly* irreversible, such as the extinction of species, or irreversible on time scales relevant to social systems. For example, large-scale changes in ecosystems or collapse of the Greenland ice sheet could only be reversed, if at all, on the time scales of thousands to hundreds-of-thousands of years.[225]

The main implication of irreversibility is that society cannot avoid many of the effects of the greenhouse gases it emits into the atmosphere. The less that is ultimately emitted, the less irreversible change humanity must face. However, some emissions trajectories to stabilize emissions at 450 ppm actually "overshoot and decline" with a peak in concentrations nearer 475 ppm or above. These scenarios require less drastic mitigation action in the near term but, given the uncertainties over irreversible impacts, carry higher risks than is apparent from the current model assessments. **In designing emissions reduction trajectories and/or global carbon budgets, a full understanding of the impact and risks of irreversible impacts will be critical to avoid dangerous high-risk pathways.**

Stationarity is dead

Today humans are altering the Earth's basic processes in unprecedented ways. Consequently, current economic and geopolitical systems are facing global climate change for the first time. Over the past 10,000 years (the Holocene epoch), the global temperature has not varied much – only about ±1°C. Following the last ice age, sea level rose rapidly for several thousand years and then stabilized about three to five thousand years ago. Pampered by this extended period of unusual climate stability, within a few millennia, humans have morphed from nomadic hunter-gatherers into modern industrialists.[226] However, the modern systems humanity has constructed are largely based on the past century or two of experience with the weather, a very stable period relative to the pre-Holocene.[227]

The climate of the past two centuries is, in fact, the ideal climate for modern society because the systems have been deliberately built around that climate.[228] Many megacities are at sea level, most food is produced in a few, rain-fed 'breadbasket' regions, and the built environment is designed to weather familiar extremes. The more the climate changes, the less well-adapted modern society will be. For this reason, scientists recently declared that "stationarity is dead."[229]

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224 Solomon et al., 2009

225 Schneider, 2007; Archer, 2009

226 Fagan, B.M., 2003

227 Jansen et al., 2007, op. cit.

228 Rockström et al., 2009

229 Milly et al., 2008

Stationarity is the assumption that the range of climate conditions for a given area occurs within a static envelop of variability that is defined by past extremes. Climate change will alter the long-term mean as well as the range of extremes. **Preparing for the future means rejecting stationarity as a guide to future outcomes. The first presumption should therefore be that all critical systems will be vulnerable without adaptive measures.**

Consider best and worst case scenarios of adaptation and mitigation together

The IPCC concluded that "Responding to climate change involves an iterative risk management process that includes both adaptation and mitigation…".[230] Although the degree of future climate change can be mitigated by reducing greenhouse gas emissions, some amount of additional future change is already unavoidable:

> *"Anthropogenic warming and sea level rise would continue for centuries even if [greenhouse gas] concentrations were to be reduced sufficiently for [greenhouse gas] concentrations to stabilize…"*[231]

The extra heat already absorbed by the oceans would continue to cause sea level rise and hydrological changes in the atmosphere for many more decades to centuries, even if greenhouse gas concentrations were stabilized immediately at their current concentrations. This delay results from the slow rate at which the ocean mixes and releases heat to the atmosphere. The consequence of this inertia in the climate system is that some additional climate change is inevitable even if future mitigation efforts are highly successful. Since some change is already occurring and more is locked into the system, society will be forced to manage these unavoidable changes through adaptation.[232]

Of course, it is not feasible to stabilize greenhouse gas concentrations immediately. Continued greenhouse gas emissions will induce further warming beyond that which is already unavoidable because of past emissions. How long society waits to begin reducing emissions will determine whether adaptive capacity will eventually be overwhelmed.

Unmitigated climate change would, in the long-term, be likely to exceed the capacity of natural, managed and human systems to adapt. The time at which such limits could be reached will vary between sectors and regions. Early mitigation actions would avoid further lock-in of carbon intensive infrastructure and reduce climate change and associated adaptation needs.[233]

230 IPCC, op. cit
231 Ibid, p. 72.
232 Ibid.
233 Ibid.

This combination of inevitable warming and the need to prevent further warming inspired the axiom: "avoid the unmanageable and manage the unavoidable."[234] Not only are both mitigation and adaptation required, they are mutually reinforcing. Adaptation increases a system's resistance or resilience to climate change impacts, buffering it against unmitigated change. However, adaptation requires time, learning and expense, and will not be entirely effective. Near-term action to mitigate climate change will enhance efforts to adapt:

> *[S]lowing emissions buys more time for planning, financing, and implementing adaptation [and] the timing of emissions reductions (i.e. earlier vs. later peaking) for given stabilization concentration (e.g., 450 ppm CO_2-e) affects how much time the mitigation effort buys... Different levels of mitigation effort could even alter which adaptation options would be feasible.*[235]

In the long-term, this interplay between adaptation and mitigation is particularly important for sea level rise because the ultimate change in sea level will take centuries to develop. Consequently, it is the *rate* rather than the amount of sea level rise that is most relevant on policy planning time scales:

> *[A] realistic stabilization target for sea level is a maximum rate of rise rather than stabilization of sea level per se. Hence, adaptation and mitigation need to be considered together for coastal areas, as collectively they can provide a more robust response to human-induced climate change than consideration of each policy alone. Mitigation will reduce both the rate of rise and the ultimate commitment to sea-level rise, while adaptation is essential to manage the commitment to sea-level rise…*[236]

Mitigation and adaptation must be considered integrally in developing policy responses to climate change, and median and worst case mitigation scenarios should be considered when framing the adaptation response rather than focus on the most optimistic ones. However, this is still considered controversial by some groups and caricatured as "preparing for defeat". **One of the benefits of a risk management approach should be to allow considered analysis and public debate on the implications of all scenarios**.

Compound vulnerability is as determinative as exposure

The tendency to equate climate impacts with exposure fails to capture variations in risk. Climate models tend to look at uncertainty surrounding certain factors such as temperature, rainfall, sea

234 Bierbaum et al., 2007, op. cit.

235 Yohe, 2010, op. cit.

236 Nicholls & Lowe, 2006

level rise, growing seasons etc. However, the potential consequences of exposure, and therefore risk, cannot be fully appreciated unless the vulnerability of an exposed natural or social system is understood. Vulnerability will be defined by the interaction of climate change and non-climate sensitive factors, and will vary depending on the scale and speed of impacts.

International Alert, an independent peace building organization, identifies the following as crucial factors for evaluating vulnerability: political instability, economic weakness, food insecurity and large-scale migration.[237]

The IPCC defines vulnerability to climate change as "the degree to which [exposed] systems are susceptible to, and unable to cope with, adverse impacts."[238] A city that is already adapted to frequent heat waves, for example, is less vulnerable to an increase in the frequency of heat waves than a city that does not have a history of coping with severe heat.[239] In general, poor populations are more vulnerable than rich populations, even within rich countries. Vulnerability also increases as countries begin to build infrastructure in climate sensitive areas. There is also evidence that low-latitude and less developed areas face a greater risk, including dry areas and mega deltas.[240]

Consequently, monitoring and forecasting exposure to climate change is not sufficient to assess its likely impacts. Comprehensive vulnerability assessment, which is still in its infancy, is required to build a compound view. Vulnerability assessment will be especially important for international development and security assessments and will be most challenging in developing countries where both environmental and socioeconomic data are sparse. The IPCC has identified a number of potential *key vulnerabilities* that might be of particular interest to decision makers. This catalog of systems and impacts is based on seven criteria:[241]

- Magnitude of impacts.
- Timing of impacts.
- Persistence or reversibility of impacts.
- Estimated likelihood of impacts and vulnerabilities, and confidence in the estimates.
- Potential for adaptation to reduce exposure or vulnerability.
- Distribution of impacts and vulnerabilities across regions and population groups.
- Importance of a system at risk.

237 Smith & Vivekananda, 2007
238 Schneider et al., 2007, op. cit.
239 Ebi, 2010, op. cit.
240 Ibid.
241 Schneider et al., op. cit.

These key vulnerabilities are organized into the various categories shown in Table 6.1: global social systems, regional systems, global biological systems, geophysical systems, and extreme events. Other categories or key vulnerabilities might be identified based on the concerns of a particular decision maker.

Table 6.1. Examples of potential key vulnerabilities from the IPCC AR4. Warming levels are relative to 1990. ***Source:*** *Adapted from Schneider et al., 2007.*

Confidence symbol legend:

*** very high confidence ** high confidence * medium confidence • low confidence

	Systems, processes or groups at risk	Prime criteria for 'key vulnerability'	Relationship between temperature and risk. Temperature change by 2100 (relative to 1990)					
			0°C	1°C	2°C	3°C	4°C	5°C
GLOBAL SOCIAL SYSTEMS	Food supply	Distribution, Magnitude		Productivity decreases for some cereals in low latitudes */•				
				Productivity increases for some cereals in mid/high latitudes */•			Cereal productivity decreases in some mid/high-latitude regions */•	
					Global production potential increases to around 3°C *		Global production potential very likely to decrease above about 3°C *	
	Infrastructure	Distribution, Magnitude, Timing	Damages likely to increase exponentially, sensitive to rate of climate change, change in extreme events and adaptive capacity **					
	Health	Distribution, Magnitude, Timing, Irreversibility	Current effects are small but discernible *		Although some risks would be reduced, aggregate health impacts would increase, particularly from malnutrition, diarrhoeal diseases, infectious diseases, floods and droughts, extreme heat, and other sources of risk */**. Sensitive to status of public health system ***			
	Water resources	Distribution, Magnitude, Timing	Decreased water availability and increased drought in some mid latitudes and semi-arid low latitudes **		Severity of floods, droughts, erosion, water-quality deterioration will increase with increasing climate change ***. Sea-level rise will extend areas of salinisation of groundwater, decreasing freshwater availability in coastal areas ***. Hundreds of millions people would face reduced water supplies **			
	Migration and conflict	Distribution, Magnitude	Stresses such as increased drought, water shortages, and riverine and coastal flooding will affect many local and regional populations **. This will lead in some cases to relocation within or between countries, exacerbating conflicts and imposing migration pressures *					
	Aggregate market impacts and distribution	Magnitude, Distribution	Uncertain net benefits and greater likelihood of lower benefits or higher damages than in TAR •. Net market benefits in many high-latitude areas; net market losses in many low-latitude areas. *. Most people negatively affected •/*				Net global negative market impacts increasing with higher temperatures * Most people negatively affected *	

Systems, processes or groups at risk	Prime criteria for 'key vulnerability'	Relationship between temperature and risk. Temperature change by 2100 (relative to 1990)					
		0°C	1°C	2°C	3°C	4°C	5°C
Africa	Distribution, Magnitude, Timing, Low Adaptive Capacity	Tens of millions of people at risk of increased water stress; increased spread of malaria •		Hundreds of millions of additional people at risk of increased water stress; increased risk of malaria in highlands; reductionsin crop yields in many countries, harm to many ecosystems such as Succulent Karoo •			
Asia	Distribution, Magnitude, Timing, Low Adaptive Capacity	About 1 billion people would face risks from reduced agricultural production potential, reduced water supplies or increases in extremes events •					
Latin America	Magnitude, Irreversibility, Distribution, and Timing, Low Adaptive Capacity	Tens of millions of people at risk of water shortages •; many endemic species at risk from land-use and climate change • (~1ºC)		More than a hundred million people at risk of water shortages •; low-lying coastal areas, many of which are heavily populated, at risk from sea-level rise and more intensecoastal storms • (about 2-3ºC). Widespread loss of biodiversity, particularly in the Amazon •			
Polar regions	Timing, Magnitude, Irreversibility, Distribution, Low Adaptive Capacity	Climate change is already having substan-tial impacts on societal and ecological systems **		Continued warming likely to lead to further loss of ice cover andpermafrost **. Arctic ecosystems further threatened **,although net ecosystem productivity estimated to increase **. While some economic opportunities will open up (e.g., shipping), traditional ways of life will be disrupted **			
Small islands	Irreversibility, Magnitude, Distribution, Low Adaptive Capacity	Many islands already experiencing some negative effects **					
			Increasing coastal inundation and damage to infrastructure due to sea-level rise **				
Indigenous, poor or isolated communities	Irreversibility, Distribution, Timing, Low Adaptive Capacity	Some communities already affected **		Climate change and sea-level rise add to other stresses **. Communities in low-lying coastal and arid areas are especiallythreatened **			
Drying in Mediterranean, western North America, southern Africa, southern Australia, and north-eastern Brazil	Distribution, Magnitude, Timing	Climate models generally project decreased precipitation in these regions. Reduced runoff will exacerbate limited water supplies, decrease water quality, harm ecosystems and result in decreased crop yields **					
Inter-tropical mountain glaciers and impacts on high-mountain communities	Magnitude, Timing, Persistence, Low Adaptive Capacity, Distribution	Inter-tropical glaciers are melting and causing flooding in some areas; shifts in ecosystems are likely to cause water security problems due to decreased storage */**			Accelerated reduction of inter-tropical mountain glaciers. Some of these systems will disappear in the next few decades *		

	Systems, processes or groups at risk	Prime criteria for 'key vulnerability'	Relationship between temperature and risk. Temperature change by 2100 (relative to 1990)					
			0°C	1°C	2°C	3°C	4°C	5°C
GLOBAL BIOLOGICAL SYSTEMS	Terrestrial ecosystems and biodiversity	Irreversibility, Magnitude, Low Adaptive Capacity, Persistence, Rate of Change, Confidence	Many ecosystems already affected ***		Circa 20-30% species at increasingly high risk of extinction *		Major extinctions around the globe **	
						Terrestrial biosphere tends toward a net carbon source **		
	Marine ecosystems and biodiversity	Irreversibility, Magnitude, Low Adaptive Capacity, Persistence, Rate of Change, Confidence	Increased coral bleaching **		Most corals bleached **	Widespread coral mortality ***		
	Freshwater ecosystems	Irreversibility, Magnitude, Persistence Low Adaptive Capacity	Some lakes already showing decreased fisheries output; pole-ward migration of aquatic species **		Intensified hydrologi-cal cycles, more severe droughts and floods ***	Extinction of many freshwater species **, major changes in limnology of lakes **, increased salinity of inland lakes **		
GEOPHYSICAL SYSTEMS	.Biogeo-chemical cycles	Magnitude, Persistence, Confidence, Low Adaptive Capacity, Rate of Change	Ocean acidification already occurring, increasing further as atmospheric CO2 concentration increases ***; ecological changes are potentially severe *. Carbon cycle feedback increases projected CO2 concentrations by 2100 by 20-220 ppm for SRES[2] A2, with associated additional warming of 0.1 to 1.5°C **. AR4 temperature range (1.1-6.4°C) accounts for this feedback from all scenarios and models but additional CO2 and CH4 releases are possible from permafrost, peat lands, wetlands, and large stores of marine hydrates at high latitudes *. Permafrost already melting, and above feedbacks generally increase with climate change, but eustatic sea-level rise likely to increase stability of hydrates ***					
	Greenland ice sheet	Magnitude, Irreversibility, Low Adaptive Capacity, Confidence	Localised deglaciation (already observed, due to local warming); extent would increase with temperature increase ***	Commitment to widespread ** to near-total * deglaciation, 2-7 m sea-level rise[3] over centuries to millennia *		Near-total deglaciation **		
	West Antarctic ice sheet	Magnitude, Irreversibility, Low Adaptive Capacity	Localised ice shelf loss and groundingline retreat * (already observed, due to local warming)	Commitment to partial deglaciation, 1.5-5 m sea-level rise over centuries to millennia •/* [19.3.5]. Likeli-hood of near-total deglaciation increases with increases in temperature **				
	Meridional overturning circulation	Magnitude, Persistence, Distribution, Timing, Low Adaptive Capacity, Confidence	Variations including regional weakening (already observed but no trend identified)	Considerable weakening **. Commitment to large-scale and persistent change including possible cooling in northern high-latitude areas near Greenland and north-west Europe • highly dependent on rate of climate change				

EXTREME EVENTS

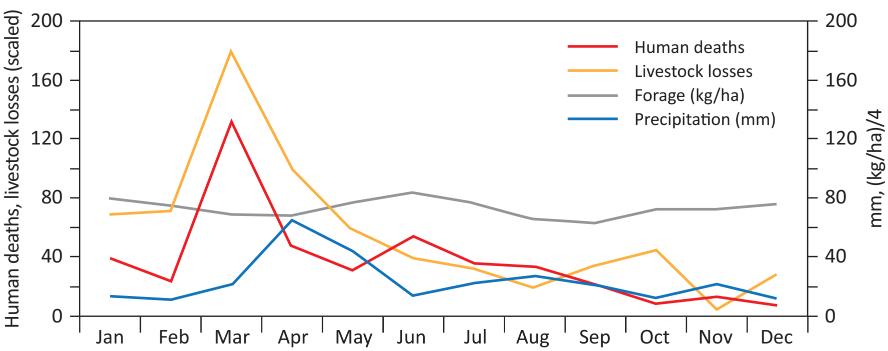
Systems, processes or groups at risk	Prime criteria for 'key vulnerability'	Relationship between temperature and risk. Temperature change by 2100 (relative to 1990)					
		0°C	1°C	2°C	3°C	4°C	5°C
Tropical cyclone intensity	Magnitude, Timing, Distribution	Increase in Category 4-5 storms */**, with impacts exacerbated by sea-level rise	Further increase in tropical cyclone intensity */** exceeding infrastructure design criteria with large economic costs ** and many lives threatened **				
Flooding, both large-scale and flash floods	Timing, Magnitude	Increases in flash flooding in many regions due to increased rainfall intensity** and in floods in large basins in mid and high latitudes.**	Increased flooding in many regions (e.g., North America and Europe) due to greater increase in winter rainfall exacerbated by loss of winter snow storage.** Greater risk of dam burst in glacial mountain lakes.**				
Extreme heat	Timing, Magnitude	Increased heat stress and heat-waves, especially in continental areas.***	Frequency of heatwaves (according to current classification) will increase rapidly, causing increased mortality, crop failure, forest die-back and fire, and damage to ecosystems.***				
Drought	Magnitude, Timing	Drought already increasing *. Increasing frequency and intensity of drought in mid-latitude continental areas projected.**	Extreme drought increasing from 1% land area to 30% (SRES A2 scenario). Mid-latitude regions seriously affected by poleward migration of Annular Modes.**				
Fire	Timing, Magnitude	Increased fire frequency and intensity in many areas, particularly where drought increases.**	Frequency and intensity likely to be greater, especially in boreal forests and dry peat lands after melting of permafrost.**				

The need to improve analysis of vulnerability is one of the most critical areas to improve risk management of climate change.

Understanding of compound vulnerabilities at national and sub-national levels is still at an early stage. A critical reason for this is the patchy nature of baseline socioeconomic and governance data at these levels. **Investment in additional and more detailed resolution climate change data will not pay off if the data needed to complete compound vulnerability assessments is missing**. For example, detailed and groundbreaking analysis by Bond and Meier brought together detailed records of rainfall and fodder availability and systematic community level reporting of conflict and peacemaking activity in parts Kenya and Uganda to examine how variations in rainfall affect low-level conflict.[242] This study was only possible because of a system of local conflict monitoring under the Conflict Early Warning and Response Mechanism (CEWARN) established by the Intergovernmental Authority on Development (IGAD) in East Africa in 2003.

The results of this work are complex. Firstly, the level of conflict was far higher than estimated by media reports or in capitals, with deaths in cattle raids reaching over 120 a month. Secondly, moderate levels of scarcity during the dry season tended to lead to increased peace building activity between communities, including visits by women and other exchanges, and a decline in conflict activity. This shows the resilience of traditional systems when faced with normal levels of stress. However, at critical points, notably the end of the dry season when fodder is very scarce and the beginning of the wet season when prime watering sites were being competed for, these systems would break down leading to large spikes in conflict, as shown in Figure 6.1.

Figure 6.1: Conflict Impact and Precipitation Levels in Ugandan Karamoja 2004



Source: *Meier et al., 2007.*

Bottom-up reporting of conflict using local monitors provides a much better tool for system-

242 Meier and Bond, 2005

atically analyzing the conflict vulnerability and can provide a richer source of data to combine with detailed sub-national climate change projections.

Though limited by available data, vulnerability mapping has been increasing rapidly over the past few years and practitioner communities have emerged supported by public funds.[243] For example, mapping of 540 sub-national regions in South East Asia highlighted a range of vulnerability 'hot spots' some of which were driven by pure exposure to climate risk (e.g. Jakarta), while vulnerability in others was determined by a lack of country disaster preparedness.[244]

Uncertainty and ignorance over socioeconomic and governance systems are at least as important as scientific uncertainty in defining compound vulnerability of communities, regions and countries. A perfect climate forecast would identify areas of exposure, but risk still cannot be measured absent of knowledge of vulnerability in those areas.

Adaptation is a complex, uncertain and political activity

A technical approach to adaptation is not enough to preserve development or stability. Climate change creates winners and losers, and so will climate adaptation measures. Approaching adaptation simply as a technical exercise will undermine its effectiveness in both protecting livelihoods and preventing social tension and violence. Institutional capacities, scope and priorities will be the principle determinant of effective adaptive response, and all institutions exist inside a political context.[245] The political economy of resource management must lie at the heart of all adaptation measures as they deal with the resources of subsistence and identity: land, water and security.

For a range of reasons, climate change is likely to lower agricultural productivity in many areas of the world. Reductions in rainfall, changes in growing seasons, introduction of diseases and pests, and greater extremes are all likely to have negative impacts. There will be increasing redundancy of traditional agricultural knowledge in the face of changing growing seasons and weather patterns. In some areas, these impacts will be offset by a positive impact of extra CO_2 in the atmosphere and by increased water availability. In Africa forecasts suggest that wheat could all but disappear from the African continent by 2080. Soybean harvest is expected to drop close to 30 percent by 2050.[246]

At a more granular level, climate change will reduce the growing seasons for many crops along climatic and soil boundaries. Figure 6.2 shows how, in Africa, the growing seasons for many staple crops is expected to shorten dramatically along an arc stretching across the Sahel and down the Eastern seaboard and Southern edge of the Congo forest.[247]

243 For example, see www.preventionweb.org

244 Yusuf and Francisco 2009

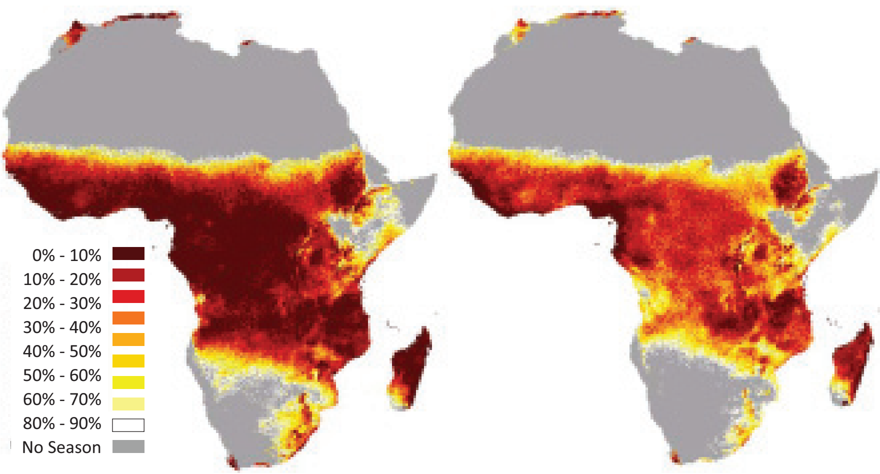
245 Downing and Dyszynski, 2010

246 Parry et al., 2004

247 Thornton et al., 2006

In principle, many of these negative changes can be managed by effective adaptation to shift to different crop varieties and change agricultural patterns. In practice, it is more likely that groups will carry on using traditional crops and practices – often, they will have no choice – until they become economically untenable. At this point, there will be no choice but to migrate and/or compete for more fertile and better managed land with other groups. These changes are far harder to predict with accuracy than larger aggregate changes because they affect marginal and border regions. However, it is precisely these types of areas that will experience the highest socioeconomic and governance stresses and which could see risks of conflict rise in the near term.

Figure 6.2: Percentage of Failed Growing Seasons in Africa 2000 and 2050



Source: *Thornton, et al, 2006*

Figure 6.2 shows how the percentage of failed growing seasons may increase towards 2050 (depicted as the lightest colors) at the shifting borders of these areas significant local migration and competition for resources will occur.

Economically marginal areas will be some of the first places to exhibit climate driven conflict, especially in dry regions such as the Sahel. Economic marginalization is both a consequence of climate vulnerability and a reason for weak and ineffective governance. A political failure to invest away from the economic heartland could see manageable disputes turn into to full-scale conflicts at a far greater frequency than they do currently. It is likely that governments will focus adaptation efforts on economically productive areas and ones linked to their own political support base.

To adapt to climate change, traditional management systems will need to be replaced which will shift power between and among communities. Informal and traditional resource management systems maintain sustainable and peaceful use in much of the world even where communal tensions are high. However, these systems often have limited resources to respond to conditions completely outside the historical precedents on which they are based. As traditional knowledge is made obsolete by a changing climate, these systems will lose authority with the population, opening political space for dispute and conflict. Even so-called modern systems of management will feel this pressure if they cannot adapt due to political or institutional inertia. Adaptation programs will have to navigate the processes of modernizing and recasting these systems if large-scale migration and conflict is to be averted.[248]

Improving economic resilience is critical as economic decline is one of the strongest drivers of instability, but is very poorly understood in economic modeling and planning.[249] In a world of tighter global markets for many commodities, the impact of price rises and shortages is transmitted far faster than in the past. The impact of combined shocks on country economies – from decline in hydroelectricity to higher food prices – will need to be taken into account when planning economic development paths and buffering systems.

There are limits to adaptation that will often emerge as societal conflict. While it is important to maximize the potential to adapt to climate change, its limits must also be acknowledged. Even at moderate levels of climate change, it will not be technically possible, or cost effective, for many communities in areas affected by drought, floods and sea level rise to remain where they are. Those affected will be forced to migrate, and the management of this displacement will be critical in preventing rising tensions.[250]

Design of adaptation programs and the shaping of international support must recognize political and security issues. Funding for adaptation under the UNFCCC is expected to increase rapidly over the next decade, amounting to tens of billions of dollars annually.[251] But these resources will only produce effective and positive outcomes in the right policy environment. Where climate related instability risks are high it is vital that assistance flows to support internal policy reforms designed to increase social resilience. This will often require governments to take on vested interests and tackle deep-seated internal problems. **Though controversial, some international funding for adaptation may need to be made conditional on resource management policy reforms in areas where dysfunctional management systems are critical drivers of instability risks and the marginalization of vulnerable at risk populations.**[252]

International Cooperative Adaptation

Climate change and growing resource scarcity will put great strain on international agree-

248 Campbell et al., 2007
249 UK Cabinet Office, 2005, op. cit.
250 CNA Corporation, 2007, op. cit. p.16
251 Both UNFCCC Copenhagen Accord, 2009 and Cancun Agreements, 2010 call for $100 billion per annum by 2020.
252 CNA Corporation, 2007, op. cit. p.18

ments to manage water, food, trade, borders and other climate sensitive resources. These international agreements underpin the open global economy our prosperity depends on, but there are clear trends showing major countries are hedging against the collapse of this order by securing bilateral access to vital strategic resources.[253] While such a hedging strategy is understandable it undermines overall trust in the international rule of law. It is in the collective interest of all countries to counter-act these trends with targeted interventions to improve the resilience and effectiveness of international agreements to climate change and resource scarcity, thus increasing the perception that the international system will deliver reliable security for all.

A good example of how climate change can destabilize highly stressed and politically contested environmental systems can be seen in the Nile Basin. The shortage of water in the Nile has led to efforts to develop more water resources and use more sustainable forms of agriculture. The internationally-supported Nile Basin Initiative has been established to address these tensions but progress toward a new framework has been undermined by the proposal of a new treaty by the upstream Nile powers.[254] Future water scarcity is already an important international political issue in the Nile Basin even without climate change.

Figure 6.3[255] illustrates the additional political consequences of scientific uncertainties over projections of future water flows, which are typical of most major rain-fed river basins. Some models show mild increases in Nile river flow, others dangerous declines. The choice of which prediction upstream states use as a basis for planning and infrastructure build will have significant implications for the water security of downstream countries.

The potential for upstream countries to use climate change as a screen for renegotiating water-sharing agreements onto more favorable terms is high, and the uncertainties around water availability are likely to increase levels of distrust in downstream countries. In times of heightened tension over other issues, water infrastructure will become an increasingly attractive weapon of diplomatic pressure, or target in military confrontation, as is already borne out by the history of recent water conflicts.[256] As with many issues related to climate change, perceptions and trust will be vital in creating a shared management regime that is resilient to the unpredictable extremes of climate change. Will upstream countries reduce water flows to their farmers during drought years to make up for a lack of water storage by downstream countries? As flood defenses are breached and dams reach maximum capacity, will floodwaters be sent downstream to vulnerable communities? The harsh politics of managing such extremes inside a country are delicate enough; when mixed with difficult trans-boundary relationships they could easily become incendiary.

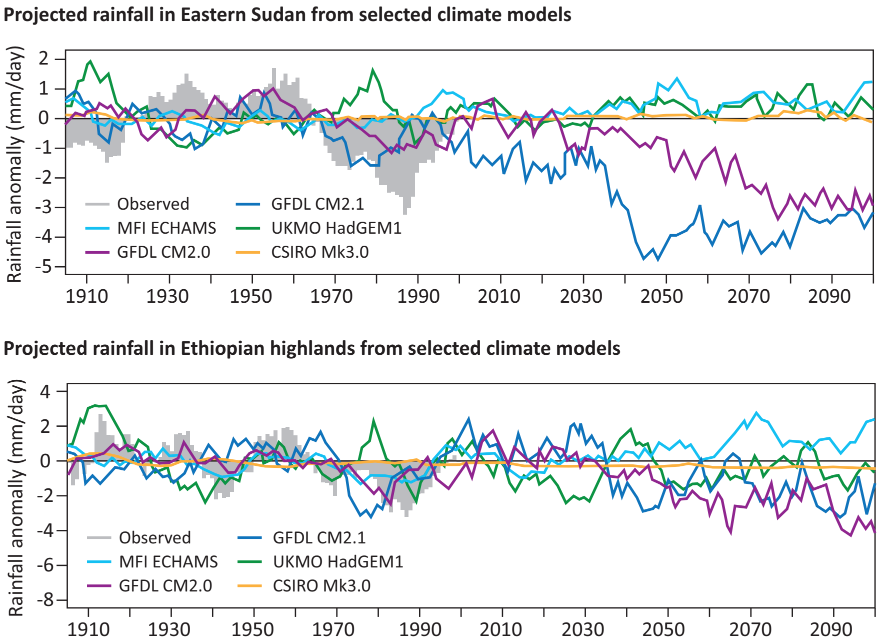
253 This is demonstrated by the recent scramble to the Arctic by major powers Russia, USA, Canada, Denmark and Norway, as valuable resources become uncovered by climate change related melting. The security and geopolitical implications are highlighted by a lack of international agreements governing the territory. See for example, Borgerson, S. (2008)

254 Nile Basin Initiative, 2010

255 KNMI (Royal Netherlands Meteorological Institute) – website 11 December 2006

256 Gleik, 2004

Figure 6.3: Uncertainties in Flow Projections on the Nile in Eastern Sudan and Ethiopian highlands



Source: *KNMI (Royal Netherlands Meteorological Institute), 2007.*

These scenarios point to the critical importance of 'climate proofing' existing water agreements by deepening co-operation in infrastructure and management schemes. Despite intensive analysis it is clear that information on the regional and local impacts of climate change is still very weak, and this is hampering the development of effective strategies to increase resilience in all countries.

Existing international disputes over climate sensitive resources such as rivers, maritime borders and fisheries will further complicate the design of adaptation strategies. Improving societal resilience will not be a politically neutral act in many of the most climate vulnerable countries of Africa, Asia and the Middle East. It is critical that these political issues are factored into adaptation program design and the approach to international cooperation.

Beware the Long Tail

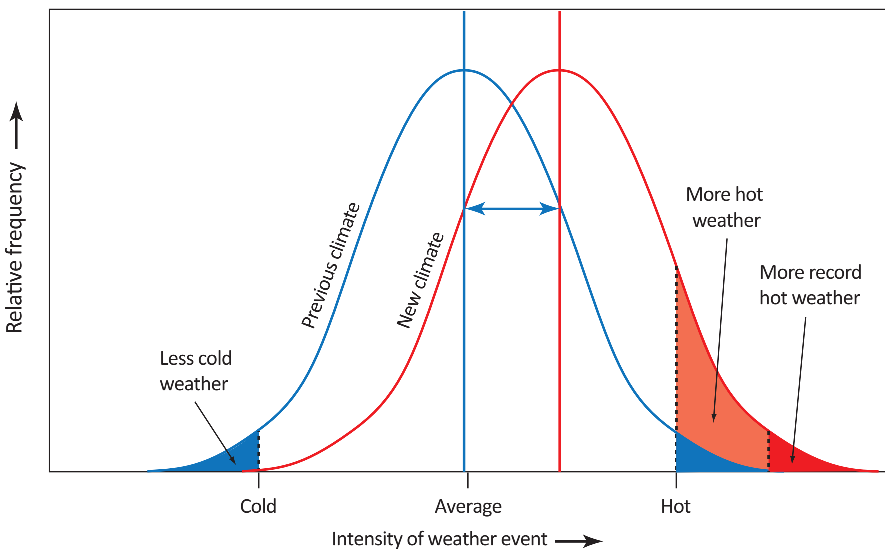
Changes in global mean temperature are useful to scientists who study the physics of the global climate system, but they are virtually useless for understanding local climate impacts. Local averages are also largely misleading. While changes in the average may be problematic in some cases (for example, a decline in average annual precipitation in arid locations), most local weather damage is, and will continue to be, caused by increased extremes – intense, low-frequency weather events – rather than changing averages.

A general feature of climate projections is that global warming causes local extremes to increase more than local averages. For example, heat waves warm up or increase in frequency more than the average temperature and the amount of precipitation in the heaviest rain events increases more than the annual average precipitation.[257] Similarly, in a number of modeling experiments, the most intense categories of hurricanes (categories 4 and 5) became more frequent, while weaker categories became less frequent, in a world with ~750 ppm CO_2 (Figure 6.4b).[258]

If the frequency distribution of a local climate variable were normally distributed, a one-standard-deviation increase in the average would increase the frequency of an extreme event that historically happened only once in 40 years (a five-percentile event) to occur about every 6 years. Moreover, the new 1-in-40 year event would be significantly more intense (Figure 6.4a).

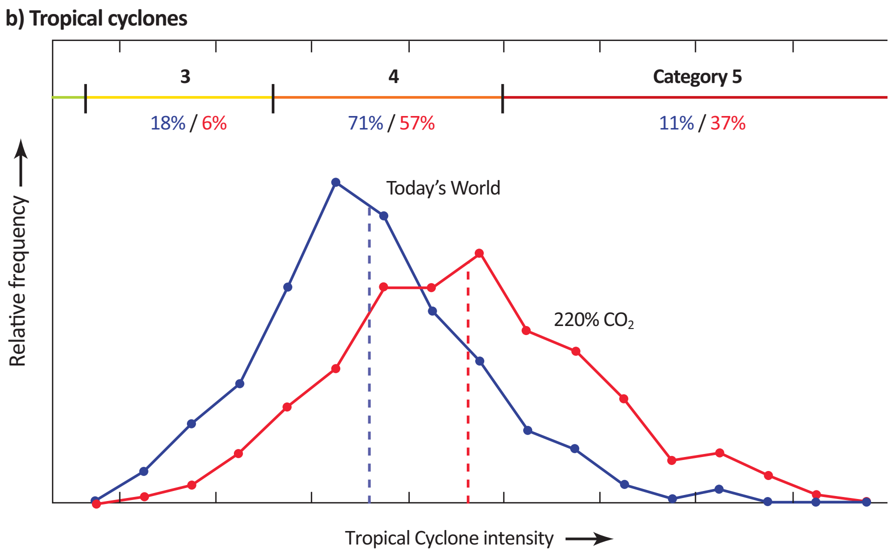
Figure 6.4: Increase in probability of extreme events in a warmer climate.

a) Temperature



257 See Box 10.2 in Meehl et al., 2007, op. cit.; Tebaldi et al., 2006

258 Knutson & Tuleya, 2004



*(**a**) Simplified depiction of the theoretical changes in climate extremes in a warming world. (**b**) Frequency distributions of hurricane intensities from a climate model under present-day CO_2 concentrations and under CO_2 increased by 220 percent (about 750 ppm).* ***Source:*** *Adapted from Karl et al., 2008.*

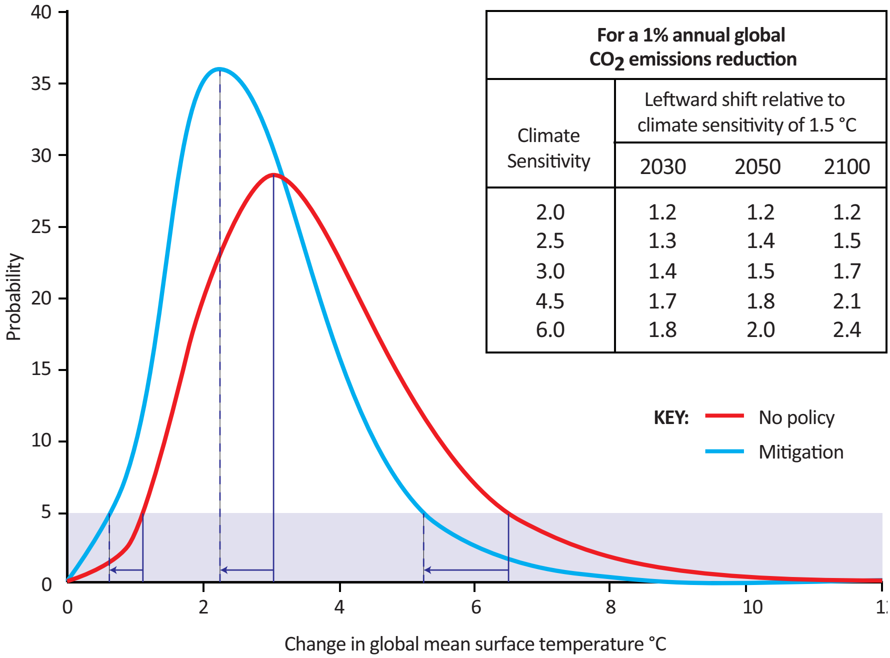
Aggressive mitigation can lop off the long tail of uncertainty

As discussed in Chapter 2, probability distributions of climate outcomes are skewed, resulting in a long tail that elevates the risks of climate change (Figure 2.2). And as discussed in Chapter 3, this uncertainty should be expected to persist for a decade or longer. Even though the underlying uncertainty surrounding climate sensitivity will likely persist, **the uncertainty surrounding future warming can be reduced simply by mitigating CO_2 emissions.** Reducing emissions shifts the entire probability distribution of future temperature change to the left – that is, toward less warming (Figure 6.2).

From a risk management perspective, the greatest value of mitigation is that it shifts the high-risk tail on the distribution curve even more to the left than it shifts the average. Therefore, mitigation has a disproportionately large impact in 'lopping off' the risky long tail of uncertainty. Also important for risk reduction, the leftward shift is stronger at higher climate sensitivities (see table insert in Figure 6.2), thus adding additional value to emissions reductions when decisions are formulated to hedge against the chance that climate sensitivity may be greater than estimated. Because this insurance against high-impact outcomes is not factored into cost-benefit analyses of climate policy, mitigation policy has been systematically undervalued.[259]

259 Rose, 2010

Figure 6.5: Mitigation of greenhouse gas emissions lops off the long tail.



For a 1% annual global CO_2 emissions reduction			
Climate Sensitivity	Leftward shift relative to climate sensitivity of 1.5 °C		
	2030	2050	2100
2.0	1.2	1.2	1.2
2.5	1.3	1.4	1.5
3.0	1.4	1.5	1.7
4.5	1.7	1.8	2.1
6.0	1.8	2.0	2.4

Illustrative reduction in the probability of higher global mean surface temperatures in an unspecified future year due to reduced greenhouse gas emissions relative to a 'business-as-usual' (no-policy) emissions scenario. Vertical lines show how much the probability of warming is reduced for the best estimate and the 5 and 95 percentiles. Note that the leftward shift is stronger for higher levels of warming, thus exerting greater leverage at higher levels of risk. This feature increases the value of mitigation when viewed through a risk management lens. ***Source:*** *Adapted from Rose, 2010.*

Uncertainties over mitigation are as significant as uncertainties about climate outcomes

Mitigation risks have been less examined than climate risks, but are of similar or larger scale in terms of affecting climate security outcomes. There is a certain amount of complacency among some policy makers regarding the high likelihood of delivering the fundamental changes in economic systems implied by the 2°C goal. This is despite decades of failures across the globe to successfully implement large-scale programs in critical areas such as domestic energy efficiency and reducing tropical deforestation. Mitigation uncertainties can be split into four main areas:

- **Mitigation program delivery failure,** wherein policies simply don't achieve expected results, for example emissions reductions from energy efficiency programs (estimated to give 50 percent of planned reductions by 2050) or reductions in deforestation (10-120 percent of emissions reductions in 2030).[260] Failure to mobilize sufficient capital into the energy sector, or failure to implement policies in a timely manner could also place major constraints on the rate of low carbon energy deployment.

- **Higher greenhouse gas emissions growth** would make achieving stabilization far harder as emissions could increase by at least 20 percent to 2030. Before the economic crisis, emissions were growing at the higher end of IPCC scenarios.[261] Emissions could increase far faster than expected to 2020 due to higher global GDP growth as economies recover from the financial crisis, faster car use growth in emerging economies, or an increase in coal and unconventional oil use driven by declining oil production or political instability in oil producing nations.

- **Underperformance/failure of new low carbon technologies** would undermine consensus projections of future low carbon energy supply trajectories, for example: carbon capture and storage (20 percent of 2050 reductions); biofuels (10-20 percent of 2050 reductions); nuclear power (10 percent of 2050 reductions).[262] The scale of the shift from 'business as usual' economic models which is needed is shown by analysis suggesting that the global diffusion rate of climate technologies would need to double from current 'normal' levels in order to meet the 2°C goal.[263]

- **Failure of international cooperation**: International climate change agreements could fail if some major countries begin to renege on their abatement promises. It is unlikely that the system would collapse completely or that countries would completely stop abatement efforts, but given currently weak unilateral commitments, failures would lead to greater climate change and less coordination of adaptation and technology development efforts.

Using their cost curve modeling McKinsey&Company examined some different combined failure cases to see how they affected the ability to reach a 450 ppm target.[264] The results of their work suggested that a 50 percent failure of energy efficiency programs coupled with only 25 percent delivery of forestry goals would put the world onto a 550 ppm trajectory in 2030. This 550 ppm scenario could also result from a weak international agreement that failed to bring in major reductions from the fast growing emerging economies. A failure to deliver all low carbon technology options in the medium-term has less of an impact leading to a 510 ppm scenario. This lower impact assumes relatively easy substitution by energy efficiency or other low carbon power options. This modeling did not consider the cases where technologies such as nuclear power and carbon capture and storage failed to be delivered at scale due to public acceptance concerns or a major accident.

260 International Energy Agency, 2008

261 Raupach et al., 2007, op. cit.

262 International Energy Agency, 2008, op. cit.

263 Lee et. al, 2009

264 McKinsey & Company, 2009

Interestingly the McKinsey&Co analysis also found that delaying the onset of serious global abatement action by 10 years until 2020 had equally serious consequences due to locked-in high carbon infrastructure, resulting in cumulative additional emissions of 21 times combined 2005 United States and China emissions by 2030. An additional risk is that the high capital intensity of a low carbon energy sector requires a doubling of investment in the next two decades, making higher interest rates and weakness in the financial sector a critical risk in delivering the scale of change required.[265]

Therefore, even if countries agree to aim for ambitious mitigation targets it is highly uncertain that these can be delivered at the pace and scale envisaged. Options for managing mitigation risks include:

- **Independent monitoring of national implementation programs** to ensure problems are identified at an early stage and remedial action can be taken. This approach has been pioneered by the UK Committee on Climate Change, which was established by statute alongside the United Kingdom 2050 mitigation targets.[266]

- **Delivery of more low carbon energy technologies** much earlier than on current plans through increased national and cooperative international RD&D.

- **Building political resilience into the UNFCCC system** through strong systems to monitor and verify progress towards country commitments and allow early cooperative resolution of any under-performance by countries against their commitments.[267]

Risk management of mitigation actions is dangerously underdeveloped at both the national and international level. Given the irreversible nature of many climate change impacts this presents a serious risk for preserving climate security.

265 Ernst and Young, 2010
266 http://www.theccc.org.uk/
267 E3G, 2009

7 Operationalizing Risk Management
Ten Key Recommendations

"We believe the 9/11 attacks revealed four kinds of failures: in imagination, policy, capabilities, and management."
9/11 Commission[268]

As set out in Chapter 1, assessments suggest that, given the major scale of the threat it poses to national security goals climate change should be treated like any other global security threat, such as nuclear proliferation, terrorism or failing states. This requires a sound plan that takes into account the full range of uncertainty and puts in place effective strategies to manage all material risks.

Too often uncertainty around climate science and climate change policy has been ignored or downplayed in order to avoid 'complicating' policy debates. It is also well documented that those ideologically or economically opposed to action on climate change have used exaggerated accusations of scientific uncertainty as argument for inaction. As a result, the proponents of urgent action have been less willing to address uncertainty head on. This has been a serious mistake.

The reluctance to engage fully with uncertainty around climate change has resulted in policy proposals that are more vulnerable to partisan attack, less believable to the general public, more likely to result in fatalism or rejection, and more likely to fail under many future scenarios. Current climate policies are therefore insufficient to deliver real climate security to the global population.

Managing Climate Security Risks

Risk management is both an art and a science. It depends on collecting the best data possible, but also being aware of what is not known, what needs to be known and what cannot be known. It requires complex and often unquantifiable trade-offs between different strategies to prevent, manage and respond to risks. It is both long-term and reactive.

As discussed in Chapter 5, the security arena is full of useful lessons of effective and ineffective risk management strategies in areas as complex and vital as climate change. There is no perfect off-the-shelf risk management approach to address national security threats. However, the lessons of the past show that all effective responses rest on:

268 The National Commission on Terrorist Attacks on the United States, 2004, op. cit.

- Setting clear objectives.
- Thorough assessment of the threat and underlying vulnerabilities.
- A willingness to address worst-case scenarios.
- A process for explicitly managing and understanding the risk implications of the uncertainties that inevitably occur in large-scale, complex problems.

In some cases it has taken a decade or more of intense debate to develop sustainable risk management strategies to tackle national security issues. There is not the luxury of such time in the case of climate change. The lessons of successful responses to other vital national security issues must be applied.

Perhaps the most fundamental uncertainty in climate change policy is by how much the world will warm, and thus the level of disruption of regional climatic patterns. At a strategic level this uncertainty can be described by two composite variables: the sensitivity of the global climate system to increasing concentrations of greenhouse gases in the atmosphere ("climate sensitivity"[269]), and the effectiveness of global mitigation efforts to limit net emissions of greenhouse gases to the atmosphere.

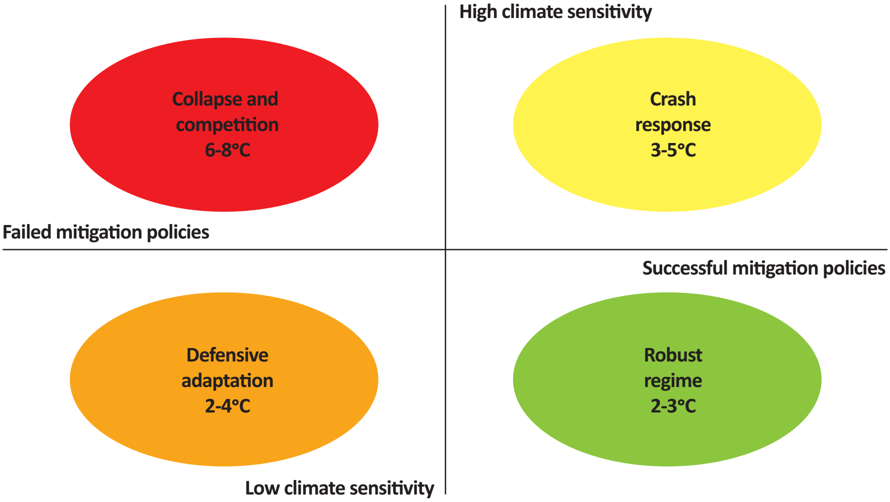
Although a commitment exists to review shifting to a 1.5°C goal, countries have only made a fragile political commitment to keep global average temperature increases to below 2°C. While this level of warming would still pose existential threats to some countries, this is where the only current global political agreement lies. Chapter 2 detailed the impacts on resources, landscapes and weather systems that form the basis for the political consensus around this objective. Yet 2°C cannot be assumed to be a ceiling for planning purposes. Current international reduction targets and actions registered under the Cancun Agreements, even if achieved, are expected to allow 3-4°C of warming.

A 3-4° C future is significantly more expensive and challenging to adapt to, but the current level of agreement on the global climate regime gives no reasonable basis to expect a lower degree of warming. The global level of ambition *may* increase in the future, but this cannot be deduced as *likely* from analysis of current climate politics. Therefore, when responding to assessments of the future hostile intent of potential adversaries, or assessing the likely impact of the global non-proliferation regime, 3-4° C should be used as the baseline planning assumption. Similarly, when making decisions about investments in community resilience, access to essential resources and protection of critical infrastructure it is safer to budget and build for at least this level of warming.

269 Note that this term is used here in a broader way than in the climate science literature where it refers to the equilibrium response of climate models to a doubling of greenhouse gas concentrations.

Indeed it is still quite possible that there will be warming of 5°C or more if climate sensitivities are higher than expected, if policies fail to deliver anticipated reductions, or if feedback loops kick in. Yet the disastrous impacts of 5°C of warming described in Chapter 2 can never be considered an acceptable outcome. Contingency planning for warming of 5°C or more, however, will help ensure that appropriate investments are made to avoid such an outcome and ensure that nations are prepared to prioritize responses if such a catastrophic level of warming becomes inevitable.

Figure 7.1: Climate Security Scenarios in 2100 based on a 2°C global mitigation target



The grid above presents four illustrative scenarios that could be used to inform a climate security risk management strategy, taking different combinations of uncertainty over climate sensitivity and the success of global mitigation policies as the key axes of uncertainty. The scenarios are constructed to illustrate the possible 2100 outcomes assuming global efforts continue to deliver the current 'consensus' scientific target of aiming for a 50:50 chance of achieving 2°C in 2100.

As a convenient short-hand, and because of their global scope, the scenarios have been identified as relating to estimated ranges of global average temperature rise. However, we recognize that this is a rather crude and misleading risk management measure for three reasons:

- **Obscuring long tails**: the use of simple temperature ranges obscures the existence of 'long tails' in the probability distributions where more extreme climate change impacts could occur.

- **Hiding regional variation**: parts of fragile regions such as Africa will experience rises at least 50 percent higher than global averages and areas associated with major climate feedbacks, for example Arctic tundra and Antarctic ice-sheets.

- **Failure to make explicit key vulnerability and impact thresholds**: an average global temperature rise of 4°C would make subsistence agriculture unviable in many regions of the world and give high probabilities of major climate tipping points occurring.[270]

Climate change scenarios should ideally be structured around meaningful measures of risk exposure and vulnerability of key areas. This is easier to do when analyzing national or regional risk management scenarios, for example, African countries could develop goals around reducing the probability of endemic crop failure.

Even the most successful mitigation scenario sees critical limits exceeded under a high climate sensitivity scenario ("Crash Response") where at least one major climate tipping point has been exceeded. However, the high level of international cooperation implied by this scenario suggests there would be coordinated international action to both lower emissions and manage high climate change impacts. This is not true in the scenarios where climate mitigation policies – and hence global cooperation – fail and countries fall back on "Defensive Adaptation" in the low climate sensitivity case. In the high sensitivity case the result is likely to be aggressive competition for resources with little support for vulnerable countries leading to widespread conflict and political instability ("Collapse and Competition").

It is highly unlikely that the current, relatively benign, global security environment with largely open trade, travel, investment and declining conflict and poverty levels would be maintained under the pressures of a high climate sensitivity and low cooperation scenario, whatever security interventions are undertaken.

A three-tier "ABC" Framework

A responsible risk management strategy will aim to reliably achieve the agreed temperature objective, while simultaneously ensuring that budgeting and contingency plans are effectively shaped to respond to potential future risks identified by these scenarios. Therefore, a prudent risk management approach should be built on a three-tier **"ABC"** framework:

- **Aim** to mitigate to stay below 2°C.

- **Build** and budget for resilience to 3-4°C.

- **Contingency** plan for capability to respond to 5-7°C.

The precise choice of temperature (or other) goal in each element of the risk management framework will depend on who is constructing it. Mitigation goals could be expressed in terms of the likelihood of exceeding critical threshold points, for example, a below 10 percent chance of exceeding 4°C, or under 1 percent chance of major sea level rise, etc. The impor-

270 Lenton et al., 2007

tant point is that each element is considered as part of an integrated whole. We do not offer the particular temperature goals above as a prescription of the 'right' risk management strategy, but rather as an illustration reflecting the current international consensus. More vulnerable countries and communities legitimately have different mitigation goals, and resilience planning assumptions will vary by geography and social vulnerability. However, mitigation goals depend on collective global action such that the goals of individual countries must combine to achieve a collective goal. Under such a constraint, failure of the collective goal is likely.

Developing an integrated risk management strategy around the ABC framework requires countries to have an explicit policy discussion on the trade-offs and risks surrounding their chosen climate change strategies. Decision makers, both public and private, who are responsible for maintaining critical national infrastructure, stability, security and economic activity, should be included inside this process so they can make the consequences of higher temperature scenarios clear if they consider global mitigation goals unlikely to be met. They might respond by requesting greater public funding in order to increase infrastructure resilience, support social structures and provide insurance instruments.

Internalizing the consequences of global mitigation failure within mainstream national decision-making, as opposed to the current mode of seeing global climate policy as an essentially international policy issue, should stimulate additional investment in both national mitigation and adaptation actions, and in cooperative action to improve the likelihood of effective global mitigation and adaptation.

We do not have the luxury of waiting for certainty, even if it were scientifically possible. Everyday we fail to act the risk becomes incrementally and irreversibly higher. Like the hands of a clock, the risks of climate change can only move forward.

Only an explicit, integrated and public risk management strategy that links efforts across the whole of government, led at the highest level, can ensure effective and balanced investment in the maintenance of national and global climate security.

Ten Priorities for Operationalizing a Risk Management Response

The question of how to shape a risk management response to climate change will be approached by many different countries around the world, at many different levels of government within each country, and will therefore be a tapestry of interconnected decisions rather than a master plan. Table 7.1 summarizes the key areas that must be prioritized in order to ensure that these plans mesh into a thorough and effective response. These ten priorities are expanded upon in the remainder of this chapter.

Table 7.1. Ten recommendations for operationalizing a risk management approach.

Aim to stay below 2°C	Sufficient mitigation goals
	Increased investment in transformational RD&D
	Resilient and flexible global climate regime
	Independent progress and risk assessment
Build and budget for 3-4°C	Adaptation strategies include 'perfect storms' and interdependent impacts
	Improved cooperation on preventive and humanitarian intervention
	Increased resilience of international resource management frameworks
	Provision of data and tools that decision makers need
Contingency plan for 5-7°C	Contingency 'crash mitigation' planning
	Systematic monitoring of tipping points

Aim to Stay Below 2°C

1. Sufficient mitigation goals

Deeper and faster greenhouse gas reductions are the only reliable way to take the worst climate risks off the table – cutting off the long tail – and therefore hopefully keep overall impacts from exceeding adaptation capacity.

The most critical security threats in most parts of the world are associated with nonlinear and abrupt regional changes and crossing crucial climate tipping points. The most certain way to mitigate the security risks associated with climate change is to limit the severity of impacts by limiting the amount of warming. While there are, and will remain, significant uncertainties associated with climate modeling (as explored in Chapter 2), synthesis of the models shows that higher levels of warming have correspondingly higher levels of impacts and much higher probability of extreme tipping point events. Greater warming, inevitably, also crosses the thresholds of more tipping points and increases the chances of large-scale catastrophic events. Recent observed phenomena, and updates to previous IPCC synthesis reports, indicate that the situation is likely to be more severe than previously understood.[271]

The current global goal, contained in the Cancun Agreements, of limiting temperature rise to 2°C would significantly reduce risks, though some argue that only a 1.5°C goal would truly eliminate the risk of large ice sheet collapse and consequent massive sea level rise. The

271 Smith et al., 2009

2°C goal began to gain international support in the 1990s when understanding of extreme climate impacts was far weaker, and lower climate sensitivity estimates implied that it could be met by limiting concentrations to around 550 ppm CO_2-e. Today, the scientific case for revisiting and redefining the 2°C goal is strong and the Cancun Agreements include a commitment to a review that could include strengthening the global goal on the basis of the best available scientific knowledge. This element of the Agreements specifically references exploration of how this might relate to a global temperature rise of 1.5°C.

Dramatically lowering the possibility of average global temperature increases exceeding a sufficiently conservative target would require quick implementation of a system to ensure global emissions reductions. As discussed in Chapter 4, there is no regime in place at this time that can deliver such a significant deviation from business as usual emissions growth. While a growing number of developed and developing countries have put forward proposals to shift to a low carbon economy, in some cases transformational ones, both the lack of a binding agreement and the fact that current voluntary targets are insufficient even if met, means there is currently no meaningful risk management framework in place.

A binding agreement to aggressively reduce emissions can only be reached if countries have a clear understanding of how their national interests benefit from reducing climate risks. The stunted diplomacy that has characterized nearly two decades of climate negotiations suggests that few countries have a clear view of their national interests under the full range of risks associated with different mitigation goals.

All countries must undertake a process to explicitly identify the level of climate risk they consider acceptable, based on a holistic risk assessment of national and human security impacts and the risk of extreme scenarios. Only explicit national goals can provide the political support necessary to underpin an effective global climate change control regime. However, explicit national goals alone are not sufficient to drive global cooperative agreement given potential differences in country risk exposure and vulnerability; this will require a parallel investment in effective climate diplomacy and political leadership to construct a regime which delivers climate security for all.[272]

2. Increased investment in transformational technology RD&D

Aggressive global emissions reductions will require rapidly accelerated innovation and diffusion of mitigation and adaptation technologies in both developed and developing countries. Although the use of existing solutions will be important, the deep cuts needed in emissions by 2050 will not be possible without rapid commercialization of new low carbon technologies. Failure to deliver low carbon innovation will mean that much of the world will become 'locked in' to carbon intensive development.

272 Mabey et al., 1997

The infrastructure choices over long lived assets such as power stations, pipelines and roads (the costs of which are typically discharged over 20 to 30 years), will have a huge bearing on national emissions profiles going forward. These choices are especially relevant for countries such as India and China, which are experiencing rapid economic growth, and those such as the United Kingdom where a significant percentage of ageing power sector infrastructure will shortly need to be replaced. In these cases accelerated investment in a large range of low carbon energy alternatives, especially in power generation and transportation, will be needed. Similarly, if climate damages accrue more rapidly than estimated, new innovations will have to be delivered sooner than is currently anticipated, including those relevant for adaptation.

Current national innovation programs are not adequate to both compensate for the risk of policy failure and manage the potential for higher ranges of climate sensitivity. They also fail to capture the global public benefits of climate technology, leading to significant underinvestment. Public sector energy research, development and demonstration (RD&D) in major economies has fallen by up to half in real terms over the last 25 years.[273] Energy RD&D as a share of total RD&D in OECD countries has declined from 11 percent in 1985, to 3 percent in 2005.[274] The fiscal stimulus in response to the financial crisis provided a short-term boost to public RD&D, but not the sustained investment necessary to drive innovation forward. International cooperation on clean technology is very weak at both the bilateral and multilateral level as countries prioritize gaining national competitiveness benefits over delivering public good benefits.[275]

Governments are increasingly aware of the need to scale-up support for technology RD&D. The Major Economies Forum countries have already committed to double public RD&D spending by 2015. However, this is not sufficient to meet the scale of the challenge. Analysis by the IEA and European Commission suggests public spending may need to rise to four or five times current levels by 2020.[276] In addition to scaling-up domestic spending, countries should also ensure that there is support for international cooperation. New institutions such as ARPA-E in the United States and a Green Investment Bank in Britain are being created to support scaled up innovation and finance. International cooperation is also moving forward slowly with new cooperative agreements, on a range of technologies, launched at the Clean Energy Ministerial in 2010.[277] Technology cooperation mechanisms are being negotiated as part of the UNFCCC process. However, the scale and pace of these efforts is not sufficient to meet the needs and risks that surround achieving aggressive emissions reductions.

Useful elements of an effective technology-based hedging strategy to manage policy and technology failures include the following elements:[278]

273 International Energy Agency, 2008, op. cit.

274 Ibid.

275 Tomlinson et al., 2008

276 International Energy Agency, 2010, op. cit.

277 http://www.energy.gov/news/documents/Clean-Energy-Ministerial-Fact-Sheet.pdf

278 Tomlinson et al., 2008, op. cit.

- **Increased national RD&D spending** with major economies committing to increase public RD&D by five times by 2020**.**

- **Increased bilateral technology cooperation** by reserving a share of national RD&D increases (for example, 10-15 percent) for cooperative activity with other countries**.**

- **Multilateral technology cooperation** to ensure development of critical mitigation and adaptation technologies, including 'orphan' technologies needed in developing countries.

- **Support for innovation systems in developing countries** to accelerate the diffusion and adaptation of existing climate change technologies, and accelerate innovation in areas of highest importance to poorer countries and communities.

International cooperation should focus on both identifying critical technologies that have the potential to make a major contribution to emissions reductions and resilience, and providing an assessment of the supporting infrastructure and other investments necessary to make them operational. The implementation of existing cooperation agreements should be periodically reviewed and updated in order to keep pace with the latest scientific developments.

3. Resilient and flexible global climate regime

There is significant potential in current global and national climate change policies for failure to deliver on finance and emissions reduction obligations. Whether due to intentional free-riding, or unavoidable under-delivery after a good-faith effort, some countries will fail to deliver on their obligations from time-to-time. If it is not possible for other actors to determine what caused a country to miss its target, there is a high potential for misunderstanding and mistrust which could, at the extreme, lead to the breakdown of an international mitigation agreement. This will slow progress against climate change by decades, resulting in greater risks than intended and concomitant underinvestment in adaptation to impacts that might otherwise have been avoided.

The next phase of the global climate regime should be designed to be resilient to under-delivery, as further delay will mean higher risk. A strong regime of reporting and transparency is essential for early identification of problems in delivering reductions and sustaining international resolve. Early identification gives time for a process to facilitate a country back into compliance with their obligations. In addition, clear information about what countries are doing on the ground will allow outsiders to distinguish intentional free-riding from imperfections in good-faith compliance efforts.

As in arms control, the principle of 'trust, and verify' is a good foundation for regime sustainability. The ability to verify others' efforts will prevent failure by one country from causing others to leave the regime due to mistrust. It also allows sharing of best and worst practices so that counties can address potential areas in their own response plans that are vulnerable to failure. **Currently, developing countries can receive international support to build national greenhouse gas monitoring and reporting systems. This support should be extended to include management systems for mitigation and adaptation actions.**

A resilient regime must also retain flexibility and allow for learning. **Given the significant uncertainty around the high-end impacts of climate change, the international and national climate regimes should have a built-in review to ensure that mitigation measures are based on the latest scientific understanding of the climate. It should also incorporate an ability to revise mitigation targets and mechanisms to reflect new information.** The Cancun Agreements include such a review and ensuring this is included in all future agreements within the UNFCCC should be a priority.

Reducing global greenhouse gas emissions to manageable levels is a marathon not a sprint. Countries must focus more on the resilience and flexibility of climate control regimes at global, regional and national levels to avoid failures in the future.

4. Independent progress and risk assessment

In order to ensure that national governments have a robust risk management strategy it is critical that progress towards specific goals is independently assessed outside the policy chain. **A failure to separate policy development from assessment introduces the risk of biasing assessment results to justify the initial policies.** This practice is widely used in other areas of security policy such as weapons proliferation assessments. In many countries it is already standard practice to separate assessment of the threat, generally undertaken by the intelligence community, from policy responses, generally undertaken by the military and legislative bodies. However, when it comes to assessing the effectiveness and implementation of policy responses to climate change, there is often no system for impartial review. Governmental assessments of the effectiveness of national and international climate strategies are largely in the hands of those charged with delivering them. A notable exception is the independent UK Committee on Climate Change, which was established by Parliament and audits both the goals and domestic delivery of United Kingdom's climate policy.

In addition to internal government procedures, public transparency and accountability should be enhanced by providing opportunities for external assessment of government policy. Civil contingency assessments are common in a number of countries and this type of model could be adapted to climate issues.[279] Timely access to information allows for an informed public to engage effectively with the policy development and political process.

All countries should commit to set up a process for explicit independent assessments of the effectiveness of both national and international policies in achieving strategic climate security

279 The UK Civil Contingencies Act of 2004 requires local responders (emergency services and local authorities) to maintain Business Continuity Plans and, since May 2006, for local authorities to provide advice and assistance to businesses in relation to business continuity.

outcomes, and addressing critical climate security risks to a country's interests. These assessments could be carried out by existing bodies and would be provided to the highest decision-making level on an annual basis. For example, in the United Kingdom system such an assessment should go to the recently established National Security Council chaired by the Prime Minister. Assessments should also be made available to the public and Parliaments to promote better informed political discourse.

Build and Budget for 3-4°C

5. Adaptation strategies account for 'perfect storms' and interdependent impacts

Some impacts of global warming are unavoidable because climate change is already underway and because even the most urgent response to climate change will take some time to peak and reduce emissions, locking in additional impacts. Even if atmospheric concentrations stabilize at a level that keeps warming below 2°C there will be significant damage in many vulnerable communities and ecosystems. From a security perspective, this requires several responses:

- Vulnerability assessment to give a better indication of where the worst impacts can be expected.
- Significant investment in measures to increase community resilience to coming changes.
- Proactive design of adaptation measures to minimize higher costs often associated with emergency measures and to reduce the potential for conflict over increasingly scarce resources.

Countries should explicitly identify the scenarios they are using to drive adaptation and resilience planning. As the central estimate for the outcome of the current climate regime is 3-4°C warming, adaptation should be designed and budgeted around providing effective resilience and response capabilities at this level of warming. Furthermore, analysis of key adaptation priorities should be based on modeling of compound climate impacts and not just individual impacts. By analyzing individual impacts climate research often misses the compound impacts of climate change on food supply, energy security, health, and ecosystems, and how they interact with socially contingent effects, like conflict and instability in areas of fragile governance and poor resource management.[280] There is also a need to develop a dynamic forecasting capability for 'perfect storm' events to give early warning for humanitarian and preventive interventions. In 2008, for example, the linkages between drought, trade policies and fuel and food prices led to food shortages and instability in Haiti, Mexico, Egypt and elsewhere across the globe. These dynamics will play out in both developed and developing countries.

280 Yohe, 2010, op. cit.

An illustrative model is the Famine Early Warning Systems Network (FEWS NET), "a USAID-funded activity that collaborates with international, regional and national partners to provide timely and rigorous early warning and vulnerability information on emerging and evolving food security issues" in developing countries.[281]

Developed Countries

It is generally recognized that adaptation is a more urgent need in developing countries and indeed adaptation support for communities at risk in least developed countries must be given high priority. However, developed countries will not escape unscathed as major investment in the built environment makes them arguably more vulnerable to infrastructure problems and economic loss. Hurricane Katrina in the United States showed that impoverished individuals and communities within developed countries are highly vulnerable.

Another important aspect of climate security analysis will be identifying the adaptation needs of military installations and impacts of climate change on training, infrastructure and overall readiness. Some militaries are already beginning this assessment. The US Department of Defense's Quadrennial Defense Review states, "operational readiness hinges on continued access to land, air, and sea training and test space. Consequently, the Department must complete a comprehensive assessment of all installations to assess the potential impacts of climate change on its missions and adapt as required."[282]

The military is not the only institution charged with protecting national security and domestic stability. There will likely also be significant climate security consequences for the police and security services, including demands for greater border security, changes in the rates and types of crime, enforcing new legislation, and responding to natural disasters and human migrations. This is largely overlooked in the present climate security debate but must be addressed in future adaptation planning.[283]

Global Security

In addition to assessing their own vulnerabilities, countries will want to assess how climate change impacts global security. A great deal of climate security analysis has focused on areas that are considered potential hot spots. Climate change impacts are expected to worsen conditions in many weak and failing states, potentially leading to increased extremism and conflict. In addition, failure to provide international support for increased resilience to climate impacts may result in greater social unrest and engender resentment toward developed countries, particularly the United States, which is widely perceived as having fallen behind on climate action. For example, Al-Qaeda leaders have repeatedly cited climate change in rhetoric aimed at fomenting anti-western resentment.[284]

281 http://www.fews.net/ml/en/info/Pages/default.aspx

282 US Department of Defense, 2010, op. cit.

283 Abbott, 2008, op. cit.

284 For example, see Imm, 2007

The dynamic relationship between adaptation and climate change is more complex than it appears. While it is evident that increasing resilience to climate-related resource scarcity can help reduce potential for conflict in key areas, it is equally true that poorly designed adaptation can increase the potential for conflict. Unless there is an upfront evaluation of potential conflict over resource access, that is, assessment of potential impacts on communities outside the one implementing the adaptation measures, there is a reasonable likelihood that one community's increased resilience may mean increased tension with others who rely on the same resource. Adaptation measures can also play into local power structures as access to resources can be used to wield power over community members or neighbors, and resource access points, such as wells, can become targets in conflict.

Adaptation decisions are not easy given the scientific uncertainty of impact assessments and the complexity of developing robust strategies for societal resilience. For example, should funds be spent on hard engineering of water control systems that could disadvantage poorer water users, or on community based solutions that support improved capability to resolve local tensions peacefully? The challenge of rebuilding Pakistan after the recent catastrophic flooding emphasizes the immediate relevance of the need to better understand and manage the complex confluence of climate, economic, governance and stability risks when planning long-term infrastructure investment. **The fact that there is no robust methodology for designing an optimal reconstruction strategy for Pakistan in the face of future climate change shows the weakness of current adaptation frameworks.**[285]

Adaptation planning is not just a technical exercise. It must take into account the broader political, economic and social impacts of both climate change itself and the necessary adaptation measures in order to avoid exacerbating rather than reducing the cost impact of climate change

6. Improved cooperation on preventive and humanitarian intervention

While not historically a core capability of the military in developed countries, though often a major responsibility in developing counties, increased demand to support disaster relief and humanitarian interventions is sure to impact future military readiness and capabilities. More frequent and severe extreme weather impacts will cause urgent humanitarian emergencies that could accelerate collapse and conflict in vulnerable states. **Thus, security in the 21st century will require a major increase in the capacity to launch coordinated international humanitarian and preventive missions.**

Recent natural disasters in both developed and developing countries show that there is still a general need to develop the capacity to coordinate and deliver effective humanitarian aid. Hurricane Katrina provides an instructive example; the disastrous effects of a hurricane

285 For discussion and links see http://judithcurry.com/2010/09/20/pakistan-on-my-mind/. This conclusion is based on the authors' off-the-record discussions with government and non-government experts responsible for Pakistan reconstruction funding in a range of countries.

hitting New Orleans were anticipated for decades, as impacts of climate change have been. The dramatic failures in providing for the evacuation of people who could not afford transportation, and the subsequent failure to ensure security in response to Hurricane Katrina, revealed that, even in the most developed countries, there is a long way to go to develop effective prevention and coordinated response strategies. One key lesson emerging from Hurricane Katrina is that time invested in preparatory planning and even gaming is well worth the effort in lives spared and harm prevented.

Additional investment in early warning systems should be prioritized to provide the ability to mitigate harm, before the event, by moving threatened populations and securing vulnerable infrastructure where possible. Examples of early warning capabilities include radio systems to provide flood warnings and data collection through rainfall and river gauges, which require small investments and are easy to implement.

Countries should form partnerships to develop regional scenarios and response strategies based on warming scenarios of, for example 3-4°C, to drive the development of contingency plans and investment in enhanced capability. The European Union, United States and African Union could, for instance, build on their existing cooperation on security issues by looking at the impacts of climate change and resource scarcity on the Nile Basin and Sahel regions over the coming decades.

As part of their comprehensive national assessments all countries should begin exploring the high impact scenarios expected with 3-4°C of warming in order to shape preventive investment and drive potential humanitarian needs assessment.

7. Increased the resilience of international resource management frameworks

Land loss, hydrological cycle shifts, temperature rise, and extreme weather events caused by climate change will impact, and add pressure to, resource scarcity. Current international resource management regimes are fragmented, and most are not equipped to respond to potentially huge disruptions in the systems they regulate. For example, many water-sharing treaties were enacted decades ago and can neither reflect new geopolitical and economic landscapes nor respond to the stresses of increased scarcity.[286] Similarly, international regimes governing the sharing of global marine resources are inadequate to address seriously climate-related changes, including ocean acidification caused by rising atmospheric CO_2 concentrations, which could intensify competition for and depletion of these resources. This is already becoming an issue in European waters as fish migrate north seeking cooler water, upsetting the balance captured in the existing regime.[287]

286 The Nile Water Agreement between Egypt and Sudan was signed in 1959 and makes no provision for climate change and its impacts on water levels in the river. Water allocations are fixed, which raises concerns about the ability to adapt to changing runoff patterns.

287 Hickman, 2010

Intra- and interstate resource management regimes were designed to prevent conflict by providing rules that reconciled the needs of multiple actors who rely on a single resource. They are intended to provide predictability and stability based on rule of law rather than power-based capture of resources. These regimes need to be actively re-evaluated and adjusted in order to incorporate measures that address the expected impacts of a changing climate. These changes could include reforming resource sharing mechanisms, enhancing international arbitration, improving scientific cooperation, and sharing of best practices.

Failure to continually monitor and improve resource management regimes may make them ineffective reconcilers in the future, giving rise to intensification of conflicts and fostering power-based approaches. It may also create climate-related backlash where countries resort to unilateral actions, such as retaliatory trade actions, escalating tensions at the international level.

The time to strengthen regimes is now, when the impacts of climate change are still at relatively low levels. This is also the time to actively identify gaps and critical areas where management and/or governance regimes are absent, and intensify multilateral and bilateral engagements to address these gaps.

8. Provision of data and tools that decision makers need

Climate change is moving from the strategic phase of identifying the problem and possible solutions, to the operational phase of programming specific investments in mitigation, adaptation, resilience and contingency planning. Climate science drawn upon by the IPCC process is mostly reliant on academic funding mechanisms, and is driven largely by academic interests that are not focused on policy questions. While this produces high-quality, independent research it does not necessarily supply the type or form of data most relevant to policy makers and the decisions they face in the operational phase.[288]

Different decision makers in the policy and security community have different questions they need answered in order to make informed and effective decisions. In many cases, the form in which information is provided to them does not answer their specific questions. While in some cases it will be possible to reconfigure existing data to meet their needs, it is essential that the policy community begins feeding its information requirements into the scientific community directly, so that they are directly met.[289] The US Navy is one of the first forces to actively create a process for feeding its needs back into policy and science communities. The US Navy Climate Change Roadmap commits the Navy to annually identifying and proposing additional studies and research regarding the national security implications of climate change on naval missions, force structure, and infrastructure.[290]

288 Rogers and Gulledge, 2010, op. cit.

289 Ibid.

290 Task Force Climate Change & Oceanographer of the Navy, 2010

In addition to the scientific analysis of climate change, decision makers need new socioeconomic analysis to inform effective decisions.

Solutions to improve 'decision-support' systems include:

- Reinterpreting existing data to reflect the time and geographic scales security analysts, planners and policy makers need.

- Developing new data that incorporate specific characteristics of vulnerable communities and helps determine fragility or resilience in the face of anticipated climate impacts.

- Involving a range of policy makers, planners and security actors more actively in defining the climate research and analysis that will help them make specific decisions.

- Creating well-designed and adequately resourced feedback loops to incorporate new data and advancements in scientific understanding effectively, and support continual refinement and validation of analyses, impact projections, and effective response mechanisms.

These solutions will not develop spontaneously and will require new policies, new relationships between the analytical and policy communities, and sustained financial resource commitments.[291] Priorities for spending should be informed by overview vulnerability assessments and will require new data extraction tools that explore specific characteristics of impacted communities, which will help determine their fragility or resilience in the face of anticipated impacts. **A core area for investment is in detailed bottom up monitoring of environment, resource and conflict interactions in vulnerable areas and countries.**

Additional information is necessary but not sufficient. Analysts also need new tools to use this information to provide compelling investment cases for priority preventive actions, especially given current financial constraints. Some models have been developed but these are not yet widely used or understood in the military, diplomatic and development policy communities. Both socioeconomic modeling and scenario analysis will be important elements of informing decisions in this space.

Operationalizing risk management strategies in real security and development decision-making will require investment in improved decision support systems, delivering more relevant information and new decision-making tools.

291 Rogers and Gulledge, 2010, op. cit.

9. Contingency 'crash mitigation' planning

There is a growing body of evidence to suggest that the likelihood of catastrophic climate impacts may be higher than expected. As catastrophe is by definition intolerable, it is essential to develop a capability to implement crash mitigation programs to reduce their impact and to stabilize the international system in the face of widespread alarm and individual country failures. The effectiveness of such a risk management option will depend on our ability to react quickly and also on how much advance warning can be obtained of extreme climate impacts; monitoring issues are covered below in Recommendation 10. These uncertain, high-risk, potentially high-reward initiatives have the chance to provide dramatic results, but also carry with them significant risks of policy failure and in some cases serious collateral risks. Good policy is rarely made in times of crisis. It is vital that contingency plans are in place to understand and manage these risks now so in the event of a crisis the right decisions can be made.

Perhaps the most often discussed option for crash mitigation revolves around the concept of geoengineering; whereby mechanisms are engineered to either absorb CO_2 or reflect heat away from Earth's surface (solar reflective). While numerous proposals have been considered – from spraying sulfur particles in the upper atmosphere to fertilizing the world's oceans so that they absorb more carbon – many have unappealing side effects that argue against wide-scale application. Moreover, the common assumption[292] that reducing the Earth's surface temperature through geoengineering would yield benefits similar (or even superior) to avoiding warming by reducing greenhouse gas emissions is misinformed. Important aspects of the climate system, such as large-scale precipitation patterns, will not respond to reduced solar radiation in the same manner that they would respond to reduced greenhouse forcing, even if the same level of cooling were achieved.[293] Analysis suggests that to control the potentially dangerous impacts of some geoengineering approaches, much greater public discussion is needed and an international agreement governing research and deployment should be reached in the near term.[294] However, it is equally important to start developing contingency deployment plans for relatively low risk carbon absorbing options that could provide insurance against extreme climatic impacts, these include:

- "Artificial trees" could be designed to strip CO_2 directly from the air and then store it.
- Biochar is a proven cultivation technique that locks large amounts of carbon in agricultural land.

292 Carlin, 2007
293 Engelhaupt, 2010
294 Royal Society 2009; Asilomar International Conference On Climate Intervention Technologies, 2010

- Combined biomass energy and carbon capture and storage – shifting fossil power plants to use sustainably harvested biomass and capturing the carbon would result in negative carbon emissions.

Some have suggested the rapid diffusion of current nuclear fission technology as a crash mitigation program. The risks associated with this option would require a robust set of hedging strategies to mitigate collateral risks of nuclear proliferation, safety concerns, terrorism and waste management. Firstly, the rapid deployment of nuclear energy would certainly require some sort of agreement on an international fuel-cycle treaty. Ideally, this would involve both safeguards against the diversion of enriched uranium, and also measures to safeguard access by all countries. Crash deployment of nuclear technology would also require a large number of additional institutional steps, including a system to handle radioactive waste, a global consensus on reprocessing and a safe fuel cycle, and an extensive program of technical support and capacity building to ensure that skills and systems are in place to ensure safe construction and operation of power stations at the necessary pace and scale. Indeed, the slowing of nuclear power development in past decades has eroded the workforce and slowed technological development in the nuclear power sector, creating a large deficit in trained nuclear engineers and workers. This deficit hampers nuclear power as an effective element of a risk management framework.[295]

Perhaps the lowest risk potential crash mitigation strategy would be rapid diffusion of non-nuclear clean energy technologies. Here too, significant efforts would be necessary before this option could be considered ready to deploy. There is a strong risk management rationale to accelerate the deployment of technologies that deliver critical 'disruptive technologies'[296] for energy and climate security.

Deployment of these technologies at a pace and scale needed to meet emergence of extreme climate risks would require significant and costly immediate retirement of existing high carbon infrastructure at the same time. This will require direct government involvement in commissioning and constructing new low carbon energy capacity and driving unsustainable increases in supply-chain capability. An optimal transition to a low carbon economy would involve a process of planned retirement and gradual construction of major new low carbon infrastructure. To prepare for a crash program it could be necessary to front–load the construction of such infrastructure (such as oversized CO_2 transport and storage networks) as it is unlikely to be possible to construct quickly. Alternatively a contingency program may need to rely on more expensive clean technologies where production can be quickly scaled up, for example solar energy generation.

295 The United Kingdom government began to address some of these issues in the run-up to the 2010 Review of the Nuclear Proliferation Treaty see http://ukunarmscontrol.fco.gov.uk/resources/en/pdf/17075878/liftingnuclearshadowpaper

296 A disruptive technology is one that disrupts the existing market in unexpected ways, for example by significantly lowering price or appealing to a different consumer base.

Contingency investments could include:

- Large-scale carbon capture and storage infrastructure that could be used to rapidly reduce emissions from fossil power plants (including negative emissions if applied to biomass) and heavy industry (steel, cement, chemicals and aluminum).

- Surge capacity for thin film solar energy and concentrated solar thermal generation technologies as fast-scaling technologies with global application, which could be deployed in response to a crash climate program.

- Front-loaded investment in smart grid technologies and systems that would allow rapid incorporation of much larger amounts renewable energy into the electricity grid, including advanced energy storage technologies.

Though work continues on developing technologies in all these areas, progress in deploying the necessary infrastructure networks and supply-chain capacity is too slow to make any of these a true hedge against extreme climate change contingencies. With cooperative investment, all of these technologies could feasibly be developed to be commercially deployable at large scale in the next five to ten years. However, countries would need to make extensive investments in contingency deployment infrastructure before demonstrating economic need; this would require a change in the economic regulation of infrastructure networks in many countries. There is also a need to invest in basic science in biotechnology, materials and nanotechnology, which will underpin the next generation of low carbon solutions. Though there is a case for increasing investment in advanced fission and fusion power systems it seems unlikely even with high levels of additional resources that either could be deployed at scale before 2035-2050. Therefore, these investments would appear to be a relatively low value hedging option compared to other technologies and approaches.

Even if the investment was forthcoming, there would be significant challenges to overcome in terms of designing an effective public/private finance regime to foster such rapid diffusion, and working through the intellectual property rights issues that this could raise. A proactive strategy on all three fronts (technology development, finance, and intellectual property rights) may be the most low cost way to prepare for any future need for a crash program.

Countries should agree to a collective management framework for potential contingency programs now, or risk serious negative side effects of panicked responses to extreme climatic events in the future. These contingency plans should include:

- Agreement on financing mechanisms to ease the large-scale early retirement of carbon-emitting capital stock, and its rapid replacement by less affordable non-emitting technologies.

- Accelerated cooperation on a range of advanced and additional low carbon energy technologies which could be deployed at scale from 2020-2025.

- An international regulatory scheme for managing solar reflecting geoengineering research and deployment.

- A deployment plan for utilizing the lowest risk carbon scrubbing technologies: carbon capture and storage with biomass; "artificial trees" and biochar.

- A deployment and management plan for rapid global acceleration of nuclear fission power plants.

Failure to construct contingency plans which could require tough choices, such as front-loading critical infrastructure or reversal of policies in some countries on use of nuclear power or carbon capture and storage, is highly risky. The pressure to act in the face of severe climate events or indications of high impact scenario will be extreme, and without contingency planning are likely to lead to dangerous or ineffective 'solutions' being implemented.

10. Systematic monitoring of climate tipping points

While many assume that climate change will be a slow and linear process toward a moderately warmer future, **there is broad acceptance amongst climate scientists that there are likely to be elements of the climate system which function like a light switch –changing rapidly to a qualitatively different state once a certain temperature threshold is surpassed**. The term 'tipping point' refers to the point at which the future state of the system is qualitatively altered. A tipping point may be irreversible but is not necessarily so. On local scales tipping points are likely to be numerous and often unidentified. A number of high-consequence tipping points that would have impacts on continental to global scales have been identified (see Chapter 2). Large-scale 'tipping points' may exist for dieback of the Amazon and Northern Hemisphere boreal forests, West African and Indian monsoon systems, Arctic and sub-sea methane emissions and for the melting of Arctic sea ice and the Greenland ice sheet. There is significant data in the paleoclimatic record to indicate that such switches may be caused by an amount of warming within the range that climate models project for unabated CO_2 emissions within this century.

Our understanding of the Earth system, and how it integrates with social systems, is not yet up to the challenge of projecting the likelihood of triggering particular tipping points and the precise consequences of doing so. There is an urgent need for research to identify early warning indicators (if such exist), to define potential impact scenarios, and to develop response plans.

A report by the US National Science Foundation Advisory Committee for Environmental Research and Education identifies the following important questions for integrated research:

Can we identify vulnerabilities to threshold change, i.e. leverage points in the dynamics of systems that make them especially sensitive to perturbations? Can we identify the processes that lead to either positive or negative feedbacks to perturbations? Can we stop movement toward a tipping point? Can we reverse a system's trajectory once a tipping point is reached? How can we mitigate the changes that we expect to occur? A tipping point may not equate to a "point of no return" but it may mark a new state in which environments and humans interact differently. How can we adapt to the new state that is reached after a tipping point?[297]

Since large-scale tipping points would impact many countries and economies, they are of direct relevance to international institutions and frameworks. Despite the truly urgent nature of the consequences of tipping points, systematic and coordinated international monitoring efforts are insufficient to promote coherent and comprehensive data collection and analysis, and not yet clear enough to develop further understanding around the potential warning signs that identify the proximity of tipping points.[298] In terms of risk management failures this is equivalent to neglecting to monitor the progress of states like Iran and North Korea in developing nuclear arsenals.

There is an urgent need for a comprehensive, long-lived monitoring system that integrates Earth and socioeconomic observations in areas and systems of high impact and vulnerability. This will require additional dedicated sources of funding to supplement current academic research. The World Meteorological Organization has found that long-term, high-quality and uninterrupted observations of atmosphere, land and ocean are vital for all countries, as their economies and societies become increasingly affected by climate variability and change. The IPCC system relies heavily on existing academic funding systems, which cannot provide the support or coordination necessary for such a comprehensive approach. **Estimates suggest that there is an urgent need for greater investment of at least $1.2-4 billion per year to provide policy makers with coordinated early warning capacity for dangerous climate scenarios.**[299]

In addition to scaling up capacity and coordination around monitoring tipping points, security analysts must consider how to present information on tipping points for policy makers. Experience shows that when faced with the devastating consequences of some tipping points, policy makers feel overwhelmed and are not able to integrate this information into their policy framework. Study of this phenomenon in the social anthropology field reveals that it lies in the 'acts of God' space of people's comprehension, and they are, therefore, not convinced that human agency can have any effect.[300] Nonetheless, tipping points are an

297 Advisory Committee for Environmental Research and Education, 2009

298 Weise, 2009

299 National Research Council, 2003

300 Fraley, 2010

essential element of facing and addressing the threat of climate change effectively. Exploratory approaches to improve how this information is presented and acted upon should be tested.

Failing to adequately monitor climate tipping points is a significant intelligence failure on a level with the absence of data on Afghanistan terrorist camps before 9/11. Putting in place an international system should be an immediate priority.

Conclusion

As with all effective risk management processes, responding to each of the above areas should be an ongoing process. For each response put in place, assumptions should be clearly identified and benchmarks established by which to measure efficacy. If benchmarks are not achieved, or if assumptions prove to be false, this should trigger a reassessment and adjustment of approach to ensure that risk is being effectively managed.

The actions above represent some priority steps towards implementing a risk management approach, but are not intended to be a comprehensive list of actions. The architecture of a risk management approach can be put in place immediately, but there is also a need for deeper research and analysis of new tools, models and systems to support decision makers in making the best decisions in response to the climate threat. **There will never be a perfect system or a right answer, and countries and actors will legitimately disagree about the right level and mix of responses. However, only by rigorous consideration of all the consequences and uncertainties we face will we construct a firm foundation for preserving climate security for everyone.**

Annex 1: Climate Science
Observed Climate Change and Attribution to Human Activities

Observed Climate Change

The IPCC's AR4 reported that annual global average surface temperature increased by 0.76 ±0.19°C between 1900 and 2005, and that warming had accelerated over time (Figure A1a).[301] Over the last three decades, satellite measurements show warming of 0.13-0.16°C per decade, equivalent to 1.3-1.6°C per century.[302] Land areas have warmed more than the oceans, the northern hemisphere more than the southern hemisphere, and the high northern latitudes more than lower latitudes (Figure A1b). At 0.62°C above the 20th century global average surface temperature, 2010 tied with 2005 as the warmest single year on the 131-year thermometer record. 2010 was the 34th consecutive year that was warmer than the 20th century average; and the nine warmest years on record all occured in the last ten years (2001-2010).[303] **The years 2000-2009 constitute the warmest decade on record, with the 1990s the second warmest and the 1980s the third warmest.**[304]

The amount of heat stored in the oceans has increased over the past half-century as well, an important observation since more than 80 percent of the heat trapped by the enhanced greenhouse effect is absorbed by the oceans before it reaches a balance with the atmosphere (this causes a delay in warming described in more detail below and discussed in Chapter 6).[305]

Other evidence[306] that the Earth's surface has warmed rapidly in recent decades includes accelerating global sea level rise (Figure A2), the synchronous retreat of mountain glaciers at different latitudes around the world (Figure A3), rapid shrinkage of the extent of Arctic sea ice (Figure A4), and net loss of land-based ice on Greenland and Antarctica.[307] Additional observed changes in climate include:

- Decreased frequency of cold days and nights and increased frequency of hot days and nights.
- Increased frequency, duration and intensity of droughts and heat waves in many areas, particularly in the tropics and subtropics where annual precipitation has declined.
- Increased precipitation in the northern hemisphere mid-latitudes and the southern hemisphere tropics, and less precipitation in the northern hemisphere dry tropics and subtropics.

301 Trenberth et al., 2007, op. cit.

302 Updated from Christy & Spencer, 2005 and Mears & Wentz, 2005

303 NOAA National Climatic Data Center, 2011

304 Arndt, Baringer and Johnson, 2010

305 Bindoff et al., 2007; Levitus, 2009

306 Except where noted, these changes are documented in IPCC Working Group 1, 2007

307 IPCC Working Group 1, 2007; Shepherd and Wingham, 2007

- Increased frequency of intense precipitation events, even in some areas where overall annual precipitation has decreased (Figure A5).[308]

- Increased storminess and changes in storm tracks in the northern hemisphere extratropics (north of 30°N).

- Increased frequency of the most powerful tropical cyclones (category 4 and 5 hurricanes/typhoons).[309]

Together, these independent observations led the IPCC AR4 to conclude:

> *Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.*[310]

Regional warming is affecting many natural and human-managed systems, both physical and biological, including:[311]

- Various effects of changes in snow and ice cover: more and larger glacial lakes, later fall freeze and spring melt of lake and river ice, destabilization of frozen ground in mountain and Arctic areas due to thawing, and some changes in Arctic and Antarctic ecosystems.

- Hydrological effects on rivers and lakes: changes in the seasonal timing of peak flows, and changes in thermal stratification and water quality due to temperature changes.

- Changes in the habitat ranges of many species, including northward movement of land and marine species and upward movements of mountain species.

- Earlier timing of spring biological events, such as plant flowering and animal migration.

- Increased fire and pest damage to timber forests.

- Earlier spring planting of crops in the northern latitudes.

- Fewer human deaths from cold weather and more deaths from hot weather.

- Shorter seasonal use of ice roads and trails in the high northern latitudes for commercial and private transport and subsistence and recreational hunting.

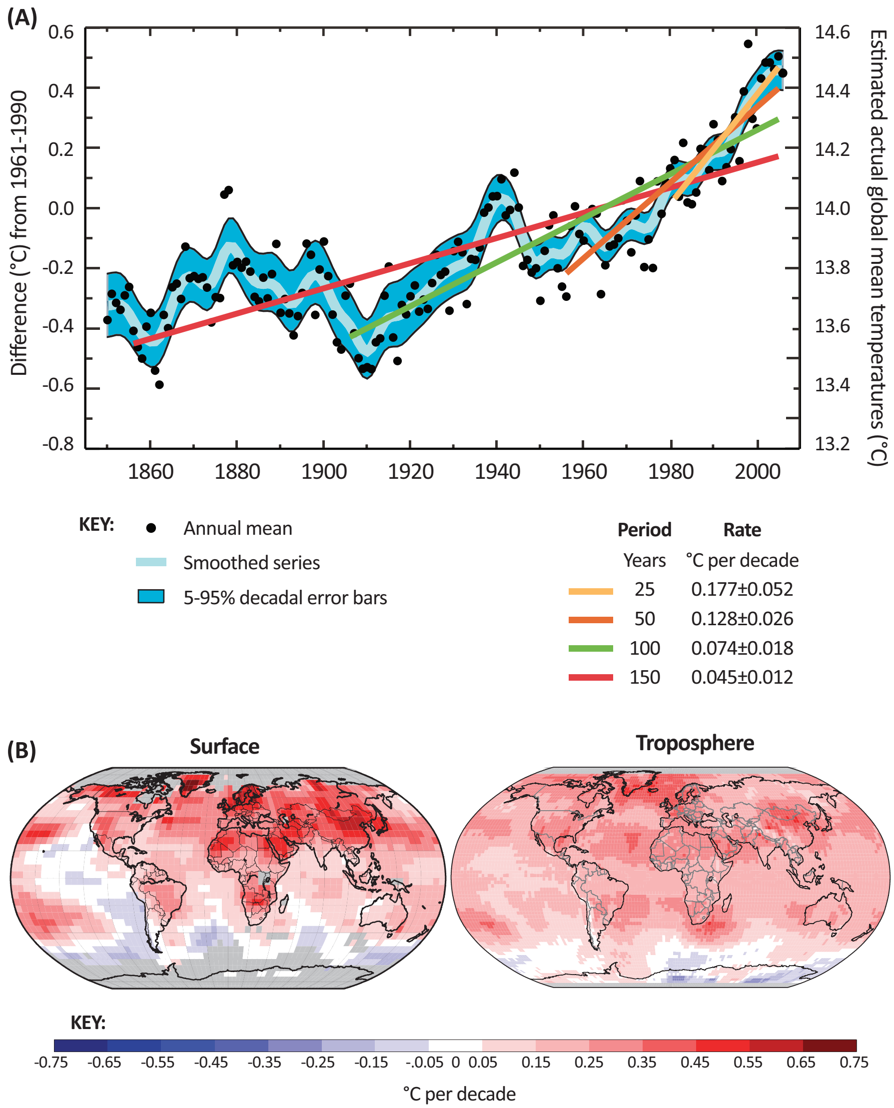
308 IPCC Working Group 1, 2007; Karl et al., 2009

309 Ibid.; Elsner et al., 2008; Knutson et al., 2009

310 IPCC, op. cit.

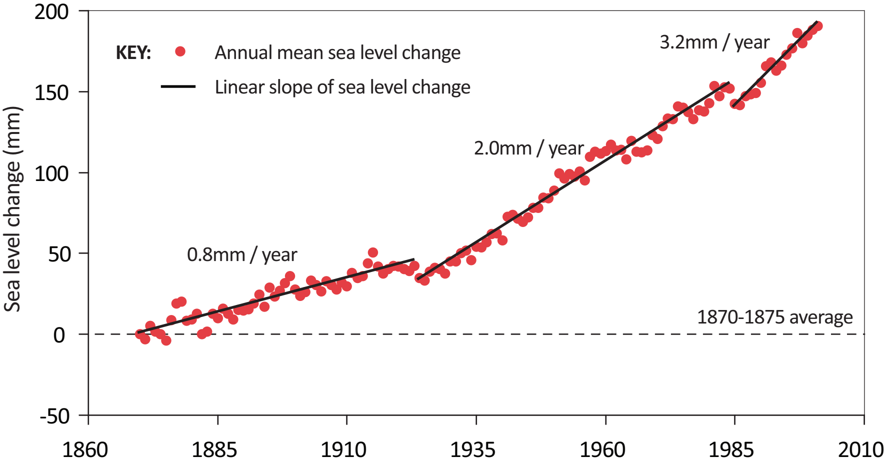
311 Unless noted, these changes are documented in ibid.

Figure A1: Observed change in average global surface temperature from 1850 to 2005.



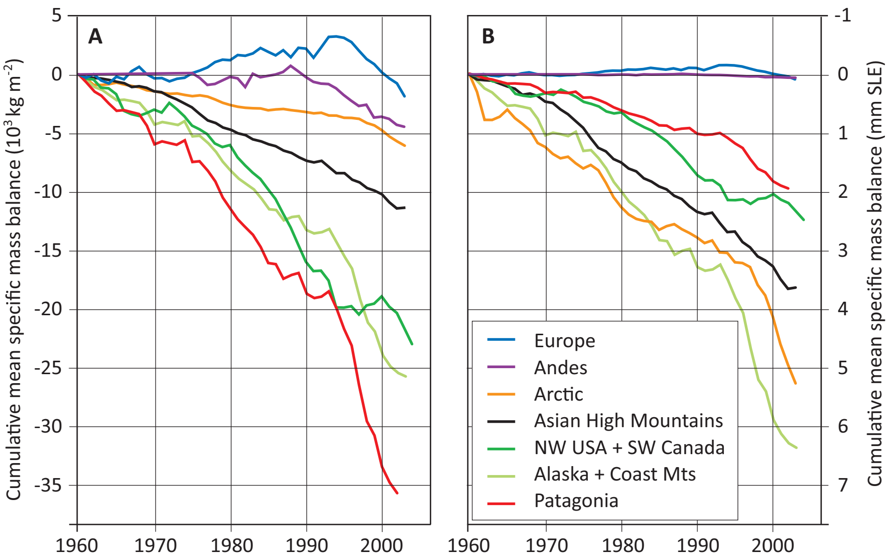
Observed change in average global surface temperature from 1850 to 2005 and the geographical pattern of warming from 1979 to 2005. ***(a)*** *Average yearly global surface temperature change from thermometer measurements, relative to the average over 1961-1990. Warming has accelerated over time as indicated by linear trend fits to the last 25 (yellow), 50 (orange), 100 (purple) and 150 years (red).* ***(b)*** *Geographical patterns of global warming in recent decades at the surface (left), and for the lower atmosphere (right) from satellite data. Grey areas signify insufficient observations near the poles.* ***Source:*** *Trenberth, et al., 2007.*

Figure A2: Global mean sea level rise from 1870 to 2001.



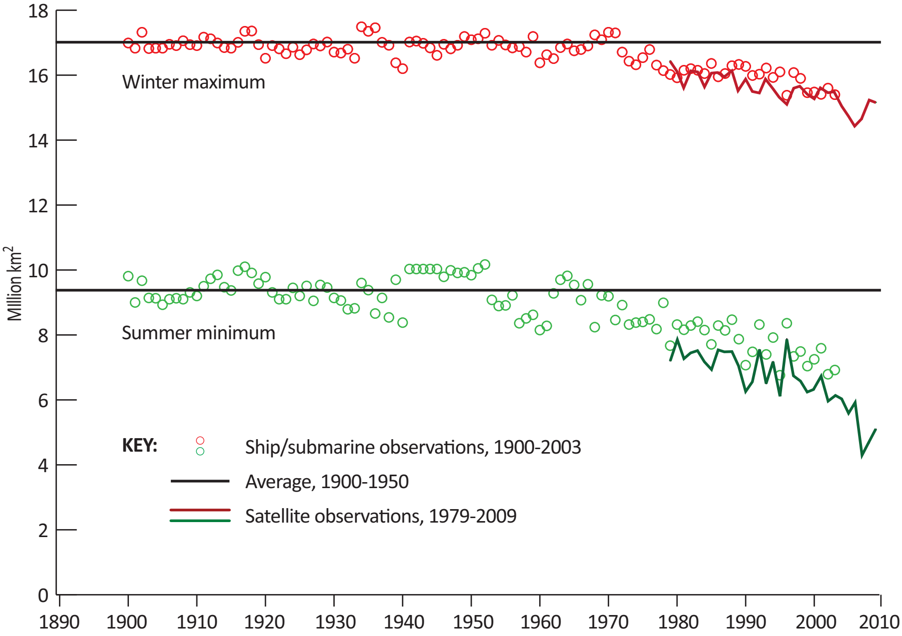
Global mean sea level change from 1870 to 2001 as indicated by coastal tide gauges from around the world. ***Source:*** *Data from Church & White, 2006.*

Figure A3: Globally synchronous retreat of mountain glaciers from 1960 to 2003.



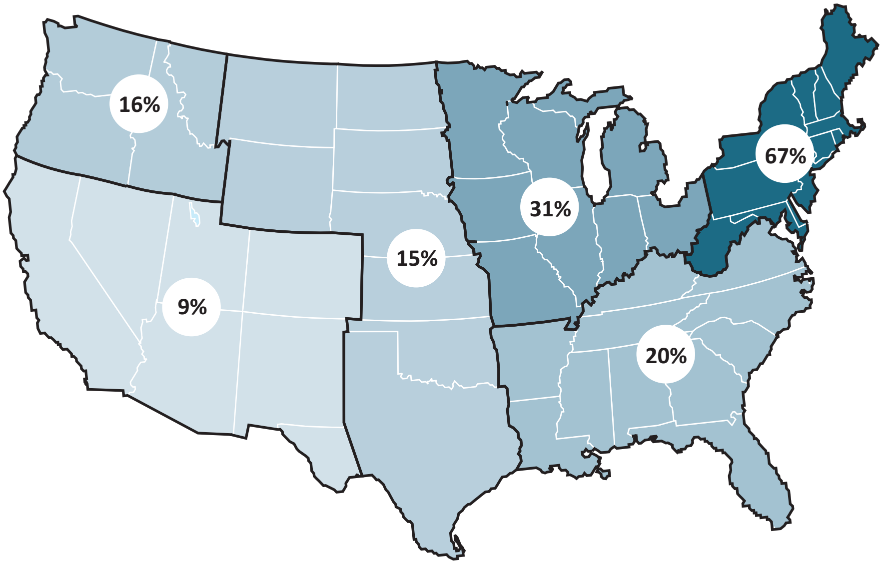
Globally synchronous retreat of mountain glaciers. (a) Cumulative change in the mass of ice in various glacier complexes from around the world, 1960-2003. (b) Cumulative contribution of ice loss from these glaciers to global average sea level rise. ***Source:*** *Lemke et al, 2007*

Figure A4: Change in winter maximum and summer minimum Arctic sea ice extent from 1979 to 2009.



Yearly winter maximum (top) and summer minimum (bottom) Arctic sea ice extent. Historical observations (green) are from ship and submarine records. Linear rates of decline since 1979 are based on satellite measurements. ***Source:*** *Historical data from Kinnard et al., 2008; satellite data from Fetterer et al., 2002, updated 2009.*

Figure A5: Increased frequency of heavy precipitation in the contiguous United States from 1958 to 2007.



An example of increased frequency of heavy precipitation in the contiguous United States. The maps shows the percentage increases in very heavy precipitation defined as the heaviest one percent of all events from 1958 to 2007 for six regions. ***Source:*** *Adapted from Karl et al., 2009.*

Projected Climate Change

This section reviews general patterns of climate change as projected by the IPCC AR4 and supplemented by more recent peer-reviewed studies; it is an update of earlier reviews.[312] Except where indicated, projections are from Chapters 10 or 11 of the Contribution of Working Group I to the AR4, which presents projections of future climate change based on modeling experiments using aggregated results of multiple global climate models.[313]

Temperature

All models in the AR4 show global surface warming in proportion to the amount of anthropogenic greenhouse gases released to the atmosphere. For the A1B emissions scenario,[314] average global surface warming relative to 1990 is about 1.3°C in 2040 and 2.8°C in 2100.

312 Gulledge, 2008a, op. cit.; Gulledge, 2008b, op. cit.

313 Meehl et al., 2007; Christensen et al., 2007

314 A future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technology. Greenhouse gas emissions in this scenario are in the medium range of all IPCC emissions scenarios. Growth of emissions in this scenario are lower than actual growth since 2000. (Raupauch et al., 2007)

It is essential to put these global averages into geographic context, as changes are far from uniform globally. **Temperature over land, particularly in continental interiors, warms about twice as much as the global average, as surface temperatures rise more slowly over the oceans. High northern latitudes also warm about twice as fast as the global average.** Moreover, the average change in any given location is not a smooth increase over time. Rather, it is associated with larger extremes, leading to generally fewer freezes, higher incidence of hot days and nights, and more heat-related impacts, such as heat waves, droughts and wildfires. Larger warming at high northern latitudes leads to faster thawing of permafrost soils, with consequent infrastructure damage (for example, collapsed roads and buildings and coastal erosion) and feedbacks that amplify climate change (for example, methane and CO_2 release from thawed organic soils).

There are also seasonal differences, with winter temperatures rising more rapidly than summer temperatures, especially at higher latitudes. Wintertime warming in the Arctic over the 21st century is projected to be three to four times greater than the global wintertime average warming, resulting in accelerated loss of ice cover and associated impacts (for example, amplified warming, faster sea level rise and loss of critical habitat for cold-region species).

Precipitation

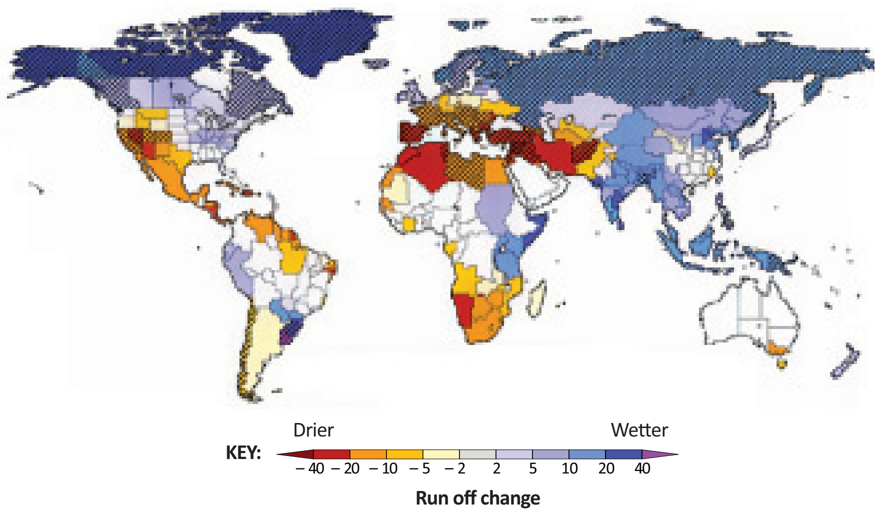
Under the A1B scenario, global average precipitation increases by 2 percent in 2040 and 5.5 percent in 2100. Because some regions experience substantially decreased precipitation, a global change of a few percent translates into very large changes, some greater than 20 percent, for particular areas. Both extreme drought and extreme rainfall events are therefore expected to become more frequent as a result of this intensification of the global water cycle.

Increased precipitation generally prevails in the wet tropics and at high latitudes, particularly over the tropical Pacific and Indian Oceans during the northern hemisphere winter and over South and Southeast Asia during the northern hemisphere summer. Decreased precipitation prevails in the subtropics and mid-latitudes, with particularly strong decreases in southern North America and Central America, southern South America (parts of Chile and Argentina), southern Europe and the Mediterranean region in general (including parts of the Middle East), and in northern and southern Africa. Central America experiences the largest decline in summer precipitation. **The main areas projected to experience greater drought are the Mediterranean region, Central America, Australia and New Zealand, and south-western North America.**

Decreases in precipitation and related water resources are projected to affect several important rain-fed agricultural regions, particularly in South and East Asia, Australia, and southern Europe. Although monsoon rainfall is projected to increase in South and Southeast Asia, this extra rain may not provide benefits as rain is already plentiful at this time of year. However, the added rainfall will likely increase damage from flooding, reminiscent of the catastrophic flooding in Pakistan during the 2010 monsoon.[315] Notably, a decrease in summer precipitation is projected for Amazonia, where the world's largest complex of wet tropical forest depends on high year-round precipitation and has experienced multiple historically severe droughts in the past decade.[316]

Two important correlates of precipitation are annual runoff (that is, the amount of water flowing in streams and rivers; Figure A6) and soil moisture. These parameters are critical to water supply for consumption and irrigation, and to the ability of soil to support crop production. Soil moisture generally corresponds with precipitation, but declines even in some areas where precipitation increases because warmer temperatures lead to greater evaporation. The biggest changes in soil moisture include a strong increase in a narrow band of equatorial Africa and a moderate increase in a band extending from northern and Eastern Europe and into central Asia. Soil drying is more widespread and decreases by 10 percent or greater over much of the United States, Mexico and Central America, southern Europe and the Mediterranean basin in general (including parts of the Middle East), southern Africa, the Tibetan Plateau, and across much of northern Asia.

Figure A6: Model-projected changes in surface water runoff/streamflow in 2050.



Model-projected changes in annual runoff for 2050 relative to the average over 1900-1970. Percentage change relative to 1900-1970 baseline. Any color indicates that >66% of models agree on sign of change; diagonal hatching indicates >90% agreement. ***Source:*** *Updated from Milly et al., 2005.*

315 Tweedie, 2010

316 German and Pine, 2010

Extreme weather events

In general, the AR4 projects an increased incidence of extreme weather events. **Droughts, flash floods, heat waves, and wildfires are all projected to occur more frequently and to become more intense in regions where such events are already common.** Intense tropical and mid-latitude storms with heavier precipitation and higher wind speeds are also projected. Projections indicate fewer cold spells and a decrease in the frequency of low-intensity storms. As a consequence, the total number of storms decreases globally even as the number of intense storms increases.

Extreme precipitation and drought

In general, **the IPCC projects that a larger fraction of total precipitation will fall during extreme events,** especially in the moist tropics and in mid and high latitudes where increased mean precipitation is projected. In the United States, this phenomenon has already been documented, with extreme rainfall increasing in different regions by 9 to 67 percent (Figure A5). In general, regional extremes are expected to increase more than the means. Even in areas projected to become drier, the average intensity of precipitation may increase because of longer dry spells and greater accumulation of atmospheric moisture between events. This pattern may result in increased incidence and duration of drought, punctuated by extreme precipitation, which may be either rainfall or snowfall, depending on latitude and season. In general, the risk of drought is expected to increase during summers in the continental interiors.

Some tropical and subtropical regions experience monsoons – distinct rainy seasons during which prevailing winds transport atmospheric moisture from the tropical oceans. This wet season and its timing are critical to the farming practices of these regions. The Asian, African and Australian monsoons are projected to bring increased rainfall to certain regions of these continents. Because this rain falls during what is already the rainy season, it may cause more flooding without bringing additional benefits. In Mexico and Central America, the monsoon is projected to bring less precipitation to the region, contributing to the increased drought generally projected for the region.

Heat waves

Hotter temperature extremes and more frequent, more intense, and longer-lasting heat waves are robust projections of the models examined by the IPCC, pointing to increased heat-related illness and mortality. **Though growing seasons will become longer because of earlier spring warming and later fall cooling, crops will face greater heat stress and associated drought during these times.** Cold spells will become less frequent, causing fewer deaths and economic losses associated with cold weather, but will increase crop pest populations in some regions. Moreover, some crops require a frost to produce fruit.

Tropical cyclones and mid-latitude storms

Projected patterns of change are similar for both tropical cyclones (including typhoons and hurricanes) and mid-latitude storms. Tropical storms may become less frequent overall, but are expected to reach higher peak wind speeds and bring greater precipitation on average. The decrease in frequency is likely to result from fewer weak tropical storms, whereas intense tropical storms may become more frequent with warming.[317] Similarly, mid-latitude storms may become less frequent in most regions yet more intense, with more damaging winds and greater precipitation. Intensification of winter mid-latitude storms may bring more frequent severe snowstorms, such as those experienced in the north-central United States in February and March of 2007 and the U.S. East Coast in February of 2010. Near coasts, both tropical and mid-latitude storms will elevate wave and storm surge heights, increasing the frequency and severity of coastal flooding.

Regions normally affected by tropical storms, including typhoons and hurricanes, include all three coasts of the United States; both coasts of Mexico and Central America; the Caribbean islands; East, Southeast, and South Asia; Australia; and many South Pacific and Indian Ocean islands.

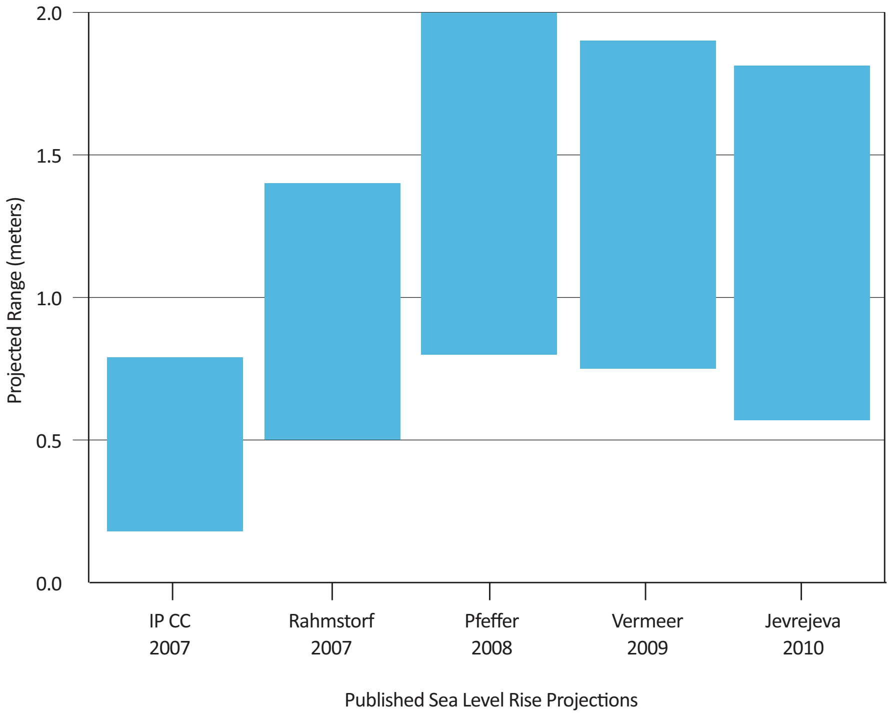
Some unusual regions have been affected by tropical storms in recent years. Hurricanes are very rare in the South Atlantic, but in 2004 Hurricane Catarina became the only hurricane to strike Brazil in recorded history. Similarly, in 2005 the remnants of Hurricane Vince became the first tropical storm on record to make landfall on the Iberian Peninsula. In June 2007 Cyclone Gonu, the first category 5 hurricane documented in the Arabian Sea, temporarily halted shipping through the Strait of Hormuz, the primary artery for exporting Persian Gulf oil. Whether such historical aberrations are related to global warming remains uncertain, but they illustrate that **extreme weather events that lack historical precedents should be expected as a general consequence of climate change.**

Sea level rise

As discussed in Chapter 2, the AR4 projected sea level rise of 0.18-0.59 meters from 1990 to 2095. However, the AR4 said that it could provide neither a best estimate nor an upper end for sea level rise in this century. More recent studies consistently project more sea level rise this century, with upper end estimates ranging from 1.4 to 2.0 meters (Figure A7) The current tenfold range of uncertainty (0.18-2 meters) for 21st century sea level rise is a significant risk management challenge. The lower end represents minor impacts overall (low-lying island states and river deltas notwithstanding), whereas the upper end points to severe global impacts.

317 Knutson et al., op. cit.

Figure A7: Projections of 21st-century sea level rise.



Sea level rise projections for the 21st century from the IPCC AR4 and subsequent studies published in the peer-reviewed literature. ***Source:*** *Jevrejeva et al, 2010*

Annex 2: Overview of Risk Management Analysis Methodology

This report approaches this dilemma based on the authors' many years of experience working on risk management issues in the security, energy, environmental and economic sectors. It has been strongly informed by the experience of senior security, intelligence and defense officials and experts from the United States, Europe and developing countries through a series of closed-door meetings during 2009 and 2010.

This annex outlines the methodology used in a series of expert workshops to analyze different elements of climate change risk. The output of these workshops helped inform, direct and identify the key risk management analysis and conclusions contained in the main body of the paper.

The process was carried out in three steps:

1. Identifying Key Uncertainties

In each critical area – climate science, impacts and adaptation, and mitigation – the main elements of risk and uncertainty were identified and split into two broad categories:

- Normal uncertainty: areas where at least some form of estimated probability distributions could reasonably be applied to the variable

- Extreme, ambiguous or tipping point impacts: areas which were likely under many scenarios (and which would have very high impacts), but where probability distributions cannot yet be defined with strong levels of confidence

The split between the categories, which has important implications for designing risk management responses, is in many cases a matter of expert judgment. This judgment may change over time as knowledge improves.

2. Overview of Risk Management Analysis

Each critical area was analyzed against core risk management questions:

- What is the range of risks we face?

- What are the biases in current risk assessments? Are risks likely to be over or underestimated?

- What surprises may exist?

- Will impacts be reversible once they have occurred and, if so, will they be reversible on policy-relevant time scales?

- How well could we monitor the emergence of serious threats? How well are we currently monitoring threats?

- How effectively are we currently managing these risks?

- What are alternative or additional risk management strategies we should employ?

The results of desk research in each area were tabulated and these summary tables were discussed and challenged through a series of workshops with climate and security experts. This multi-disciplinary challenge process was essential in identifying critical gaps and uncertainties in the data and knowledge base which would be needed by decision makers to form a mature risk management system. It also began the process of identifying some of the most important risk management options.

3. Key Risk Management Insights

The analytical insights formed the inputs to a further process of detailed analysis and policy design. This resulted in the ten recommendations contained in the report, and the identification priority steps needed to build a comprehensive risk management regime.

As with any syncretic exercise this process involved many judgment calls on the relative importance of different areas and actions. However, the structured analysis around the risk factors gave a comprehensive and comparable analytic framework on which to base these conclusions. The multi-disciplinary nature of the workshops – crossing scientific and security analysis boundaries and mixing analysts with decision makers and advisors – was essential to avoid disciplinary bias.

Risk management frameworks are specific to particular groups of decision makers; there is no 'right' answer. The exercise carried out here was aimed at national level decision makers across a full spectrum of government departments. However, the basic three-step process of risk analysis and multi-disciplinary challenge can be tailored and applied to develop risk management approaches specific to any group of decision makers, and the analytic content deepened to provide more specific recommendations, for example, to guide regional adaptation planning.

A.2.1: Risk Management Analysis of Climate Science

Key Risk Factors Considered

Normal Uncertainty

- Rate of greenhouse gas accumulation in Atmosphere
  - Terrestrial and oceanic sinks

- Radiative forcing impact of greenhouse gases
  - Ozone, CH_4 and CO_2 Forcing
  - Aerosol Forcing

- Climatic feedbacks to radiative forcing
  - Cloud behavior
  - Albedo effects

Extreme Impacts

- Tipping points and positive feedback loops
  - Methane hydrates
  - Permafrost methane
  - Large ice sheet collapse
  - Boreal and Tropical Forest dieback

Key Insights from Expert Workshops

- Need to redefine 'climate sensitivity' to make this concept more useful for decision makers. Minimizing the risk of triggering tipping point effects is critical for maintaining security objectives.

- Monitoring of key tipping points events is unsystematic giving little early warning of approaching thresholds. Cooperative action could improve this.

- Underlying instability of climate system suggests that emissions cuts will need to be far steeper than current trajectories.

- Significant probability of a 'crash' greenhouse gas reduction program in next decades.
  - Need for contingency planning to make this feasible, including geoengineering.
  - The implications of rapid global nuclear fission build for proliferation and safety need immediate consideration.

A.2.2: Risk Management Analysis of Climate Impacts

Key Risk Factors Considered

Normal Uncertainty

- River basin hydrological cycles
- Glacial melting changing major river flows
- Speed of Greenland ice-shelf melting
- Frequency of extreme weather events
- Ocean acidification/ecosystem impacts
- Impact of maladaptation and climate driven conflict

Tipping Point Impacts

- Indian Monsoon weakening/increased volatility
- Arctic Sea Ice Melting
- West Antarctic Ice shelf melting
- Atlantic circulation shifting

Key Insights from Expert Workshops

- The current approach of fragmenting impacts does not capture the elements of most interest for security and government actors; there is a need for new analysis frames.
- For near term security planning, critical interest lies in 'perfect storm' events where climate stresses/extreme events combine with water, food, energy and governance issues to drive emergencies and instability.
- For the longer-term analysis, understanding resilience in response to multiple shocks is critical, especially in developed countries where resilience is overestimated.
- There is a gap in practical tools to guide investment in resilience to climate change/resource pressures in unstable regions. The risk that adaptation funds will drive hard engineering responses and may ignore or heighten instability such as on transboundary waterways is significant.

- It is critical to understand how to reduce the risk that countries will shift their adaptation strategies from a reliance on interdependence (for example, food trade) to a focus on resource capture? Need for a pre-emptive investment in international cooperative frameworks.

A.2.3: Risk Management Analysis of Climate Mitigation

Key Risk Factors Considered

Normal Risks

- Slower energy efficiency increases (reducing the 50 percent of planned reductions by 2050)

- Higher BAU projections (20-50 percent higher emissions)
    - Global GDP growth
    - Oil price/energy security politics
    - Transportation use in developing countries

- Slower reduction in deforestation rates (10-20% of emissions cuts)

- Underperformance/failure of new low carbon technologies
    - Carbon Capture and Storage (20 percent of 2050 reductions?)
    - Biofuels (10-20 percent of 2050 reductions?)
    - Nuclear (10 percent of 2050 reductions?)

Disruptive Impacts

- Collapse in integrity of the climate change control regime.

- Impact of serial nuclear accidents/terrorism.

- Positive impact of development of surprise low carbon technologies (for example, cheap solar).

- Geoengineering.

Key Insights from Expert Workshops

- Mitigation risks are less well examined than scientific risks, but are of similar or larger scale. There is a general complacency among policy makers on the expected delivery of fundamental changes, especially in energy efficiency and forestry.

- There will be a need for more low carbon energy technologies much earlier than on current plans. Increased cooperative international RD&D is a vital risk management tool but the track record of success is low.

- The UNFCCC system is critical to set goals and monitor and verify progress. There is a need for effective and independent verification of country actions to make system resilient in face of shocks. This should take into account the mixed record of trust in UN monitoring systems for example, IAEA vs. Bioweapons.

- Large oil price rises could stimulate more use of clean technology or a retreat to unabated coal. Carbon capture and storage is a critical technology to hedge this eventuality. Understanding the real potential for nuclear energy as a mitigation technology is critical for managing proliferation risks.

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