UNEP

Research Priorities on Vulnerability, Impacts and Adaptation

RESPONDING TO THE CLIMATE CHANGE CHALLENGE

ISBN: 978-92-807-3317-4

Job Number: DEW/1631/NA

Disclaimers

The content and views expressed in this publication are those of the authors and do not necessarily reflect the views or policies, or carry the endorsement of the contributory organisations or the United Nations Environment Programme (UNEP).

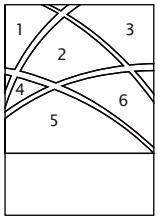
The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of UNEP concerning the legal status of any country, territory or city or its authorities, or concerning the delimitation of its frontiers and boundaries.

Reference to a commercial company or product in this publication does not imply the endorsement of UNEP.

The Programme of Research on Climate Change Vulnerability, Impacts and Adaptation (PROVIA) is a global scientific initiative of the United Nations Environment Programme (UNEP), the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the World Meteorological Organization (WMO) that seeks to harmonize, mobilize and communicate the growing knowledge-base on vulnerability, impacts and adaptation.

Design and Layout:
Audrey Ringler, UNEP

Cover Photo credits:



1. © Volodymyr Goinyk/shutterstock.com
2. © Grobler du Preez/shutterstock.com
3. © duckeesue/shutterstock.com
4. © stoonn/shutterstock.com
5. © Piyato/shutterstock.com
6. © Constantine Androsoff/shutterstock.com

Printing:
UNON/Publishing Services Section
UNON, Nairobi
ISO 10041:2004-certified

Research Priorities on Vulnerability, Impacts and Adaptation

RESPONDING TO THE CLIMATE CHANGE CHALLENGE

UNEP

Acknowledgements

The Writing Team: Cynthia Rosenzweig (NASA Goddard Institute for Space Studies and Columbia University) and Radley M. Horton (Columbia University).

Richard Moss (Joint Global Change Research Institute) and David Warrilow (United Kingdom Department of Environment and Climate Change) facilitated policymaker interactions in the development of the PROVIA Research Priorities. Marc Levy of the Center for International Earth Science Information Network (CIESIN) led the Foresight Panel for the PROVIA Scientific Steering Committee. Sandra Baptista of CIESIN assisted with survey preparation and analysis. Lumari Pardo, Gary Monitz, Daniel Bader and Elisabeth Gawthrop of Columbia University's Center for Climate Systems Research assisted with background research and document preparation. The inputs and review by the following at UNEP were instrumental: Volodymyr Demkine, Neeyati Patel, Janak Pathak and Sarah Abdelrahim.

We would also like to thank the U.S. National Academy of Sciences and the United Kingdom Department of Environment and Climate Change for hosting workshops with policymakers in the U.S. and U.K respectively, which provided input to the identification of the Research Priorities.

We thank members of UNFCCC Least-Developed Countries' delegations who participated in the PROVIA Research Priorities consultation in Bonn, Germany.

Finally, we wish to thank all the people who participated in the expert and policymaker pathways that are the foundation of this work.

Programme of Research on Climate Change Vulnerability, Impacts and Adaptation (PROVIA) Scientific Steering Committee: Saleemul Huq, Chair (International Institute for Environment and Development and International Centre for Climate Change and Development), Martin L. Parry, Former Chair (Imperial College London), Joseph Alcamo (United Nations Environment Programme), Christopher B. Field (Carnegie Institution for Science), Christopher Gordon (University of Ghana), Richard J.T. Klein (Stockholm Environment Institute), Balgis Osman-Elasha (African Development Bank), Lin Erda (Chinese Academy of Agricultural Sciences), Ian Noble (Global Adaptation Institute), Jean P. Palutikof (National Climate Change Adaptation Research Facility), Anand Patwardhan (Indian Institute of Technology and University of Maryland), Carolina Zambrano Barragan (Avina Foundation).

Editor: Neeyati Patel

Photograph Credits: Title page: © Grobler du Preez/shutterstock.com; Page 1: © Mliberra/shutterstock.com; Page 3: © Constantine Androsoff/shutterstock.com; Page 13: © Christian Lambrechts; and Page 23: © Piyato/shutterstock.com

Table of Contents

Introduction

Climate variability and change affect virtually all physical, biological and human systems on the planet. A major challenge of the research community is to provide relevant information to policymakers on vulnerability, impacts and adaptation (VIA) in the context of a changing climate and to do so in a coherent and coordinated way. The Programme of Research on Climate Change Vulnerability, Impacts and Adaptation (PROVIA) aims to respond to this challenge by harmonizing, mobilizing and communicating the growing knowledge-base on VIA to relevant audiences.

PROVIA, in consultation with both experts and policymakers, has developed a set of Research Priorities for the global VIA community whose activities are primarily carried out by individual researchers and research institutions. The topics reflect a balance between research 'supply' from the expert community and research 'demand' from policymakers and decision-makers. The Research Priorities include new and emerging topics as well as topics that have long been recognized as important but for which research is still required.

The focus of the PROVIA Research Priorities is on vulnerability, impacts and adaptation, rather than climate science per se, and the VIA topics depend to a varying extent on the state of climate knowledge. Since there remains significant uncertainty about how some key climate drivers may change (e.g., future evolution of tropical cyclones and stability of polar land and sea-ice), a common theme is the importance of building capacity for adaptation, resilience and risk management under uncertainty in both developing and developed countries.

The Expert and Policymaker Process

To develop the Research Priorities, input was gathered from expert and policymaker communities through separate solicitation path-ways. The expert prioritization of research topics began with a gap analysis of existing literature. The gap analysis produced an initial list of 172 priority topics for VIA research based on a broad range of sources including recent Intergovernmental Panel on Climate Change (IPCC) Working Group II Reports, peer-reviewed articles, books, reports and white papers, as well as conference, workshop and meeting proceedings and presentations.

The members of the PROVIA Scientific Steering Committee (SSC) then participated in a two-day Foresight Panel that focused on determining selection criteria for inclusion in the Research Priorities, grouping the research topics into themes and identifying additional topics.

Based on SSC feedback, three selection criteria were identified: (a) salience for policymakers and decision-makers tasked with short- and long-term adaptation management and implementation mandates; (b) potential for advances in understanding at reasonable cost and time and (c) extent to which the topic represents an emerging theme or requires more research. Each SSC member was then asked to identify the 30 highest-priority topics. A newly framed list of 54 priority research topics was generated by compiling the SSC selections and updated findings from new literature. This list was distributed as an electronic survey to a broad group of experts in the VIA community. The approximately 120 respondents scored the topics on a scale of 1 to 10 in importance, provided suggestions for additional topics and offered other comments.

A research prioritization process with policymakers was developed in parallel with the expert community process described above. Policymaker meetings were held in Washington, D.C. (October 28, 2011) and London (November 2, 2011). Each meeting had at least 15 policymakers representing both developed and developing countries. At the meetings, policymakers scored the research topics on a scale of 1 to 10 in importance, advised on ways to frame the organizational structure of the Research Priorities to support decision-making and identified additional research topics.

The rankings of the expert and policymaker processes were then combined, along with an emerging research topic section. Additional comments and review from the SSC, the broader expert community and a Least-Developed Countries Policymaker Consultation in Bonn, Germany (May 22, 2012) also provided inputs.

Structure of the Report

Research Priorities on Vulnerability, Impacts and Adaptation: Responding to the Climate Change Challenge consists of 33 topics presented in three sections: Information to Support Policymaker Decisions, Systems and Regions and Emerging Topics. Each of the 33 topics includes a description of why the research is needed, followed by several paragraphs describing specific activities that respond to that need. A short bulleted list thereafter highlights representative examples of critical activities from the broader set of proposed activities for each Research Topic. While many of the activities are specific research tasks, others describe the support needed to conduct scientific research on VIA. An example of the latter includes fostering technological innovation, such as optimizing the integration of remotely sensed and ground-based information.

Use of the Research Priorities

PROVIA is engaging with a variety of groups including donor agencies, science foundations, international organizations and national adaptation planning groups to explore potential uses of the Research Priorities. For example, they are being used as inputs to national research plans for climate change vulnerability, impacts and adaptation and as contributions to the development of comprehensive international research programs. PROVIA will monitor the Research Priorities as they are addressed and as new topics emerge and will periodically update them as they evolve.

SECTION A

Information to Support Policymaker Decisions

This section describes research topics that support policymaker decision-making on a broad range of climate change and VIA issues related to vulnerability reduction and adaptation. Diverse groups face significant short-term and long-term vulnerabilities, with many urgently in need of adaptation solutions today.

Four main areas emerged from dialogues with policymakers: Identifying the problem; Advancing vulnerability reduction and adaptation solutions; Developing more inclusive cost estimates and prioritization criteria and Enhancing communication and stakeholder/ public participation.

Given widespread vulnerability and the reality that it will take time to scale-up adaptation to climate change, a framework is urgently needed to ensure that priority is given to adaptive actions that can be most effective for vulnerable groups. In addition, some long-term risks may call for action today, for example where solutions will take time to implement and risks are large.

A.1 Identifying the Problem

These topics provide need-to-know information for risk management that point policymakers towards the greatest vulnerabilities and articulate the scope of climate adaptation policy challenges.

A.1.1 Measure and Map Vulnerability

Develop a robust framework to define, measure and map vulnerability and the most vulnerable groups (based on gender, age, poverty and other factors), sectors, ecosystems and places in order to determine where adaptation is most needed

The IPCC has documented that many groups, sectors, ecosystems and places are highly vulnerable to today's weather and climate and that climate change is likely to exacerbate such vulnerabilities (IPCC, 2007a; IPCC, 2012). However, vulnerability assessments to date are based on a range of disparate methodologies, which makes it challenging to integrate results. Furthermore, comparable climate events can lead to dramatically different levels of impact across regions or groups. For example, communities

with weak governance, little local participation, limited land-use planning and no access to insurance may be particularly vulnerable to flood damage. This suggests that if amplifiers/dampeners of vulnerability and impacts can be identified and tracked, it may be possible to better prioritize and target the most vulnerable regions, subpopulations and sectors, both for emergency preparedness and response and for longer-term adaptation.

Efforts are needed to integrate data, models and maps used by disparate groups for vulnerability and impact assessment. Mining of large data sets ('big data') pertaining to human geography, climate and other factors will be critical for identifying vulnerabilities. Important research includes comparison studies of vulnerability assessments to identify best practices, development of protocols for future assessments, use of agreed-upon protocols across groups (e.g., randomized control trials), sectors and places and improved documentation and systems for recording, sharing and evaluating results. Researching the relative importance of factors that can influence vulnerability (e.g., economic, political, legal, institutional and cultural) among different regions and groups can facilitate tailored responses (Pearce et al. 2012). 'Before and after' vulnerability assessments tailored towards testing the efficacy of adaptation strategies are also needed.

Critical activities that support this research priority include:

- Conducting comparative studies on vulnerability assessments
- Developing community-based protocols for future assessments
- Mining big data to identify vulnerability
- Designing 'before and after' vulnerability evaluations to test adaptation efficacy

A.1.2 Develop and Strengthen Indicator and Monitoring Systems

Formulate cost-effective indicators and monitoring for tracking impacts, changes and the crossing of thresholds related to climate, ecological and socio-economic systems

The IPCC 2007 Assessment revealed conclusively that climate change is occurring now and that it is affecting ecological and hydrological systems on all continents (IPCC, 2007b). This means that the onset and evolution of impacts (e.g., their timing, location and magnitude) can now be measured. While some such measurement systems do exist, more are needed to track climate change and its impacts. This information, along with projections and state-of-the-art modeling provided by the scientific community, can help policymakers determine the need for effective adaptation policies (Seneviratne et al. 2012).

Several complementary research activities are needed to establish robust VIA indicator and monitoring systems: a) developing indicators that can be readily monitored; b) establishing information technology systems; c) monitoring at the regional and local levels, where gradual and abrupt climate changes are having effects on physical, biological and human systems, including health and agriculture and d) analyzing whether there may be thresholds of impacts in some systems and places and the rates at which these are being approached.

These indicator and monitoring systems should be designed to address both traditional and emerging topics (e.g., challenges associated with monitoring extreme climate events and their impacts and early identification of signs

of maladaptation). As remote sensing products become increasingly powerful and ubiquitous in their applications, there is a growing need for complementary research on how best to advance and optimize the interactive use of remotely sensed and ground-based information. Research is also needed on how to improve public-private partnerships devoted to indicators and monitoring.

Critical activities that support this research priority include:

- Developing robust indicators that can be readily monitored
- Analyzing thresholds of impacts
- Optimizing the integration of remotely sensed and ground-based information
- Advancing public-private partnerships

A.1.3 Understand Risks of Extreme Climate Events, Non-Linear Impacts and Tipping Points

Improve understanding of risks and uncertainties related to the impacts of extreme climate events (including low-probability, high-impact events), non-linear impacts and tipping points

There is a growing awareness that extreme climate events, non-linear impacts and tipping points should play a central role in risk assessment given their important implications for VIA (Lenton et al. 2008). For example, since climate researchers are increasingly considering the possibility that summer Arctic sea ice may largely disappear decades sooner than climate models suggest, there is a need for investigation of the implications for the region's human population and ecosystems (Liu et al. 2012). As systems are perturbed further from the realm of historical experience, the probability of non-linear impacts and crossing tipping points can increase dramatically. There is likewise growing concern that changes in some types of extreme events, such as heat waves, intense precipitation and droughts may be outpacing climate model and scientific community projections (Fasullo and Trenberth, 2012; van Aalst, 2006). This possibility needs to be understood, since VIA outcomes related to changes in extreme events are likely to be exacerbated.

The very infrequency of rare events speaks to both the challenges of understanding their impacts and developing indicators for monitoring them. This points to the need for analysis of how rapid climate change in the recent geological past may have affected ecosystems (Lenton et al. 2008). Research is also needed on how interdependencies among exposed systems can enhance risks and VIA implications. For example, health risks associated with heat waves may be enhanced by an elevated probability of concurrent poor air quality (Frumkin et al. 2008) and power supply system failures.

Fundamental research on extreme events, non-linear impacts and tipping points needs to be extended beyond physical climate systems to biological, social and economic systems (Berkes, 2007), such as the effects of world food crises and financial crises on adaptive capacity. More diagnostic studies (Peterson and Manton, 2008) of exposure and vulnerability to climate extremes and their related socio-economic, demographic and cultural factors are also important (Russill and Nyssa, 2009). These studies can contribute to understanding societal vulnerability to climate variability and extreme events today as well as how this may change under changing climate conditions. Finally, more research should focus

on how to effectively mobilize and conduct rapid scientific assessment both for short-term policy decisions and long-term understanding when extreme events occur.

Critical activities that support this research priority include:

- Assessing consequences of interdependencies among exposed systems at risk
- Extending studies of consequences of climate-related disasters for biological, social and economic systems
- Conducting rapid scientific assessments when extreme events occur

A.2 Advancing Vulnerability Reduction and Adaptation Solutions

These topics focus on how to effectively develop and implement solutions to VIA policy challenges.

A.2.1 Develop Integrated Solutions

Research integrated approaches that maximize adaptation, mitigation and sustainable development benefits while minimizing economic, social, environmental and other costs

Many of the strategies and activities designed to achieve adaptation to climate change overlap with and will be integrated into those taken to achieve national development goals, poverty alleviation, disaster risk reduction and other dimensions of sustainable development and resilience (e.g., the green economy, green jobs and green growth). Simultaneously, efforts to mitigate climate change are gathering momentum and are generating changes within human society as well (Klein et al. 2007).

Mitigation efforts may profoundly transform societal systems with respect to energy, land use, infrastructure and manufacturing, with the potential for far-reaching consequences at local, national and global scales. Understanding the complex nature of VIA-mitigation interactions is a high priority in order to make possible more effective elaboration of development pathways that achieve desired combinations of adaptation and mitigation and that maximize co-benefits and minimize undesired side-effects (Wilbanks, 2010; Wilbanks and Sathaye, 2007).

The applicability of existing policy tools for addressing this interface should be explored and guidance developed for how decision-makers can choose appropriate tools that integrate adaptation, mitigation and sustainable development and for the particular conditions they are addressing (Yohe and Leichenko, 2010). Research is needed to understand the complexities of the challenge and to determine which potential organizational and governance structures can be effective in different contexts (Klein et al. 2007; Wilbanks and Sathaye, 2007).

Critical activities that support this research priority include:

- Developing cross-disciplinary tools
- Exploring the applicability of existing policy mechanisms that address topics individually
- Assessing the role of organizational and governance structures

A.2.2 Identify Factors that Support or Hinder Vulnerability Reduction and Adaptation

Identify economic, financial, political, legal, institutional, psychological, social and cultural factors that support, or act as barriers to, vulnerability reduction and adaptation

Vulnerability reduction and adaptation decisions are multifaceted, with climate often serving as only one factor under consideration. Furthermore, what may appear to be logical adaptation decisions may not be feasible given constraints and pressures faced by individuals and groups (O'Brien et al. 2006). With greater understanding of these context-dependent factors, strategies can be developed to both increase the uptake and efficacy of adaptation responses and ensure that they are consistent with the values and contexts of individuals and decision-makers. These are key elements in making the economic, political and social 'case' for adaptation.

More research is needed on how lack of security – including risk of physical violence, loss of property and environmental damage – can influence individual and societal willingness to work collectively to address long-term challenges associated with climate change. Studies are needed to determine the region, group and sector-specific factors that can support or hinder vulnerability reduction and adaptation (Few et al. 2007; O'Brien et al. 2006). Given the complex nature of such factors, subject-matter experts with sector and regional knowledge are needed to understand and improve adaptation effectiveness. For example, research is needed on how to identify adaptation strategies that align with cultural values and/or belief systems; such adaptations may be more likely to succeed and to limit societal conflict and disruption. Conclusions from such comparative studies could help inform what spatial scales and levels of governance are most likely to be effective in different locations and contexts.

Critical activities that support this research priority include:

- Assessing the role of individual security in supporting collective action
- Determining region, group and sector-specific factors that encourage or hinder adaptation
- Identifying adaptation strategies that align with social and cultural values

A.2.3 Conduct Focused Research on Implementation

Advance understanding of the opportunities and challenges of implementing adaptation (e.g., integrating adaptation into planning frameworks and budgets, coordinating activities across agencies, the private sector and other entities)

Many regions, sectors and groups have made rapid progress in proposing possible adaptation strategies for climate variability and climate change. A key issue that has received less attention is how best to implement these adaptation strategies. This issue is important because without consideration of effectiveness and efficiency, investments may be unnecessarily costly, ineffective or have unintended consequences. For example, it is critical that one sector or community's flood prevention adaptation not lead to a 'surprise' increase in flood risk for those 'outside' the proposed adaptation. Failure to implement

successfully could also undermine existing momentum behind adaptation initiatives (Ford et al. 2011). Therefore, there is an urgent need for greater documentation of adaptation 'experiments' (Saavedra and Budd, 2009) being conducted, including which aspects have succeeded and which have failed and why. As important as documentation will be formalized and standardized evaluation protocols, which are largely lacking at present.

Because some adaptation measures will be expensive and require significant modifications to existing modes of operation, research is required on how to implement them while keeping costs and disruption as low as possible. For example, municipalities might wait until a culvert is due for replacement before installing one designed to withstand the changing precipitation extremes expected within the new culvert's lifetime. Management studies for adaptation implementation are needed that span end-to-end operations (including fiduciary considerations, strategic planning, damage inspection, insurance, procurement and engineering). Research should be conducted on the cultural and institution-specific factors that determine opportune times for 'tacking-on' a climate adaptation strategy into a more general change or update.

The implementation process also needs to be documented and researched, with feedback from all involved and local knowledge highlighted. Place-and context-specific factors that may have hindered or assisted prior initiatives, such as the degree of openness to change, trust placed in leadership and decision-makers and extent of transparency, should also be identified.

Other study topics to support successful implementation include: (a) how to secure long-term access to funding; (b) how to nurture and ultimately operationalize and share technological innovations; (c) how to sustain political support and (d) how to make current decision-making frameworks more flexible and dynamic in the face of uncertainty and new information.

Critical activities that support this research priority include:

- Incorporating local knowledge
- Developing mechanisms for sustained adaptation finance
- Supporting the transition from technological innovation to on-the-ground implementation

A.3 Developing More Inclusive Cost Estimates and Prioritization Criteria

Policymakers require tools that will help them identify adaptation actions that will be effective and practical.

A.3.1 Improve Approaches for Valuing Adaptation

Create effective and innovative approaches to measure and value the monetary and non-monetary aspects of short- and long-term adaptations and maladaptations and to compare these across groups, sectors, regions and timeframes

Traditional economic approaches are ill-equipped to measure non-monetary costs and benefits of adaptation (e.g., the value of biodiversity for an ecosystem or human health); they can include unrealistically high discount rates through time; and they sometimes fail to consider fully principles such as equity and justice, especially

for certain minorities and disadvantaged groups. As such they may not be the most appropriate tools to inform selection of adaptation strategies (including inaction).

It is important for decision-makers to understand the value of ecosystem services (Handmer et al. 2012; Füssel, 2010), such as the protection mangrove forests and coral reefs provide from storm surges and the prevention of runoff and soil erosion by forests. Estimating the value of these services should play a part in prioritizing adaptive measures for regions and systems.

Inclusion of a broad set of disciplines (e.g., ecology, environmental economics and social psychology) is required to advance holistic costing analysis in an evidence-based way. Research is needed on how to extend integrated valuation approaches across groups, sectors and regions, with inputs from sector and regional experts, to ensure that no important factors (traditionally defined or otherwise) are externalized across sectors, space or time. Multi-criteria approaches that acknowledge the subjectivity inherent in developing weightings for non-market and market values should be advanced as well. The temporal component of such approaches must be given adequate consideration, so further research is required on what discount rates (whether monetized or non-monetized) are appropriate under which circumstances (Yohe and Leichenko, 2010).

Because the value of ecosystem services is so crucial yet difficult to quantify, there is an urgent need for standardized metrics, meta-analyses of prior studies and sharing of research results related to the value of ecosystem services in the VIA context. Researchers and decision-makers should include in participatory processes those whose livelihoods depend upon specific ecosystems and those with experiential knowledge of them (Füssel, 2010).

Critical activities that support this research priority include:

- Developing holistic costing analysis
- Characterizing discount rates under varying circumstances
- Expanding metrics of ecosystem services

A.3.2 Advance Criteria for Prioritizing Adaptation Strategies

Investigate a range of evaluation criteria for prioritizing adaptation decisions

Besides improved measurements and valuations of monetary and non-monetary aspects of adaptation, research is needed on the criteria for prioritizing actions (Füssel, 2007; Lobell et al. 2008). Elements to be tested include framing of the decision set of possible solutions for the affected sectors, groups, communities and regions and the spectrum of evaluative criteria. Decision frameworks to be analyzed could include feasibility of implementation, probability of success if implemented and potential for non-climate co-benefits and costs (Wilbanks and Sathaye, 2007; Füssel, 2010; Major and O'Grady, 2010). Potential for dynamic modification to adaptation strategies is important as climate impacts evolve (i.e., flexible adaptation pathways) (Rosenzweig and Solecki, 2010). Evaluation approaches and adaptation itself should be grounded in a process framework, rather than addressed piecemeal.

Critical activities that support this research priority include:

- Assessing feasibility of implementation
- Assigning probability of success if adaptations are implemented
- Identifying co-benefits and costs
- Incorporating potential for modifying adaptative measures as knowledge evolves

A.4 Enhancing Communication and Stakeholder/Public Participation

These topics articulate the role of communication and public participation throughout society in reducing vulnerability and supporting adaptation. They are based on the proposition that communication and participation can serve as multipliers across groups and through time, increasing the efficacy and impact of adaptation strategies.

To be successful, the adaptation process should include representatives from local communities, as well as the private sector and other groups and agencies with a stake in the adaptation decisions. This helps to ensure that broader perspectives and contexts are considered.

A.4.1 Conduct Studies on Communication, Participation and Capacity Building

Analyze how to build capacity of local communities and institutions (including government, educational and research organizations, media outlets, the private sector and other practitioners) to communicate about and participate in climate change and VIA activities

At the individual level, having access to information about climate impacts, vulnerability and adaptation is a prerequisite to improving one's condition vis-à-vis exposure to climate hazards. More generally, research has shown that public participation in policy development can enhance effective policy design and implementation (Boykoff, 2008). Communication is a critical tool for reducing vulnerability and enhancing stakeholder involvement/public participation in VIA policymaking processes and the implementation of adaptation strategies (Cutter et al. 2012). Communication and partnership within civil society can also be a path to building political will towards action. VIA research involvement in local communities can provide a major boost to local knowledge and decision-making.

Because women are often society's principal educators and often lead natural resource collection, food production, family health care and other highly VIA-relevant activities, there is an urgent need for VIA education and training tailored to women (Pearce et al. 2012). Development of VIA messaging and curricula related to climate would improve communication and education. One challenge is how to translate highly technical information into content that resonates with local communities (Nisbet, 2009). Research is also needed on how to increase the efficacy of messaging by grounding content in local institutional and cultural contexts (Moser, 2009). For example, for one group framing climate change action as a way to ameliorate poverty may be more effective, whereas for another group emphasizing environmental stewardship elements might offer more traction.

Research is also needed on which media are most effective among which groups and how content should be tailored to specific media

(Nerlich et al. 2010; Nisbet, 2009). The role of new media including social networking in catalyzing (or hindering) change should be a particular research focus.

Development of adaptation content is a priority, since information about adaptation is generally less available than information about impacts. Research is also needed on skills development and knowledge creation regarding VIA integration into existing educational systems (Nerlich et al. 2010).

The potential for "citizen science" to contribute to VIA and enhance public participation should be explored. More research is also needed on how the arts and humanities can be more effectively engaged and supported around VIA issues.

Critical activities that support this research priority include:

- Supporting VIA education and training
- Understanding local institutional and cultural contexts
- Incorporating new media including social networking
- Fostering citizen science
- Including arts and humanities

A.4.2 Determine how Communication between the VIA Research Community and Policymakers can be more Effective

Improve ways that VIA researchers and decision-makers interact

There is a growing recognition that the scientific and policy/practice communities need to work in tandem to advance VIA solutions. The scientific community requires guidance on where the greatest need for solutions resides in order to prioritize research, and the policy/practice community can increase effectiveness of their VIA efforts by incorporating the latest scientific information in decision-making. Research is needed to bridge the science/policy-practice gap through effective communication and collaboration across these two communities (Wardekker et al. 2008; Scott et al. 2008).

To enhance communication and collaboration, research efforts are needed to develop a common language between the science and practitioner communities (Wardekker et al. 2008; Scott et al. 2008). Further integration in each other's activities, through participation in meetings and conferences for example, should be encouraged. More information is needed about how each community perceives information provided by the other community.

Key questions include how the intended messages are being received and how they could be conveyed more effectively. Research is also needed on how communication practices vary by region and sector. Interdisciplinary programs that bring together practitioners (including the private sector) and scientists offer fertile ground for documenting shared learning.

Critical activities that support this research priority include:

- Developing a common language between researchers and policymakers
- Advancing opportunities for science-policy integration
- Documenting shared learning through collaboration

A.4.3 Advance Research on Lessons Learned from Developing Country Experiences and Local and Traditional Knowledge

Conduct research on how developing country VIA research and activities and local and traditional knowledge can inform global knowledge

Many developing countries have been at the forefront of adaptation activities for a variety of reasons, including high vulnerability to extreme weather and climate (Mertz et al. 2009). However, many of these 'bottom-up, learning-by-doing' adaptation experiences have not been well documented.

Sharing of successful strategies across regions and sectors holds the promise of more efficient and timely VIA advancement for the most vulnerable populations and can also be a means of empowerment (Conway and Schipper, 2011; Rawlani and Sovacool, 2011; Revi, 2008; Sovacool, 2012).

Documenting best practices for successful adaptation strategies is needed. Research topics include how to identify effective approaches that may be disappearing due to societal change and loss of traditional knowledge. Research is also needed on how to determine efficient routes for channeling adaptation funding to the most vulnerable.

Potential new pathways for developing country to developing country (and developing country to developed country) research activities also need to be identified and supported. For example, new VIA research partnerships where joint leadership and equal information-sharing are core parts of the research plan should be encouraged. Supporting partnerships with strong developing country leadership will be a key element of advancing this priority topic.

Critical activities that support this research priority include:

- Focusing on the most vulnerable
- Developing inclusive research partnerships
- Documenting best practices across developing countries and local communities

Systems and Regions

SECTION B

This section identifies specific research topics to inform decision-making about management of key systems, human well-being and critical geographical areas under changing climate conditions and multiple stresses.

B.1 Key Systems

Management of food systems, water resources, ecosystems, energy and infrastructure and the built environment under climate change – and interactions with population growth, development, technology and insurance – are key VIA research and policy issues. Because these systems are fundamental to human survival and livelihood, issues of justice, equity and supply for all members of the population are central. The topics described here have potential to contribute to knowledge generation on the broader set of VIA topics, including human health and the potential for conflict.

B.1.1 Food Systems

Understand how food systems, including production, processing, distribution and access will be impacted by and adapt to climate change and extreme events and how these impacts and adaptation strategies interact with other stresses

In recent years, global food surpluses have been reduced due to a range of factors, and food price shocks have led to civil unrest in many countries (Meakin and Kurvits, 2009). Climate extremes such as the U.S. drought of 2012 have played a role, as have socioeconomic factors such as the economic crisis, conversion of agricultural land to other uses and increased meat consumption globally. As agricultural markets become more global and complex, there is a growing awareness that climate change may cause a broad spectrum of food system impacts. Critical climate change impacts on food systems extend beyond changes in production to include food processing, distribution, access to food and food security.

There is a need for research linking recent advances in understanding of climate extremes to impacts on food systems (Bryan et al. 2009; Clark et al. 2010; Lobell et al. 2008; Olesen et al. 2011; Schmidhuber and Tubiello, 2007; Wolfe et al. 2011a). Non-linear crop and livestock impacts associated with climate/weather

thresholds and timing of extreme events relative to sensitive points in crop and livestock growth cycles are of particular importance (Schlenker and Roberts, 2009). Research is also needed on how climate extremes may impact food processing (e.g., through power outages and reduced employee attendance) and distribution (e.g., disrupting supply routes and timing of delivery, with implications for spoilage). More studies should also be conudcted on the efficacy of adaptation strategies in agriculture, as well as associated costs and the environmental impacts of agricultural decisions (e.g., use of pesticides, as well as carbon-cycle feedbacks associated with crop choice, tilling method and fertilizer use).

Specific agricultural adaptation strategies requiring further research include modifications to crop and livestock systems and genetic resources. A holistic research approach is needed that considers multiple factors in regional contexts yet with a global perspective. Given the potential for non-linear responses, process-based multi-model intercomparison (especially agricultural and economic modeling) will be critical (Rosenzweig et al. 2013). Research techniques are needed that emphasize food security for the most vulnerable populations today and in the future.

Critical activities that support this research priority include:

- Targeting food insecurity
- Assessing impacts of climate extremes on crops and livestock
- Conducting process-based multi-model intercomparisons

B.1.2 Water Systems

Build greater knowledge about water use/ demand, availability and quality in relation to water use decisions, water law and governance, under changing climate and other stresses

Access to water is becoming or is expected to become a limiting factor to development in many regions, due to water scarcity, a changing climate, unsustainable use and projected changes in demand (Biggs and Watmough, 2012; Kundzewicz et al. 2007; Nicol and Kaur, 2009; Oates et al. 2011; Refsgaard et al. 2012; Shaw et al. 2011; Sowers and Weinthal, 2011).

Furthermore, in a growing number of regions, the water that is available is increasingly threatened by chemical and microbial pollution. Both water availability and quality can be expected to change further as climate changes, yet a lack of or poor baseline information hinders the ability to document and understand the impacts of changing climatic and socioeconomic contexts (Rijsberman, 2006). Even defining sustainable water use for the present climate is challenging in some countries, for reasons including a lack of baseline data on demand and use, as well as limited understanding of the role of climate variability in the reliability of water supply.

There is a critical need for baseline information about how water is being used (and in some cases wasted, e.g., through leaky pipes) and what demands are not being met. More information is also essential to understand the availability of water supplies (e.g., estimates of sustainable extraction rates) including deep groundwater sources, especially in arid regions (Kundzewicz et al. 2007). In much of the world, there is virtually no information about possible chemical or

microbial pollution, especially for the small-scale water systems such as ground wells and small rivers that are the dominant source of drinking water for many populations outside municipal areas (Kistemann et al. 2002). Research is also needed on VIA issues facing large municipal treatment systems, including vulnerability to combined sewer overflow events (Shaw et al. 2011), damage incurred during storm-surge events and greenhouse gas emissions associated with water treatment. Information is also lacking with regard to the efficacy and potential costs and benefits associated with adaptation strategies including water conservation, reuse and desalination. The policy context, including water law and governance, is a critical component as well (Biggs and Watmough, 2012). This includes international policy issues, given the large spatial scale of many water supplies such as aquifers, lakes and river basins. While research on baseline conditions is required, research must also focus on how changing climate (primarily through changes in precipitation patterns, temperature and evaporation) and socioeconomic changes will influence water availability and quality in the future.

Critical activities that support this research priority include:

- Characterizing impacts of pollution on water quality
- Determining sustainable extraction rates for groundwater
- Reviewing role of water law and governance

B.1.3 Ecosystems

Investigate how ecosystems and their management will be affected by interactions between climate change and other ecosystem stressors including air pollution, overfishing, wildfires, loss of biodiversity, invasive species and disturbance regimes

There is a growing understanding of both the broad set of complex services that ecosystems provide and the many direct and indirect ways that ecosystems are threatened by a changing climate (Fischlin et al. 2007). Healthy ecosystems can provide human populations with sustainable harvestable resources; help to prevent erosion and inland and coastal flooding; support biodiversity, including endangered species; remove pollutants from the air and water and play an important role in climate regulation.

More research is needed on how ecosystems respond to extreme events such as droughts and fire, extreme high and low temperatures and gradual changes such as those associated with sea level rise (Mooney et al. 2009). These climatic effects on ecosystems need to be researched in the context of other stresses, which themselves may be influenced by climate change. For example, the presence of invasive species locally may be influenced by climate change in distant regions, as well as by tourism (Wolfe et al. 2011b).

Research is also required to understand how adaptive (or maladaptive) ecosystems and existing and planned management approaches are responding to a changing climate and other stressors. All of the above research is predicated on baseline data, which are presently lacking in many areas.

Tropical rainforests should continue to be a priority, given their high biodiversity, role in the carbon cycle and impact on the hydrological cycle and atmospheric circulation (Bonan, 2008).

Critical activities that support this research priority include:

- Studying ecosystem responses to extreme events as well as gradual climate changes
- Analyzing combined impacts of multiple stressors
- Comparing different management approaches

B.1.4 Energy Systems

Determine how climate change will influence energy production, distribution, demand and consumption, including renewables like hydropower, wind, solar and bio-energy

Secure access to energy is a basic need from the individual/microeconomic level to the national/macroeconomic scale, and energy issues have been root causes of small and large-scale conflicts. There is now growing awareness that climate change should be incorporated into all aspects of the energy system (Hammer et al. 2011). For example, effective greenhouse gas mitigation strategies in the energy sector will need to consider how a changing climate may modify the availability and reliability of renewable and nonrenewable energy sources. The results will impact everything from food and water security to the production of goods and services.

Research is needed on how climate change will impact availability and reliability of renewable energy sources including hydropower, solar, wind and biomass, both in terms of average conditions and during extreme events (which can impact energy supply and demand) (Pryor and Barthelmie, 2010; de Lucena et al. 2009; Vicuña et al. 2008). Further studies are also required on how the distribution and transmission of energy (e.g., through damage to infrastructure, changes in efficiency or operability associated with changing thermal gradients) are and will be affected by climate extremes and slower changes (Hammer et al. 2011).

More information is also essential regarding how demand and consumption for cooling and heating will change under changing climate and socio-economic conditions (Isaac and van Vuuren, 2009; Wang et al. 2010). Other critical topics include the role of greenhouse gas regulations in the energy sector, global energy flows and trade and the evaluation of energy sector adaptations.

Critical activities that support this research priority include:

- Modeling global energy flows and trade
- Projecting energy demand
- Improving understanding of energy transmission and distribution

B.1.5 Infrastructure Systems and the Built Environment

Examine the impacts of climate change on infrastructure and buildings, focusing on extreme events, multiple stresses and interactions with mitigation

Critical infrastructure systems include transportation and telecommunications and the built environment ranging from private dwellings to critical facilities such as hospitals, schools, ports, factories and storage containers for hazardous materials. Much existing infrastructure was designed with limited knowledge of local climate and climate variability. Climate change is expected to undermine the ability of some infrastructure to perform its intended functions while producing costly damage, both directly

to infrastructure itself and indirectly through loss of economic productivity and opportunities (Jacob et al. 2011a; Kirshen et al. 2008; Koetse and Rietveld, 2009; Major et al. 2011).

Furthermore, some infrastructure and facilities have outlived their intended lifetimes and in some cases were not built to specifications and codes. Increases in population served and changes in societal uses can put additional strains on infrastructure. Further research on how infrastructure and buildings can be designed to simultaneously support greenhouse gas mitigation and adaptation should be encouraged (Coley and Kershaw, 2010; Jaroszweski et al. 2010). Research is also needed on which infrastructure failures can have cascading effects on other infrastructure (e.g., electrical grids and transportation systems).

Adaptation strategies are needed that increase system redundancy (e.g., sharing of networks by telecommunications carriers during extreme climate events) and reduce the risk of entire networks going off-line due to localized failures (Jacob et al. 2011b; Kirshen et al. 2008). Research is needed on how to design appropriate climate protection levels (e.g., engineering standards, codes and regulations) to protect against sea level rise and other climate changes (Solecki et al. 2010). Another critical issue is how to fund adaptation in the infrastructure sector (Major et al. 2011).

Critical activities that support this research priority include:

- Assessing the potential for cascading effects across interdependent systems
- Encouraging innovations that build system resilience and redundancy
- Including increasing climate risk in engineering standards, codes and regulations

B.2 Human Well-being

Human well-being, a basic human right, is broadly defined here to include human health as well as human security and absence of conflict.

B.2.1 Human Health

Advance research on climate change and human health, including health sector adaptation

Climate change is projected to impact human health in many ways including changes in water quality and availability, access to food and nutrition, air quality, sanitation and vector-borne disease (Confalonieri et al. 2007). Investments in health sector adaptation have the potential to directly save lives and reduce human suffering, and also offer indirect benefits through, for example, improved worker productivity and prevention of long-term costs associated with chronic illness.

In some countries, there is a lack of baseline information and research on the present-day impacts of climate and extreme weather on health (Costello et al. 2009). Research is also needed on the varying health impacts and levels of support available to vulnerable populations, including children, women, the elderly and marginalized groups such as refugees (Costello et al. 2009; Frumkin et al. 2008; Kinney et al. 2011).

Because climate change impacts in the health sector are expected to be non-linear (e.g., populations of insect vectors can increase exponentially as temperatures increase) modeling studies are needed for impact assessment (Tong and McMichael, 2011). More research is also needed on effectiveness and costs of health

sector adaptation (Confalonieri et al. 2007; Tong and McMichael, 2011). Another key research area is the long-term health impacts of extreme climate events (e.g., mental health implications, exposure to mold and pollutants that may be mobilized) (Confalonieri et al. 2007; Frumkin et al. 2008; Kinney et al. 2011).

Critical activities that support this research priority include:

- Assessing climate impacts on health of vulnerable groups
- Studying long-term conequences of extreme events on affected communities
- Modeling non-linear human-health responses to climate

B.2.2 Human Security and Risk of Conflict

Investigate how climate change modifies human security and the risk of conflict through changes in resource scarcity, likelihood of migration, capacity of the government to respond and frequency and intensity of extreme weather events

Human security and risk of conflict are not merely factors that increase human vulnerability and suffering; they can in addition be precipitated by preconditions, many of which are climate-related (Barnett and Adger, 2007; Nordas and Geditsch, 2007; Salehyan, 2008; Temesgen, 2010). For example, droughts can lead to greater resource scarcity, bring groups with limited history of interaction into close contact and strain the capacity of governments to provide for and protect their populations.

Once there is conflict and threat to human security, a vicious cycle can occur whereby, for example, access to resources is further reduced. In contrast, populations and individuals who feel secure are more willing to make long-term investments in their communities and co-operate to achieve an improved quality of life. Populations displaced by climate events can lose access to critical services, including education and medical care, and may be more likely to experience a range of traumas. Thus, even temporary disruptions can have long-term consequences for individuals and society.

More research is needed on the role of climate and extreme climate events in historical conflicts and other instances of reduced human security (Temesgen, 2010). Research is also needed on adaptation strategies that minimize the risk of conflict and protect human security (Barnett and Adger, 2007) either directly (e.g., by protecting the vulnerable from physical harm, improving communication and building trust between potentially adversarial groups) or indirectly (e.g., by ameliorating resource scarcity and other preconditions for conflict).

Critical activities that support this research priority include:

- Identifying vulnerabilities of displaced populations
- Addressing loss of access to critical services including medical care and education
- Analyzing relationships between climate extremes and human conflict

B.3 Critical Geographical Areas

Examples of critical geographical areas include, but are not limited to, coastal areas and islands, arid and semi-arid regions, oceans, mountain regions and the cryosphere and urban areas.

B.3.1 Vulnerable Coastal Areas and Islands

Increase understanding of VIA and natural processes in the most vulnerable coastal areas, which include mega deltas, coastal wetlands, islands, coral reefs and coastal cities

A large part of the world's population lives near coasts, many in dense urban areas. The combination of high population density and rapid growth, especially in Asia, is putting strain on many coastal areas while climate changes such as sea level rise and increased coastal flooding are simultaneously increasing vulnerability (Nicholls et al. 2007; Nicholls and Cazenave, 2010). The geographical isolation of many islands can present a range of specific challenges, increasing vulnerability and impacts while limiting the potential for adaptation. Since many islands include distinct cultures and endemic ecosystems and species, potential losses associated with climate change and other stressors are very large (Mimura et al. 2007; Sem, 2007; Sovacool, 2012; Wong, 2010).

Research is needed to identify: (a) the most vulnerable populations to a range of coastal hazards including storm surge flooding (Buonaiuto et al. 2011; Few et al. 2007); (b) impacts of sea level rise on groundwater, fisheries, coral reefs and mangroves (Werner and Simmons, 2009; Mimura et al. 2007; Loucks et al. 2010); (c) how natural systems and processes affect vulnerability (e.g., the role of coral reefs and mangroves in reducing storm surge damage and erosion) and (d) the pros and cons of hard infrastructure (e.g., sea walls and surge barriers) and soft infrastructure (e.g., sand dunes and coastal wetlands) (Sovacool, 2011).

Integrated studies are also needed to determine how vulnerable coastal areas, including islands with endemic species, may be affected by multiple stresses caused by growing human populations and a changing climate. Studies on effective ways to protect endemic populations and cope with invasive species are needed as well. There is a need for small islands to form research partnerships to learn from each other and pool resources (Sem, 2007). Key topics include options for migration as sea levels rise and legal recourse and liability. Another topic is how local resources upon which small island populations depend (e.g., food and tourism) may be influenced by sea level rise. Research on how populations can be made more resilient in the face of these changes is also critical (Sovacool, 2012; Sem, 2007).

Critical activities that support this research priority include:

- Assessing coastal adaptations (e.g., hard and soft infrastructure)
- Evaluating options for, and desirability of, migration and retreat
- Analyzing multiple stresses facing islands

B.3.2 Arid and Semi-Arid Regions

Focus studies on VIA issues facing arid and semi-arid regions, including water quantity and quality, deforestation and fire

VIA issues in arid and semi-arid regions have been relatively under-researched, despite the fact that climate projections consistently show that many arid and semi-arid regions will experience less precipitation in the future (Ragab and Prudhomme, 2002). The potential for greater evaporation in these regions as temperatures rise and possible changes in the

distribution of rain toward more extreme events and fewer moderate events could worsen the hydrological situation. Many arid and semi-arid regions already face deteriorating hydrological conditions due to unsustainable groundwater extraction and decline of surface water bodies (Ragab and Prudhomme, 2002).

In some arid and semi-arid regions, demographic trends and increasing reliance on water-intensive economic activities (e.g., non-native agriculture, fossil-fuel extraction and mining) are further exacerbating water supply issues (Lioubimtseva and Henebry, 2009). Without consistent access to clean water, neither individuals nor societies will be able to reach their potential due to a combination of factors (e.g., health burden, time spent collecting water, constraints to economic activities and human potential and added risk of conflict).

More research is needed in arid and semi-arid regions on soil, erosion, fire, dust storms, air quality and human health. Studies should identify (a) less water-dependent industries for which semi-arid and arid regions may have unique advantages (e.g., solar energy) and (b) ways to encourage and promote the distribution of these technologies. Because many arid and semi-arid regions are characterized by large climate variability, research would be beneficial on how society can best prepare for, and to the extent possible exploit, climate variability, for example by better capturing heavy rains when they do fall.

Given the scarcity of historical data in many arid and semi-arid regions, indigenous populations should be involved when developing adaptation strategies as they can be a critical source of information on climate and impacts, as well as coping mechanisms for adaptation to climate variability, especially droughts and floods.

Critical activities that support this research priority include:

- Studying impacts of fires and dust storms
- Quantifying water dependence of economic sectors and activities
- Identifying environmental advantages (e.g., solar energy generation)

B.3.3 Open Ocean

Explore key open ocean topics in need of further research, including ocean acidification, the carbon cycle of the ocean, changes in the marine food chain and potential for regional de-oxygenation

In recent years, the ability to observe and model the ocean has grown. This expansion in knowledge has coincided with an increasing human imprint on ocean systems. There is now rising awareness of how dependent human and other land-based life is on ocean systems (e.g., as a source of food and as a regulator of local and global climate) as well as how vulnerable ocean systems are to effects of human activities including resource extraction, nutrient and sediment runoff, climate change and ocean acidification.

Research is needed on likely rates of ocean acidification associated with different greenhouse gas concentration pathways and the impacts of acidification on marine species and ecosystems (Doney et al. 2009; Fabry et al. 2008; Guinotte and Fabry, 2008; Pörtner, 2008). Acidification and its impacts need to be considered in the larger climatic context of possible changes in ocean temperatures, salinity, nutrients/nutrient loading and circulation (Doney et al. 2009).

Other important research topics include coral bleaching, hypoxia events (Pörtner, 2008), algal blooms and chemical and bacterial/viral pollution and contamination. More information is also needed about populations that are directly reliant on the open ocean, whether for employment or nourishment.

Methods to promote international VIA research and collaborations around ocean science and policy should be encouraged. In order to better understand challenges posed by climate variability and change, more participatory research involving scientists, decision-makers and marine industries would be beneficial. Research is often hampered by a lack of baseline data.

Critical activities that support this research priority include:

- Improving understanding of ocean acidification impacts
- Studying VIA implications of coral bleaching
- Researching ocean response to resource extraction

B.3.4 Mountain Regions and the Cryosphere

Advance understanding of VIA issues facing mountain regions and the cryosphere (e.g., glacier retreat, changes in streamflow and runoff, loss of livelihoods and unique ecosystems and the emergence of new regional development opportunities)

Some of the largest temperature increases associated with climate change are occurring in mountain regions and the cryosphere. These temperature increases, along with precipitation changes, are producing dramatic reductions in ice and snow cover in many high-latitude and high-elevation areas (Allamano et al. 2009; Beniston, 2003; Nogués-Bravo et al. 2007). Climatic and socio-economic changes are having dramatic impacts on the unique and often-isolated human and natural populations in these areas. Many high-latitude and high-altitude regions can also be thought of as island refugia for many species; these regions are VIA priorities in part because they represent a 'last stand' for some species.

More baseline information should be collected on human populations, ecosystems and rare species in the generally remote and isolated montane and high-latitude regions (Beniston, 2003; Nogués-Bravo et al. 2007). Information is also needed on the climate hazards these regions have faced in the past, including impacts and adaptation strategies (Beniston, 2003; Buytaert et al. 2010). Emerging hazards include the growing risk of glacial dam breaks in montane regions and beach erosion and storm surge as sea ice retreats in polar regions.

Research should focus on how vulnerabilities and impacts may have changed due to factors associated with development, including loss of traditional knowledge (about hazards and possible adaptations), population growth in high-risk zones such as flood plains and deforestation (which generally increases flood and landslide risk) (Allamano et al. 2009; Beniston, 2003).

Also, research should focus on the potential impacts of rapid sea ice loss in the Arctic (Liu et al. 2012; Liu et al. 2013), enhanced permafrost thawing, accelerated sea level rise and storm surge flooding and climate teleconnections to remote regions such as the mid-latitudes. Direct geopolitical and socio-economic impacts of sea ice loss, including the potential for more Arctic shipping and resource extraction from the Arctic and greater activity across Arctic borders, should be considered as well.

Critical activities that support this research priority include:

- Understanding global and local implications of permafrost thaw
- Assessing the effects of Arctic sea ice retreat
- Evaluating direct and indirect impacts of glacier retreat

B.3.5 Urban Areas

Investigate the VIA issues related to urban areas, including how cities are playing a leading role in early adoption of both mitigation and adaptation policies

The world's population is more than 50 percent urban and growing (Hunt and Watkiss, 2011; Rosenzweig et al. 2011). High population density and growth can enhance vulnerability and impacts. For example, in some cities rapid growth is concentrating more and more people in marginal areas, such as floodplains. Other vulnerabilities include the health impacts of the urban heat island effect and poor air quality. However, just as cities have been centers of innovation and leadership generally, many are increasingly showing leadership in climate and sustainable development (Revi, 2008).

Research should be increased on issues facing mega-cities and rapidly growing cities in developing countries, including informal settlements with limited access to resources and governance (Revi, 2008). In many cities of the world, baseline information is lacking on both historical climate hazards like storm surge and human populations, the latter in part due to rapid growth in those living uncounted in informal settlements. Research on urban microclimates such as heat islands and their interactions with air pollution, especially in hot places (Hunt and Watkiss, 2011); research on climate impacts and adaptation activities in urban corridors (e.g., transportation and energy networks); and research on urban-rural linkages should be increased.

Finally, opportunities for cities to share experiences and collaborate on VIA issues should be encouraged through formal and informal mechanisms. Identification and evaluation of adaptation strategies and the role of cities as first responders to climate change would be beneficial (Rosenzweig et al. 2011).

Critical activities that support this research priority include:

- Identifying vulnerabilities and adaptation challenges faced by informal settlements
- Understanding the relationship between urban microclimates and hazard exposure
- Supporting holistic planning that considers urban-rural linkages

SECTION C

Emerging Topics

This section describes cutting-edge Research Priorities that were identified through feedback from the policymaker and expert communities. In general, their importance has been recognized but they have not been covered extensively in the scientific literature.

C.1 Transformative Change

Explore the potential for, and VIA implications of, transformative change and transformative learning in social-ecological systems

Just as some physical systems can experience tipping points that lead to rapid phase changes, human systems can change rapidly as well (Lenton et al. 2008). It is important that this perspective be incorporated into scenario planning, in order to project the full range of possible outcomes. Growing awareness of the possibility for transformative change may itself encourage action, leading to a positive feedback cycle.

Further research should be conducted on historical instances of transformative change, including the circumstances that led to transformation or fast action (e.g., Hurricane Sandy in 2012 and international efforts to prevent the collapse of the global financial system in 2008) (Nelson et al. 2007; Tonn, 2007). This research will require a range of disciplines, including behavioral sciences, to answer such questions as: Was the change motivated by a sense of urgency? Are there key groups that accelerate change? Is there a minimum buy-in needed by a society before the rate of change accelerates? Can outcomes be successfully predicted once transformative change is underway?

Research is also needed on the types of learning associated with transformative change, including the role of different types of media and messaging. For example, the relationship between media coverage of a climate hazard/risk (e.g., sea level rise or fire risk) and societal perception of that risk (expressed for example through property values), as well as potential feedbacks between societal perception of risk and media coverage, should be researched (Lorenzoni and Pidgeon, 2006).

Another important topic is the extent to which globalization and long-distance interactions and communication supports or hinders transformative change. The role of worldviews (e.g., perception that global governance and economic systems may be ill-equipped to address VIA implications of climate change) in transformation should be investigated. Finally, research on potential costs (including economic, environmental and human rights) of transformative responses to climate change should be advanced.

Critical activities that support this research priority include:

- Documenting historical examples of transformation
- Identifying key social groups that accelerate change
- Studying the role of worldviews

C.2 Impacts of Geoengineering

Investigate the potential impacts of geoengineering, including implications of unilateral actions and unintended consequences

Geoengineering is increasingly being proposed as a potential back-stop climate change solution beyond mitigation and adaptation, especially as concern grows about tipping points and possible surprises (e.g., releases of stored methane as the polar regions warm in a positive feedback cycle) (MacCracken, 2009). Some small-scale geoengineering experiments have been conducted, with little oversight. Yet there is growing awareness of the potential for serious negative impacts of geoengineering (UNESCO, 2011), such as changes in regional precipitation and ozone concentrations that might accompany intentional high-altitude releases of cooling aerosols (Victor et al. 2009; Virgoe, 2009).

More research is needed on the implications of of different geoengineering strategies, which include both carbon dioxide removal methods and radiation management techniques. Carbon dioxide removal addresses the problem directly at its source by removing greenhouse gases from the atmosphere, while solar radiation management aims to offset the warming effect by decreasing the absorption of solar radiation.

Carbon dioxide geoengineering methods include (but are not limited to) enhancement of natural weathering processes to remove carbon dioxide from the atmosphere, direct engineered capture and geological sequestration of carbon dioxide and increasing oceanic uptake of carbon dioxide through fertilization (Shepherd, 2009). Solar radiation management techniques include (but are not limited to) aerosol injection into the upper atmosphere (Rasch et al. 2008; Robock and Stenchikov, 2008) and manipulation of surface albedo (Ridgwell et al. 2009).

Current research is lacking on how geoengineering methods may affect regional climates and the resulting VIA implications. Research priority could be given to those strategies that are relatively easy to implement (especially via unilateral action) and have large VIA implications. Studies on the ethical, social, political and legal aspects of engineering the climate (MacCracken, 2009; Virgoe, 2009) and research on whether the perception of geoengineering as a viable solution might ultimately increase the mitigation and adaptation challenge by delaying mitigation and adaptation action, is necessary.

Critical activities that support this research priority include:

- Investigating the ethical, social, political and legal implications of geoengineering
- Studying impacts of carbon dioxide and solar radiation management on vulnerable groups
- Assessing the costs and benefits of geoengineering techniques

C.3 Legal Principles and Role of Law

Improve understanding of legal challenges related to climate change and the role of law, legal tools and legal principles in promoting or preventing adaptation

Because legal systems are strong policy levers for responding to change, research on the law is a key part of VIA initiatives (Craig, 2010; Dernbach and Kakade, 2008; Ruhl, 2011; Ruhl, 2010; Zinn, 2007). Legal questions are central to the issue of assigning responsibility for losses and damages associated with climate change, including impacts associated with extreme climate events relative to other drivers of vulnerability. For example, legal conflicts may arise from deforestation of hillsides upstream of flood locations.

Research is needed on how and why existing legal systems can either promote or hinder adaptation. For example, permitting and zoning can promote and incentivize vulnerability reduction in the face of climate hazards. The law may serve as a barrier to adaptation as well, for example by protecting other principles such as privacy and property rights. Further research topics include how regulations and contracts can be used to promote adaptation, e.g., through requirements that climate risks and adaptation solutions be considered in large transactions; how legal systems can be made flexible enough to respond to climate change as it evolves; how the law can enhance communication, participation and access to justice; the role of international law in transnational VIA issues and legal implications of climate change impact detection and attribution findings.

Critical activities that support this research priority include:

- Evaluating how existing legal systems promote or hinder adaptation
- Assessing how regulations and contracts can be flexible as climate change progresses
- Determining the legal implications of detection and attribution of climate change impacts

C.4 Food-Water-Energy-Security Nexus

Apply a systems approach to the food-water-energy-security nexus that considers cross-sectoral interdependencies, transboundary impacts and adaptation tradeoffs (e.g., potential conflicts over water use in agriculture and energy generation)

Many of the most complex and intractable VIA issues involve multiple systems and cross many spatial scales and levels of governance. For example, in a globally interconnected world, the relationships between availability and prices of food, water and energy should be considered together since they are so interdependent. Given these complexities, developing a sound understanding of these systems today is

challenging. Discerning how the systems may be affected by changing climate and socio-economic conditions and how holistic adaptation strategies can be developed and implemented across government, the private sector, and NGOs is even more challenging. A unified, science-based approach is needed to help ensure that adaptation benefits for some sectors do not come at greater expense for others.

More baseline information is needed about how (and how much) water is used for agriculture and energy production and distribution and how (and how much) energy is used for food and water production and distribution (de Fraiture et al. 2008). Information is lacking on how energy (e.g., bioenergy systems) and water systems and distribution (e.g., protected-area reservoirs) may hinder food production and distribution, especially for the most vulnerable populations (Hanjra and Qureshi, 2010). Key issues include how international markets may assist or create distortions that hinder access to food, water and energy. Research is needed on how adaptation strategies can maximize outcomes in the food-water-energy-security nexus, with special attention to vulnerable groups and regions. Existing sectoral strategies should be analyzed for intersectoral effects.

Critical activities that support this research priority include:

- Integrating holistic assessment techniques for interdependent systems
- Distinguishing the relative roles of changing climate and socio-economic conditions on food, water, energy and security
- Identifying the role of international markets and price distortions in adaptation effectiveness

C.5 Participatory Processes for Mitigation and Adaptation Scenarios

Create protocols that enable stakeholders to explore mitigation and adaptation decisions, such as scenario processes based on Shared Socio-economic Pathways (SSPs) and Representative Concentration Pathways (RCPs)

There is a need for tools that help link local and regional decision-making to global future scenarios. The scenario development process motivated by the IPCC Fifth Asessment Report (AR5) is based on a three-dimensional matrix comprising: (a) the degree of global climate mitigation provided by the Representative Concentration Pathways (RCPs) (van Vuuren et al. 2011), (b) the state of the atmosphere and climate provided by the Fifth Climate Model Intercomparison Project (CMIP5) and (c) the state of human societies and ecological systems provided by the Shared Socio-economic Pathways (SSPs). The SSPs include a narrative storyline and measures that define society over the 21st century at the national level (Kriegler et al. 2012).

While there has been considerable interaction of the climate science and integrated assessment modeling communities in the scenario development process, there has been less involvement by the VIA research community. Research is thus necessary to develop more detailed sectoral and regional scenarios related to both mitigation and adaptation (Kriegler et al. 2010; Kriegler et al. 2012). Scenarios the VIA research communities need to develop include trajectories of societal factors, such as population and economic growth rates, as well as mitigation levels and climate futures relevant to policymakers at international, national and sub-national regional scales. Drawing greater connections across

spatial scales can help produce purposeful and internally consistent visions of the future based on input from an expanded group of voices.

Critical activities that support this research priority include:

- Investigating how participatory scenario processes can influence decision-making
- Developing alternate sectoral and regional scenarios
- Characterizing relationships between scenarios used for mitigation and adaptation

C.6 Integrated Impact Model Intercomparisons

Develop frameworks for integrated impact model intercomparisons within and across sectors to advance system understanding, characterize uncertainty, test adaptation strategies and improve impact models

While significant resources have been devoted to climate and Earth System modeling, fewer resources have been invested in impact model improvement (Breuer et al. 2009; Semenov and Stratonovich, 2010). Given the impacts associated with climate variability and change, better understanding of impacts and improved impact models are needed to assist policy (Hempel et al. 2013). Process-based modeling approaches are needed to supplement statistical approaches since direct impacts may change in non-linear ways with a changing climate (e.g., crop yield response to temperature) (Semenov and Stratonovich, 2010). Integrated process models are needed because of the potential for non-linear feedbacks between the climate and other impact drivers (e.g., socioeconomic changes and adaptation actions).

Validation and refinement of impact models based on historical evidence and observed physical relationships and processes is needed. Also needed are studies on sources of differences in projections across existing impact models (e.g., the extent to which biophysical models consider how changes in productivity may be influenced by CO_2 fertilization effects) (Rosenzweig et al. 2013) and how these differences and uncertainties contribute to total (or end-to-end) uncertainty in projected impacts (Semenov and Stratonovich, 2010). In order for such comparisons to be effective, modeling and scenarios protocols are important, as well as standardized data storage and outputs accessible to a broad range of communities globally (Rosenzweig et al. 2013).

Capacity-building efforts should focus on training a next generation of VIA modelers around the globe with local expert knowledge. As impact models continue to improve (in part due to such intercomparison initiatives) and more is learned about the sources of uncertainty across models, they will contribute to enhanced adaptation decisions, build capacity through education and advance meta-models and intersectoral analyses. Individual impact modeling systems include agriculture, hydrology and economics. Rigorous testing and improvement of impact models should be a key component of this effort.

Critical activities that support this research priority include:

- Validating and refining impact models
- Creating consistent modeling and scenarios protocols to support comparative studies
- Building capacity in developing countries for multi-model impact and adaptation assessment

C.7 Decision Theory

Deepen decision theory research, including studies of who makes decisions and how they are made in different institutional, political, legal, historical and cultural contexts

It is now well understood that adaptation decisions are context-specific. Without knowledge of who makes different types of decisions at macro (e.g., national) and micro (e.g., household) scales, what types of information they consider and what factors they weigh in making decisions, optimal adaptation strategies can neither be defined nor effectively promulgated or implemented (Keller, 2012).

There is a need for decision frameworks to be developed for – and shared among – regions, sectors and groups. Baseline information is needed on how climate and impact information and associated treatment of uncertainty and risk have informed decision-making (Clarke, 2008; Pidgeon and Fischoff, 2011).

More studies are necessary about how and why approaches taken to provide climate and VIA decision support (e.g., data products and forecasts and their dissemination, training and co-generation of knowledge) have or have not improved decision-making. As underlying methodologies for understanding adaptation decisions are developed and standardized, the potential for sharing results and expanding knowledge grows. Interview and survey protocols will be critical for determining the sets of factors that most influence decisions.

Critical activities that support this research priority include:

- Developing baseline VIA decision frameworks by region, sector and group
- Identifying factors that influence climate-related decisions
- Improving methodologies and protocols for climate change decision research

C.8 Risk Peception, Climate Knowledge and Behavior

Characterize the factors that shape risk perception, including social and cultural contexts, and study links to behavior

There is growing awareness that information does not always lead to action. Perception of risk, and of information more generally, is shaped by a variety of factors including social and cultural contexts (Leiserowitz, 2005; Leiserowitz, 2006; Lorenzoni and Pidgeon, 2006; Weber and Stern, 2011). Furthermore, behavior does not always conform to beliefs and perception. This is important from a VIA perspective since it suggests that pathways to specific actions to reduce vulnerability should extend beyond traditional fact-based learning about climate and impacts to include, for example, inputs from disciplines like psychology and sociology.

Research is needed on how people process different types and sources of information (Leiserowitz, 2005; Leiserowitz, 2006) and what types of information (including contributions from the humanities and artistic media) are most likely to change risk perception and/or to lead to different types of actions (McCright and Dunlap, 2003; Pidgeon and Fischoff, 2011; Weber and

Stern, 2011) would be beneficial. For example, it is important to understand which approaches to characterizing uncertainty (e.g., probabilistic vs. deterministic) have the largest impacts on different communities and why.

It is also important to investigate (a) risk perception, behavior and receptiveness to new information after extreme climate events; (b) 'non-informational' factors, such as prior beliefs, degree of perceived power to enact change and perceptions of fairness that influence risk perception and behavior and (c) how to promote self-protective behavior, including insights from sociology and the law. Studies on non-climate-related precedents, such as seat belt and anti-smoking campaigns and laws, should be considered as well.

Critical activities that support this research priority include:

- Devising approaches to characterizing uncertainty
- Studying risk perception and behavior before and after extreme events
- Identifying 'non-informational' factors that influence behavior
- Investigating how to promote self-protective behavior

C.9 Governance, Collaborative Frameworks and Networks

Investigate how different types of governance, collaborative frameworks and networks are effective at fostering partnerships and multi-stakeholder approaches in support of VIA

As awareness grows that individual actions and beliefs are context-dependent, it is increasingly clear that attention needs to be given to which types of governance and frameworks for stakeholder engagement and partnerships encourage reductions in vulnerability (Bulkeley, 2005; Camacho, 2009; Corfee-Morlot et al. 2009). The results are likely to be place-specific and group-dependent, suggesting that there is no 'one-size fits all' best approach.

More research is needed about the roles of top-down leadership and distributed decision-making in risk reduction and adaptation (Corfee-Morlot et al. 2009); the role of power and politics in vulnerability assessment and adaptation should be further studied, including how and why the ideas and information presented and championed by different individuals or groups do or do not gain traction and influence. Studies should be conducted on how to build the types of broad partnerships based on co-generation of knowledge needed for holistic approaches, while ensuring that each sub-group identifies with the adaptation process and feels invested and engaged in it. Research is also needed on how to support collaboration across inter-national, national, sub-national, municipal and community scales (Camacho, 2009) and about how civil society partnerships can influence political processes.

Critical activities that support this research priority include:

- Understanding the role of political processes in vulnerability assessment and adaptation
- Co-generating VIA knowledge through partnerships
- Identifying strategies that support collaboration across spatial scales, sectors and groups

C.10 Long-Term Planning and Design

Examine how long-term regional planning and design can support adaptation, mitigation and sustainable development potential

Planning and design are critical to regional vulnerability reduction and effective adaptation because they can have long-term effects and can change the way people behave (Saavedra and Budd, 2009; Smit and Pilifosova, 2003; Tanner et al. 2009). For example, centralized, 'vertical' cities may reduce transportation-sector pollution and greenhouse gas emissions from vehicles. Innovative design can invoke and illuminate new visions of possible futures and inspire further creativity and optimism. There is a major role for both the arts and the humanities in such planning and design. Changes in engineering standards, coastal and flood zone planning and management, requirements for private and public sector climate hazard disclosure and in public and private insurance and reinsurance markets could also lead to a 'new normal' that catalyzes large-scale changes in mitigation, sustainable development and adaptation potential (Dawson, 2007).

Research is needed on the effectiveness of planning and design for climate change responses in urban areas, their surrounding infrastructure and resource-sheds and rural areas (Tanner et al. 2009). The role of innovative design in adaptation, mitigation and sustainability paradigms should be investigated as well. Key questions include how to minimize impacts of transition on the most vulnerable communities, the extent to which transitional costs (e.g., shoreline retreat) should be borne by those exposed to the hazard or society as a whole and how to ensure that all stakeholders are included in long-term decision-making (Smit and Pilifosova, 2003). Integrated research is needed across private and public entities on how insurance can provide incentives, data and projections in support of adaptation, mitigation and sustainable development. Research on how to minimize the risk of perverse incentives, including those that can be associated with price distortions in insurance markets, would also be beneficial.

Critical activities that support this research priority include:

- Supporting coastal and flood zone planning and management
- Advancing innovative design research for interactive mitigation and adaptation strategies
- Identifying the role of insurance

References

Allamano, P., Claps, P., & Laio, F. (2009). Global warming increases flood risk in mountainous areas. *Geophysical Research Letters, 36*(24), L24404. doi: 10.1029/2009GL041395

Barnett, J., & Adger, W.N. (2007). Climate change, human security and violent conflict. *Political Geography, 26*(6), 639-655. doi: 10.1016/J.Polgeo.2007.03.003

Beniston, M. (2003). Climatic change in mountain regions: A review of possible impacts. *Climatic Change, 59*(1-2), 5-31. doi: 10.1023/A:1024458411589

Berkes, F. (2007). Understanding uncertainty and reducing vulnerability: lessons from resilience thinking. *Natural Hazards, 41*(2), 283-295. doi: 10.1007/S11069-006-9036-7

Biggs, E.M., & Watmough, G.R. (2012). A Community-Level Assessment of Factors Affecting Livelihoods in Nawalparasi District, Nepal. *Journal of International Development, 24*(2), 255-263. doi: 10.1002/Jid.1844

Bonan, G.B. (2008). Forests and climate change: Forcings, feedbacks, and the climate benefits of forests. *Science, 320*(5882), 1444-1449. doi: 10.1126/Science.1155121

Boykoff, M.T. (2008). Media and scientific communication: a case of climate change. *Geological Society, London, Special Publications, 305*(1), 11-18.

Breuer, L., Huisman, J.A., Willems, P., Bormann, H., Bronstert, A., Croke, B.F.W., Frede, H.G., Gräff,T., Hubrechtsf, L., Jakemang, A.J., Kiteh, G., Laninih, J., Leavesleyi, G., Lettenmaierh, D.P., Lindström, G., Seibert, J., Sivapalan, M., & Viney, N.R. (2009). Assessing the impact of land use change on hydrology by ensemble modeling (LUCHEM). I: Model intercomparison with current land use. *Advances in Water Resources, 32*(2), 129-146. doi: http://dx.doi.org/10.1016/j.advwatres.2008.10.003

Bryan, E., Deressa, T.T., Gbetibouo, G.A., & Ringler, C. (2009). Adaptation to climate change in Ethiopia and South Africa: options and constraints. *Environmental Science & Policy, 12*(4), 413-426. doi: 10.1016/J.Envsci.2008.11.002

Bulkeley, H. (2005). Reconfiguring environmental governance: Towards a politics of scales and networks. *Political Geography, 24*(8), 875-902. doi: 10.1016/J.Polgeo.2005.07.002

Buonaiuto, F., Patrick, L., Gornitz, V., Hartig, E., Leichenko, R., & Vancura, P. (2011). Coastal Zones. In C. Rosenzweig, W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol & P. Grabhorn (Eds.), *Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation in New York State* (Vol. 1244, pp. 121-162). New York: Annals of the New York Academy of Sciences.

Buytaert, W., Vuille, M., Dewulf, A., Urrutia, R., Karmalkar, A., & Celleri, R. (2010). Uncertainties in climate change projections and regional downscaling in the tropical Andes: implications for water resources management. *Hydrology and Earth System Sciences, 14*(7), 1247-1258. doi: 10.5194/Hess-14-1247-2010

Camacho, A.E. (2009). Adapting Governance to Climate Change: Managing Uncertainty through a Learning Infrastructure. *Emory Law Journal, 59*(1).

Clark, W.C., Kristjanson, P., Campbell, B., Juma, C., Hollbrook, N.M., Nelson, G., & Dickson, N. (2010). *Enhancing Food Security in an Era of Global Climate Change*. Paper presented at the An Executive Session on Grand Challenges of the Sustainability Transition, Venice, Italy.

Clarke, H. (2008). Classical decision rules and adaptation to climate change. *Australian Journal of Agricultural and Resource Economics, 52*(4), 487-504. doi: 10.1111/J.1467-8489.2008.00421.X

Coley, D., & Kershaw, T. (2010). Changes in internal temperatures within the built environment as a response to a changing climate. *Building and Environment, 45*(1), 89-93. doi: 10.1016/J.Buildenv.2009.05.009

Confalonieri, U., Menne, B., Akhtar, R., Ebi, K.L., Hauengue, M., Kovats, R.S., Revich, B., & Woodward, A. (2007). Human health. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 391-431). Cambridge, UK: Cambridge University Press.

Conway, D., & Schipper, E.L.F. (2011). Adaptation to climate change in Africa: Challenges and opportunities identified from Ethiopia. *Global Environmental Change, 21*(1), 227-237. doi: http://dx.doi.org/10.1016/j.gloenvcha.2010.07.013

Corfee-Morlot, J., Kamal-Chaoui, L., Donovan, M., Cochran, I., Robert, A., & Teasdale, P.J. (2009). Cities, climate change and multilevel governance: OECD publishing.

Costello, A., Abbas, M., Allen, A., Ball, S., Bellamy, R., Friel, S., Groce, N., Johnson, A., Kett, M., Lee,

M., Levy, C., Maslin, M., McCoy, D., McGuire, B., Montgomery, H., Napier, D., Pagel, C., Patel, J., de Oliveira, J.A., Redclift, N., Rees, H., Rogger, D., Scott, J., Stephenson, J., Twigg, J., Wolff, J., & Patterson, C. (2009). Managing the health effects of climate change. *Lancet, 373*(9676), 1693-1733.

Craig, R.K. (2010). "Stationarity Is Dead" - Long Live Transformation: Five Principles for Climate Change Adaptation Law. *Harvard Environmental Law Review, 34*(1), 9-73.

Cutter, S., Osman-Elasha, B., Campbell, J., Cheong, S.M., McCormick, S., Pulwarty, R., Supratid, S., & Ziervogal, G. (2012). Managing the risks from climate extremes at the local level. In C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.K. Plattner, S.K. Allen, M. Tignor & P.M. Midgley (Eds.), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press.

Dawson, R. (2007). Re-engineering cities: a framework for adaptation to global change. *Philosophical Transactions of the Royal Society of the Mathematical Physical and Engineering Sciences, 365*(1861), 3085-3098. doi: Doi 10.1098/Rsta.2007.0008

de Fraiture, C., Giordano, M., & Liao, Y.S. (2008). Biofuels and implications for agricultural water use: blue impacts of green energy. *Water Policy, 10*, 67-81. doi: Doi 10.2166/Wp.2008.054

de Lucena, A.F.P., Szklo, A.S., Schaeffer, R., de Souza, R.R., Borba, B.S.M.C., da Costa, I.V.L., Pereira, Jr. A.O., & da Cunha, S.H.F. (2009). The vulnerability of renewable energy to climate change in Brazil. *Energy Policy, 37*(3), 879-889. doi: 10.1016/J.Enpol.2008.10.029

Dernbach, J.C., & Kakade, S. (2008). Climate Change Law: An Introduction. *Energy Law Journal, 29*(1).

Doney, S.C., Fabry, V.J., Feely, R.A., & Kleypas, J.A. (2009). Ocean Acidification: The Other CO_2 Problem. *Annual Review of Marine Science, 1*, 169-192. doi: 10.1146/Annurev.Marine.010908.163834

Fabry, V.J., Seibel, B.A., Feely, R.A., & Orr, J.C. (2008). Impacts of ocean acidification on marine fauna and ecosystem processes. *Ices Journal of Marine Science, 65*(3), 414-432. doi: Doi 10.1093/Icesjms/Fsn048

Fasullo, J.T., & Trenberth, K.E. (2012). A Less Cloudy Future: The Role of Subtropical Subsidence in Climate Sensitivity. *Science, 338*(6108), 792-794. doi: 10.1126/Science.1227465

Few, R., Brown, K., & Tompkins, E.L. (2007). Climate change and coastal management decisions: Insights from Christchurch Bay, UK. *Coastal Management, 35*(2-3), 255-270. doi: 10.1080/08920750601042328

Fischlin, A., Midgley, G.F., Price, J.T., Leemans, R., Gopal, B., Turely, C., Rounsevell, M.D.A., Dube, O.P., Tarazona, J., & Velichko, A.A. (2007). Ecosystems and their properties, goods, and services. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 211-272). Cambridge, UK: Cambridge University Press.

Ford, J.D., Berrang-Ford, L., & Paterson, J. (2011). A systematic review of observed climate change adaptation in developed nations. *Climatic Change, 106*(2), 327-336. doi: 10.1007/S10584-011-0045-5

Frumkin, H., McMichael, A.J., & Hess, J.J. (2008). Climate Change and the Health of the Public Introduction. *American Journal of Preventive Medicine, 35*(5), 401-402. doi: 10.1016/J.Amepre.2008.08.031

Füssel, H.M. (2007). Adaptation planning for climate change: concepts, assessment approaches, and key lessons. *Sustainability Science, 2*(2), 265-275. doi:10.1007/S11625-007-0032-Y

Füssel, H.M. (2010). Modeling impacts and adaptation in global IAMs. *Wiley Interdisciplinary Reviews-Climate Change, 1*(2), 288-303. doi: 10.1002/Wcc.40

Guinotte, J.M., & Fabry, V.J. (2008). Ocean acidification and its potential effects on marine ecosystems. *Year in Ecology and Conservation Biology 2008, 1134*, 320-342. doi: 10.1196/Annals.1439.013

Hammer, S.A., Parshall, L., Leichenko, R., Vancura, P., & Panero, M. (2011). Energy. In C. Rosenzweig, W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol & P. Grabhorn (Eds.), *Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation in New York State* (Vol. 1244, pp. 255-298). New York: Annals of the New York Academy of Sciences.

Handmer, J., Honda, Y., Kundzewicz, Z.W., Arnell, N., Benito, G., Hatfield, J., Mohamed, I.F., Peduzzi, P., Wu, S., Sherstyukov, B., Takahashi, K., & Yan, Z. (2012). Changes in impacts of climate extremes: human systems and ecosystems. In C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor & P.M. Midgley (Eds.), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* (pp. 231-290). Cambridge, UK: Cambridge University Press.

Hanjra, M.A., & Qureshi, M.E. (2010). Global water crisis and future food security in an era of climate change. *Food Policy, 35*(5), 365-377. doi: 10.1016/J.Foodpol.2010.05.006

Hempel, S., Frieler, K., Warszawski, L., Schewe, J., & Piontek, F. (2013). A trend-preserving bias correction – the ISI-MIP approach. *Earth Syst. Dynam. Discuss., 4*(1), 49-92.

Hunt, A., & Watkiss, P. (2011). Climate change impacts and adaptation in cities: a review of the literature. *Climatic Change, 104*(1), 13-49. doi: 10.1007/S10584-010-9975-6

Intergovernmental Panel on Climate Change. (2007a). *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press.

Intergovernmental Panel on Climate Change. (2007b). *Climate Change 2007: The Physical Science Basis Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press.

Intergovernmental Panel on Climate Change. (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press.

Isaac, M., & van Vuuren, D.P. (2009). Modeling global residential sector energy demand for heating and air conditioning in the context of climate change. *Energy Policy, 37*(2), 507-521. doi: 10.1016/J.Enpol.2008.09.051

Jacob, K., Deodatis, G., Atlas, J., Whitcomb, M., Lopeman, M., Markogiannaki, O., Kennett, Z.,Vancura, P. (2011a). Transportation. In C. Rosenzweig, W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol & P. Grabhorn (Eds.), *Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation in New York State* (Vol. 1244, pp. 299-362). New York: Annals of the New York Academy of Sciences.

Jacob, K., Maxemchuck, N., Deodatis, G., Morla, A., Schlossberg, E., Paung, I., Jacob, K., Lopeman, M., & Klein, Y. (2011b). Telecommuncations. In C. Rosenzweig, W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol & P. Grabhorn (Eds.), *Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation in New York State* (Vol. 1244, pp. 363-396). New York: Annals of the New York Academy of Sciences.

Jaroszweski, D., Chapman, L., & Petts, J. (2010). Assessing the potential impact of climate change on transportation: the need for an interdisciplinary approach. *Journal of Transport Geography, 18*(2), 331-335. doi: 10.1016/J.Jtrangeo.2009.07.005

Keller, K. (2012). Bayesian decision theory and climate change. *Encyclopedia of Energy, Natural Resource and Environmental Economics*, edited by J. Shogren, in review.

Kinney, P.L., Sheffield, P., Ostfeld, R.S., Carr, J.L., Leichenko, R., & Vancura, P. (2011). Public Health. In C. Rosenzweig, W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol & P. Grabhorn (Eds.), *Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation in New York State* (Vol. 1244, pp. 397-438). New York, NY: Annals of the New York Academy of Sciences.

Kirshen, P., Ruth, M., & Anderson, W. (2008). Interdependencies of urban climate change impacts and adaptation strategies: a case study of Metropolitan Boston USA. *Climatic Change, 86*(1-2), 105-122. doi: 10.1007/S10584-007-9252-5

Kistemann, T., Classen, T., Koch, C., Dangendorf, F., Fischeder, R., Gebel, J., Vacata, V., & Exner, M. (2002). Microbial load of drinking water reservoir tributaries during extreme rainfall and runoff. *Applied and Environmental Microbiology, 68*(5), 2188-2197. doi:10.1128/Aem.68.5.2188-2197.2002

Klein, R.J., Huq, S., Denton, F., Downing, T.E., Richels, R.G., Robinson, J.B., & Toth, F.L. (2007). Inter-relationships between adaptation and mitgation. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 745-777). Cambridge, UK: Cambridge University Press.

Koetse, M.J., & Rietveld, P. (2009). The impact of climate change and weather on transport: An overview of empirical findings. *Transportation Research Part D-Transport and Environment, 14*(3), 205-221. doi: Doi 10.1016/J.Trd.2008.12.004

Kriegler, E., O'Neill, B.C., Hallegatte, S., Kram, T., Lempert, R., Moss, R., & Wilbanks, T. (2010). Socio-economic scenario development for climate change analysis: CIRED Working Paper DT/WP.

Kriegler, E., O'Neill, B.C., Hallegatte, S., Kram, T., Lempert, R., Moss, R.H., & Wilbanks, T. (2012). The need for and use of socio-economic scenarios for climate change analysis: A new approach based on shared socio-economic pathways. *Global Environmental Change-Human and Policy Dimensions, 22*(4), 807-822. doi: 10.1016/J.Gloenvcha.2012.05.005

Kundzewicz, Z.W., Mata, L.J., Arnell, N.W., Doll, P., Kabat, P., Jimenez, B., Miller, K., Oki, T., Zekai, S., & Shiklomanov, I.A. (2007). Freshwater resources and their management. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 173-210). Cambridge, UK: Cambridge University Press.

Leiserowitz, A. (2005). American risk perceptions: Is climate change dangerous? *Risk Analysis, 25*(6), 1433-1442. doi: 10.1111/J.1540-6261.2005.00690.X

Leiserowitz, A. (2006). Climate change risk perception and policy preferences: The role of affect, imagery, and values. *Climatic Change, 77*(1-2), 45-72. doi: 10.1007/S10584-006-9059-9

Lenton, T. M., Held, H., Kriegler, E., Hall, J.W., Lucht, W., Rahmstorf, S., & Schellnhuber, H.J. (2008). Tipping elements in the Earth's climate system. *Proceedings of the National Academy of Sciences of the United States of America, 105*(6), 1786-1793. doi: 10.1073/Pnas.0705414105

Lioubimtseva, E., & Henebry, G.M. (2009). Climate and environmental change in arid Central Asia: Impacts, vulnerability, and adaptations. *Journal of Arid Environments, 73*(11), 963-977. doi: Doi 10.1016/J.Jaridenv.2009.04.022

Liu, J. P., Curry, J.A., Wang, H.J., Song, M.R., & Horton, R.M. (2012). Impact of declining Arctic sea ice on winter snowfall. *Proceedings of the National Academy of Sciences of the United States of America, 109*(11), 4074-4079. doi: 10.1073/Pnas.1114910109

Liu, J.P., Song, M., Horton, R.M., & Hu, Y. (2013). Reducing spread in climate model projections of a September ice-free Arctic. *Proceedings of the National Academy of Sciences.* doi: 10.1073/pnas.1219716110

Lobell, D.B., Burke, M.B., Tebaldi, C., Mastrandrea, M.D., Falcon, W.P., & Naylor, R.L. (2008). Prioritizing climate change adaptation needs for food security in 2030. *Science, 319*(5863), 607-610. doi: 10.1126/Science.1152339

Lorenzoni, I., & Pidgeon, N.F. (2006). Public views on climate change: European and USA perspectives. *Climatic Change, 77*(1-2), 73-95. doi: 10.1007/S10584-006-9072-Z

Loucks, C., Barber-Meyer, S., Hossain, M.A.A., Barlow, A., & Chowdhury, R.M. (2010). Sea level rise and tigers: predicted impacts to Bangladesh's Sundarbans mangroves. *Climatic Change, 98*(1-2), 291-298. doi: 10.1007/S10584-009-9761-5

MacCracken, M.C. (2009). On the possible use of geoengineering to moderate specific climate change impacts. *Environmental Research Letters, 4*(4). doi: 10.1088/1748-9326/4/4/045107

Major, D.C., & O'Grady, M. (2010) Adaptation Assessment Guidebook. *Climate change adaptation in New York City: Building a Risk Management Response,* C. Rosenzweig, and W. Solecki, Eds., New York Academies of Science 229-292.

Major, D.C., Zimmerman, R., Falcocchio, J., Jacob, K., Horton, R., O'Grady, M., Bader, D., Gilbride, J., & Tomczyszyn, T. (2011). Mainstreaming Climate Change Adaptation Strategies into New York State Department of Transportation's Operations: Final Report, NYSDOT Technical Working Group, NYSDOT Research Project C-08-09. New York.

McCright, A.M., & Dunlap, R.E. (2003). Defeating Kyoto: The conservative movement's impact on U.S. climate change policy. *Social Problems, 50*(3), 348-373. doi: 10.1525/Sp.2003.50.3.348

Meakin, S., & Kurvits, T. (2009). Assessing the Impacts of Climate Change on Food Security in the Canadian Arctic (pp. 48pp): GRID-Ardenal and UNEP.

Mertz, O., Halsnaes, K., Olesen, J.E., & Rasmussen, K. (2009). Adaptation to Climate Change in Developing Countries. *Environmental Management, 43*(5), 743-752. doi: 10.1007/S00267-008-9259-3

Mimura, M., Nurse, L., McLean, R.F., Agard, J., Briguglio, L., Lefale, P., Payet, P., & Sem, G. (2007). Small islands. In M.L. Parry, O.F. Canziani, J. P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 687-716). Cambridge, UK: Cambridge University Press.

Mooney, H., Larigauderie, A., Cesario, M., Elmquist, T., Hoegh-Guldberg, O., Lavorel, S., Mace, G.M., Palmer, M., Scholes, R., & Yahara, T. (2009). Biodiversity, climate change, and ecosystem services. *Current Opinion in Environmental Sustainability, 1*(1), 46-54. doi: 10.1016/J.Cosust.2009.07.006

Moser, S.C. (2009). Communicating Climate Change and Motivating Civic Action: Renewing, Activating, and Building Democracies. *Changing Climates in North American Politics: Institutions, Policymaking, and Multilevel Governance*, 283-302.

Nelson, D.R., Adger, W.N., & Brown, K. (2007). Adaptation to environmental change: Contributions of a resilience framework. *Annual Review of Environment and Resources, 32*, 395-419. doi: 10.1146/Annurev.Energy.32.051807.090348

Nerlich, B., Koteyko, N., & Brown, B. (2010). Theory and language of climate change communication. *Wiley Interdisciplinary Reviews-Climate Change, 1*(1), 97-110. doi: Doi 10.1002/Wcc.002

Nicholls, R.J., & Cazenave, A. (2010). Sea-Level Rise and Its Impact on Coastal Zones. *Science, 328*(5985), 1517-1520. doi: 10.1126/Science.1185782

Nicholls, R.J., Wong, P.P., Burkett, V.R., Codignotto, J.O., Hay, J.E., McLean, R.F., Ragoonaden, S., & Woodroffe, C.D. (2007). Coastal systems and low-lying areas. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 315-356). Cambridge, UK: Cambridge University Press.

Nicol, A., & Kaur, N. (2009). Adapting to climate change in the water sector. Overseas Development Institute Background Note. London, ODI.

Nisbet, M.C. (2009). Communicating Climate Change Why Frames Matter for Public Engagement. *Environment, 51*(2), 12-23.

Nogués-Bravo, D., Araújo, M.B., Errea, M.P., & Martínez-Rica, J.P. (2007). Exposure of global mountain systems to climate warming during the 21st Century. *Global Environmental Change, 17*(3–4), 420-428. doi: http://dx.doi.org/10.1016/j.gloenvcha.2006.11.007

Nordas, R., & Gleditsch, N.P. (2007). Climate Change and conflict. *Political Geography, 26*(6), 627-638.

Oates, N., Conway, D., & Calow, R. (2011). The 'mainstreaming' approach to climate change adaptation: insights from Ethiopia's water sector. Overseas Development Institute Background Note. London, ODI.

O'Brien, K., Eriksen, S., Sygna, L., & Naess, L.O. (2006). Questioning complacency: Climate change impacts, vulnerability, and adaptation in Norway. *Ambio, 35*(2), 50-56. doi: 10.1579/0044-7447(2006)35[50:Qccciv]2.0.Co;2

Olesen, J.E., Trnka, M., Kersebaum, K.C., Skjelvag, A.O., Seguin, B., Peltonen-Sainio, P., Rossi, F., Kozyra, J., & Micale, F. (2011). Impacts and adaptation of European crop production systems to climate change. *European Journal of Agronomy, 34*(2), 96-112. doi: 10.1016/J.Eja.2010.11.003

Pearce, T., Ford, J.D., Caron, A., & Kudlak, B.P. (2012). Climate change adaptation planning in remote, resource-dependent communities: an Arctic example. *Regional Environmental Change, 12*(4), 825-837. doi: 10.1007/S10113-012-0297-2

Peterson, T.C., & Manton, M.J. (2008). Monitoring Changes in Climate Extremes: A Tale of International Collaboration. *Bulletin of the American Meteorological Society, 89*(9), 1266-1271. doi: 10.1175/2008BAMS2501.1

Pidgeon, N., & Fischhoff, B. (2011). The role of social and decision sciences in communicating uncertain climate risks. *Nature Climate Change, 1*(1), 35-41. doi: 10.1038/Nclimate1080

Pörtner, H.O. (2008). Ecosystem effects of ocean acidification in times of ocean warming: a physiologist's view. *Marine Ecology Progress Series, 373*, 203-217. doi: 10.3354/Meps07768

Pryor, S.C., & Barthelmie, R.J. (2010). Climate change impacts on wind energy: A review. *Renewable & Sustainable Energy Reviews, 14*(1), 430-437. doi: 10.1016/J.Rser.2009.07.028

Ragab, R., & Prudhomme, C. (2002). SW–Soil and Water: Climate Change and Water Resources Management in Arid and Semi-arid Regions: Prospective and Challenges for the 21st Century. *Biosystems Engineering, 81*(1), 3-34. doi: http://dx.doi.org/10.1006/bioe.2001.0013

Rasch, P.J., Crutzen, P.J., & Coleman, D.B. (2008). Exploring the geoengineering of climate using stratospheric sulfate aerosols: The role of particle size. *Geophysical Research Letters, 35*(2). L02809.

Rawlani, A.K., & Sovacool, B.K. (2011). Building responsiveness to climate change through community based adaptation in Bangladesh. *Mitigation and Adaptation Strategies for Global Change, 16*(8), 845-863. doi: 10.1007/S11027-011-9298-6

Refsgaard, J.C., Arnbjerg-Nielsen, K., Drews, M., Halsnæs, K., Jeppesen, E., Madsen, H., Markandya, A., Olesen, JE., Porter, J.R., & Christensen, J.H. (2012). The role of uncertainty in climate change adaptation strategies–A Danish water management example. *Mitigation and Adaptation Strategies for Global Change*. doi: 10.1007/s11027-012-9366-6

Revi, A. (2008). Climate change risk: an adaptation and mitigation agenda for Indian cities. *Environment and Urbanization, 20*(1), 207-229. doi: 10.1177/0956247808089157

Ridgwell, A., Singarayer, J.S., Hetherington, A.M., & Valdes, P.J. (2009). Tackling Regional Climate Change By Leaf Albedo Bio-geoengineering. *Current Biology, 19*(2), 146-150. doi: http://dx.doi.org/10.1016/j.cub.2008.12.025

Rijsberman, F.R. (2006). Water scarcity: Fact or fiction? *Agricultural Water Management, 80*(1-3), 5-22. doi: 10.1016/J.Agwat.2005.07.001

Robock, A., Oman, L., & Stenchikov, G.L. (2008). Regional climate responses to geoengineering with tropical and Arctic SO2 injections. *Journal of Geophysical Research-Atmospheres, 113*(D16). D16101.

Rosenzweig, C., Jones, J.W., Hatfield, J.L., Ruane, A.C., Boote, K.J., Thorburn, P., Antle, J.M., Nelson, G.C., Porter, C. Janssen, S., Asseng, S., Basso, B., Ewert, F., Wallach, D., Baigorria, G., & Winter, J.M. (2013). The Agricultural Model Intercomparison and Improvement Project (AgMIP): Protocols and pilot studies. *Forest. Agr. Meteorol.*, 170, 166-182, doi:10.1016/j.agrformet.2012.09.011.

Rosenzweig, C., Solecki, W.D., Hammer, S.A., & Mehrotra, S. (2011). *Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network*: Cambridge University Press.

Rosenzweig, C., and Solecki, W. (2010). Climate Change Adaptation in New York City: Building a Risk Management Response. *Ann. New York Acad. Sci., 1196*, 13-18, doi:10.1111/j.1749-6632.2009.05306.x.

Ruhl, J.B. (2010). Climate Change Adaptation and the Structural Transformation of Environmental Law. *Environmental Law, 40*, 343.

Ruhl, J.B. (2011). General Design Principles for Resilience and Adaptive Capacity in Legal Systems: Applications to Climate Change Adaptation Law. *North Carolina Law Review*.

Russill, C., & Nyssa, Z. (2009). The tipping point trend in climate change communication. *Global Environmental Change, 19*(3), 336-344. doi: http://dx.doi.org/10.1016/j.gloenvcha.2009.04.001

Saavedra, C., & Budd, W.W. (2009). Climate change and environmental planning: Working to build community resilience and adaptive capacity in Washington State, USA. *Habitat International, 33*(3), 246-252. doi: 10.1016/J.Habitatint.2008.10.004

Salehyan, I. (2008). From climate change to conflict? No consensus yet. *Journal of Peace Research, 45*(3), 315-326. doi: 10.1177/0022343308088812

Schlenker, W., & Roberts, M.J. (2009). Nonlinear temperature effects indicate severe damages to US crop yields under climate change. *Proceedings of the National Academy of Sciences of the United States of America, 106*(37), 15594-15598. doi: 10.1073/Pnas.0906865106

Schmidhuber, J., & Tubiello, F.N. (2007). Global food Security under climate change. *Proceedings of the National Academy of Sciences (PNAS) of the United States of America, 104*(50), 19703-19708. doi: 10.1073/pnas.0701976104

Scott, J. M., Rachlow, J.L., & Lackey, R.T. (2008). The Science-Policy Interface: What Is an Appropriate Role for Professional Societies? *Bioscience, 58*(9), 865-869. doi: 10.1641/B580914

Sem, G. (2007). *Vulnerability and Adaptation to Climate Change in Small Island Developing States*. Paper presented at the Expert Meeting on Adaptation for Small Island Developing States, Kingston, Jamaica.

Semenov, M.A., & Stratonovitch, P. (2010). Use of multi-model ensembles from global climate models for assessment of climate change impacts. *Climate Research, 41*(1).

Seneviratne, S.I., Nicholls, N.,Easterling, D., Goodess, C.M., Kanae, S., Kossin, J., Luo, Y., Marengo, J., McInnes, K., Rahimi, M., Reichstein, M., Sorteberg, A., Vera, C., & Zhang, X. (2012). Changes in climate extremes and their impacts on the natural and physical environment. In C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.K. Plattner, S.K. Allen, M. Tignor & P.M. Midgley (Eds.), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* (pp. 109-230). Cambridge, UK: Cambridge University Press.

Shaw, S., Scheinder, R., McDonald, A., Riha, S., Tryhorn, L., Leichenko, R., Frei, A., & Montz, B. (2011). Water Resources. In C. Rosenzweig, W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol & P. Grabhorn (Eds.), *Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation in New York State* (Vol. 1244, pp. 80-118). New York: Annals of the New York Academy of Sciences.

Shepherd, J.G. (2009). *Geoengineering the climate: science, governance and uncertainty*: The Royal Society, London.

Smit, B., & Pilifosova, O. (2003). Adaptation to climate change in the context of sustainable development and equity. *Sustainable Development, 8*(9).

Solecki, W., Patrick, L., Brady, M., Grady, K., & Maroko, A. (2010). Climate Protection Level: Incorporating Climate Change into Design and Performance Standards. In C. Rosenzweig & W. Solecki (Eds.), *Climate Change Adaptation in New York City: Building a Risk Management Response:* (Vol. 1196, pp. 293-352): Annals of the New York Academy of Sciences.

Sovacool, B.K. (2011). Hard and soft paths for climate change adaptation. *Climate Policy, 11*(4), 1177-1183. doi: 10.1080/14693062.2011.579315

Sovacool, B.K. (2012). Expert views of climate change adaptation in the Maldives. *Climatic Change, 114*(2), 295-300. doi: 10.1007/S10584-011-0392-2

Sowers, J., Vengosh, A., & Weinthal, E. (2011). Climate change, water resources, and the politics of adaptation in the Middle East and North Africa. *Climatic Change, 104*(3-4), 599-627. doi: 10.1007/S10584-010-9835-4

Tanner, T., Mitchell, T., Polack, E., & Guenther, B. (2009). Urban Governance for Adaptation: Assessing Climate Change Resilience in Ten Asian Cities. *IDS Working Papers, 2009*(315), 01-47. doi: 10.1111/j.2040-0209.2009.00315_2.x

Temesgen, A.K. (2010). Climate Change to Conflict: Lessons from Southern Ethiopia and Northern Kenya. *FAFO Report*.

Tong, S., & McMichael, A.J. (2011). Climate Change and Health: Risks and Adaptive Strategies. In O. N. Editor-in-Chief: Jerome (Ed.), *Encyclopedia of Environmental Health* (pp. 690-698). Burlington: Elsevier.

Tonn, B. (2007). The intergovernmental panel on climate change: A global scale transformative initiative. *Futures, 39*(5), 614-618. doi: 10.1016/J.Futures.2006.10.010

United Nations Educational, Scientific, and Cultural Organization. (2011). Engineering the Climate: Research questions and policy implications *UNESCO-SCOPE-UNEP Policy Briefs No. 14*.

van Aalst, M.K. (2006). The impacts of climate change on the risk of natural disasters. *Disasters, 30*(1), 5-18. doi: 10.1111/J.1467-9523.2006.00303.X

van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G., Kram, T., Krey, V., Lamarque, J.F., Masui, T., Meinhausen, M., Nakicenovic, N., Smith, S.J., & Rose, S.K. (2011). The representative concentration pathways: an overview. *Climatic Change, 109*(1-2), 5-31. doi: 10.1007/S10584-011-0148-Z

Victor, D.G., Morgan, M.G., Apt, F., Steinbruner, J., & Ricke, K. (2009). The Geoengineering Option A Last Resort Against Global Warming? *Foreign Affairs, 88*(2), 64.

Vicuña, S., Leonardson, R., Hanemann, M. W., Dale, L.L., & Dracup, J.A. (2008). Climate change impacts on high elevation hydropower generation in California's Sierra Nevada: a case study in the Upper American River. *Climatic Change, 87*, S123-S137. doi: 10.1007/S10584-007-9365-X

Virgoe, J. (2009). International governance of a possible geoengineering intervention to combat climate change. *Climatic Change, 95*(1-2), 103-119. doi: 10.1007/S10584-008-9523-9

Wang, X.M., Chen, D., & Ren, Z.G. (2010). Assessment of climate change impact on residential building heating and cooling energy requirement in Australia. *Building and Environment, 45*(7), 1663-1682. doi: 10.1016/J.Buildenv.2010.01.022

Wardekker, J.A., van der Sluijs, J.P., Janssen, P.H.M., Kloprogge, P., & Petersen, A.C. (2008). Uncertainty communication in environmental assessments: views from the Dutch science-policy interface. *Environmental Science & Policy, 11*(7), 627-641. doi: 10.1016/J.Envsci.2008.05.005

Weber, E.U., & Stern, P.C. (2011). Public Understanding of Climate Change in the United States. *American Psychologist, 66*(4), 315-328. doi: 10.1037/A0023253

Werner, A.D., & Simmons, C.T. (2009). Impact of Sea-Level Rise on Sea Water Intrusion in Coastal Aquifers. *Ground Water, 47*(2), 197-204. doi: 10.1111/J.1745-6584.2008.00535.X

Wilbanks, T.J. (2010). Research and development priorities for climate change mitigation and adaptation: Oak Ridge National Laboratory (ORNL).

Wilbanks, T.J., & Sathaye, J. (2007). Integrating mitigation and adaptation as responses to climate change: a synthesis. *Mitigation and Adaptation Strategies for Global Change, 12*(5), 957-962.

Wolfe, D.W., Comstock, J., Lasko, A., Chase, L., Fry, W., Petzoldt, C., & Vancura, P. (2011a). Agriculture. In C. Rosenzweig, W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol & P. Grabhorn (Eds.), *Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation in New York State* (Vol. 1244, pp. 218-253). New York: Annals of the New York Academy of Sciences.

Wolfe, D.W., Comstock, J., Menninger, H., Weinstein, D., Sullivan, K., Kraft, C., Chabot, B., Curtis, P., & Vancura, P. (2011b). Ecosystems. In C. Rosenzweig, W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol & P. Grabhorn (Eds.), *Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation in New York State* (Vol. 1244, pp. 164-215). New York: Annals of the New York Academy of Sciences.

Wong, P.P. (2010). Small island developing states. *Wiley Interdisciplinary Reviews: Climate Change, 2*(1). doi: 10.1002/wcc.84

Yohe, G., & Leichenko, R. (2010). Adopting a risk-based approach In C. Rosenzweig & W. Solecki (Eds.), *Climate Change Adaptation in New York City: Building a Risk Management Response:* (Vol. 1196, pp. 29-40): Annals of the New York Academy of Sciences.

Zinn, M.D. (2007). Adapting to climate change: Environmental law in a warmer world. *Ecology Law Quarterly, 34*(1), 61-105.

Bibliography of Additional Sources

Adger, W.N., Agrawala, S., Mirza, M.M.Q., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit, B., & Takahashi, K. (2007). Assessment of adaptation practices, options, constraints, and capacity, *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 717-743), M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson, Eds., Cambridge, UK: Cambridge University Press.

Adger, W.N., Lorenzoni, I., & O'Brien, K.L. (2009). *Adapting to Climate Change: Thresholds, Values, Governance.* Cambridge, UK: Cambridge University Press.

Africa Partnership Forum. (2007). *Climate Change and Africa.* Paper presented at the 8th Annual Meeting of the African Partnership Forum, Berlin, Germany.

Alcamo, J., Moreno, J.M., Novaky, B., Bindi, M., Corobov, R., Devoy, R.J.N., Giannakopoulos, C., Martin, E., Olesen, J.E., & Shvidenko, A. (2007). Europe. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 541-580). Cambridge, UK: Cambridge University Press.

Anisimov, O.A., Vaughan, D.G., Callaghan, T.V., Furgal, C., Marchant, H., Prowse, T.D., Vilhjálmsson, H., & Walsh, J.E.. (2007). Polar regions (Arctic and Antarctic), In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 653-685). Cambridge, UK: Cambridge University Press.

Babuggura, A. (2010). Gender and Climate Change: South Africa Case Study. Cape Town: Heinrich Böll Stiftung Southern Africa.

Berrang-Ford, L., Ford, J.D., & Paterson, J. (2011). Are we adapting to climate change? *Global Environmental Change, 21*(1), 25-33. doi: 10.1016/j.gloenvcha.2010.09.012

Bhutiyani, M.R., Kale, V.S., & Pawar, N.J. (2009). Climate change and the precipitation variations in the northwestern Himalaya: 1866–2006. *International Journal of Climatology, 30*(4), 535-548.

Blum, M.D., & Roberts, H.H. (2009). Drowning of the Mississippi Delta due to insufficient sediment supply and global sea-level rise. *Nature Geosci, 2*(7), 488-491.

Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Osman-Elasha, B., Tabo, R., & Yanda, P. (2007). Africa. In M.L. Parry, O.F. Canziani, J. P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 433-467). Cambridge, UK: Cambridge University Press.

Brody, A., Demetriades, J., & Esplen, E. (2008). Gender and climate change: mapping the linkages - A scoping study on knowledge and gaps (27pp). Brighton, UK: BRIDGE Institute of Development Studies.

Brown, O. (2008). Migration and Climate Change *IOM Migration Research Series*. Geneva: International Organization for Migration.

Cardona, O.D., van Aalst, M.K., Birkmann, J., Fordham, M., McGregor, G., Perez, R.T., Pulwarty, R.S., Schipper, E.L.F., & Sinh, B.T. (2012). Determinants of risk: exposure and vulnerability. In C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.K. Plattner, S.K. Allen, M. Tignor & P.M. Midgley, (Eds.,), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* (pp. 65-108), Cambridge, UK: Cambridge University Press.

Carter, J.G. (2011). Climate change adaptation in European cities. *Current Opinion in Environmental Sustainability, 3*(3), 193-198.

Carter, T.R., Jones, R.N., Lu, X., Bhadwal, S., Conde, C., Mearns, L.O., O'Neill, B.C., Rounsevell, M.D.A., & Zurek, M.B. (2007). New Assessment Methods and the Characterisation of Future Conditions. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 133-171). Cambridge, UK: Cambridge University Press.

Carter, T. (2009). *Some thoughts on IAV community Cooperation.* Paper presented at the Workshop on Climate Change Impacts, Adaptation, and Vulnerability (IAV) Community Coordination, Boulder, CO.

Claessens, L., Antle, J. M., Stoorvogel, J. J., Valdivia, R.O., Thornton, P.K., & Herrero, M. (2012). A method for evaluating climate change adaptation strategies for small-scale farmers using survey, experimental and modeled data. *Agricultural Systems, 111*(0), 85-95. doi: http://dx.doi.org/10.1016/j.agsy.2012.05.003

Craft, C., Clough, J., Ehman, J., Joye, S., Park, R., Pennings, S., & Machmuller, M. (2008). Forecasting the effects of accelerated sea-level rise on tidal marsh ecosystem services. *Frontiers in Ecology and the Environment, 7*(2), 73-78.

Cruz, R.V., Harasawa, H., Lal, M., Wu, S., Anokhin, Y., Punsalmaa, B., Honda, Y., Jafari, M., Li, C., & Huu Ninh, N. (2007). Asia. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 469-506). Cambridge, UK: Cambridge University Press.

Daze, A., Ambrose, K., & Ehrhart, C. (2009). *Climate Vulnerability and Capacity Analysis Handbook*

Denzer, R., Schlobinski, S., & Gidhagen, L. (2011). *A Decision Support System for Urban Climate Change Adaptation.* Paper presented at the System Sciences (HICSS), 2011 44th Hawaii International Conference on Systems Sciences.

Dessai, S. (2009). *Research gaps in adaptation*. University of Exeter.

Di Falco, S., Veronesi, M., & Yesuf, M. (2011). Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *American journal of agricultural economics, 93*(3), 829-846.

Dinar, A., Hassan, R., Mendelsohn, R., & Benhin, J. (2012). *Climate change and agriculture in Africa: impact assessment and adaptation strategies*: Routledge.

Dodman, D., Bicknell, J., & Satterthwaite, D. (2012). *Adapting Cities to Climate Change: Understanding and addressing the development challenges*: Routledge.

Doherty, S.J., Bojonski, S. , Henderson-Sellers, A., Noone, K. , Goodrich, D., Bindoff, N.L.,Church, J.A., Karl, T.R., Kajfez-Bogataj, L., Lynch, A.H., Parker, D.E., Prentice, I.C., Ramaswamy, V., Saunders, R.W., Smith, M.S., Steffen, K., Stocker, T.F., Thorne, P.W., Verstraete, M.M., & Zwiers, F.W. (2009). Lessons Learned from IPCC AR4: Scientific Developments Needed to Understand, Predict, and Respond to Climate Change. *Bulletin of the American Meteorological Society, 90*(4), 497-513.

Eamus, D., & Palmer, A.R. (2008). Is climate change a possible explanation for woody thickening in arid and semi-arid regions? *International Journal of Ecology, 2007*.

Easterling, W.E., Aggarwal, P.K., Batima, P., Brander, K.M., Erda, L., Howden, S.M., Kirilenko, A., Morton, J., Soussana, J.F., Schmidhuber, J., & Tubiello, F.N. (2007). Food, fibre, and forest products. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 273-313). Cambridge, UK: Cambridge University Press.

Eriksen, S., Aldunce, P., Bahinipati, C.S., Martins, R.D.A., Molefe, J.I., Nhemachena, C., O'Brien, K., Olorunfemi, F., Park, J., Sygna, L., & Ulsrud, K. (2011). When not every response to climate change is a good one: Identifying principles for sustainable adaptation. *Climate and development, 3*(1), 7-20.

Field, C.B., Mortsch, L.D., Brklacich, M., Forbes, D.L., Kovacs, P., Patz, J.A., Running, S.W., & Scott, M.J. (2007). North America. In M.L. Parry, O. F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 617-652). Cambridge, UK: Cambridge University Press.

Food and Agriculture Organization of the United Nations. (2007). People-centered climate change adaptation: Integrating gender issues.

Food and Agriculture Organization of the United Nations. (2010). Climate-Smart Agriculture: Policies, Practices and Financing for Food Security, Adaptation, and Mitigation (41pp)

Fundación Futuro Latinoamericano. (2008). Consultation to Assess Regional Priorities, Capabilities and Research Gaps on Climate Change and Poverty Reduction in Latin America and the Caribbean (114pp). Quito, Ecuador.

Fünfgeld, H., & McEvoy, D. (2011). Framing climate change adaptation in policy and practice *Climate change adaptation program: Global Cities Institute*. Melbourne.

Füssel, H.M. (2007). Vulnerability: A generally applicable conceptual framework for climate change research. *Global Environmental Change, 17*(2), 155-167. doi: 10.1016/j.gloenvcha.2006.05.002

Gelbspan, R., Hertsgaard, M., & Scherr, S. (2009). *The Adaptation Imperative: Food Security and Climate Change*, New York, NY.

Gender CC: *Women for Climate Justice*. (2010). Gender and Climate Change Research: Gaps and Questions, Bonn, Germany.

Gero, A., Méheux, K., & Dominey-Howes, D. (2011). Integrating community based disaster risk

reduction and climate change adaptation: examples from the Pacific. *Natural Hazards and Earth System Sciences, 11*(1), 101-113.

Gerrard, Michael B. (2007). What the Law and Lawyers Can and Cannot Do About Global Warming. *Se. Envtl. LJ, 16*, 33.

Giannini, A., Biasutti, M., & Verstraete, M.M. (2008). A climate model-based review of drought in the Sahel: Desertification, the re-greening and climate change. *Global and Planetary Change, 64*(3–4), 119-128. doi: http://dx.doi.org/10.1016/j.gloplacha.2008.05.004

Greiving, S., & Fleischhauer, M. (2012). National Climate Change Adaptation Strategies of European States from a Spatial Planning and Development Perspective. *European Planning Studies, 20*(1), 27-48.

Guan, L. (2009). Preparation of future weather data to study the impact of climate change on buildings. *Building and Environment, 44*(4), 793-800. doi: http://dx.doi.org/10.1016/j.buildenv.2008.05.021

Harries, T., & Penning-Rowsell, E. (2011). Victim pressure, institutional inertia and climate change adaptation: The case of flood risk. *Global Environmental Change, 21*(1), 188-197. doi: http://dx.doi.org/10.1016/j.gloenvcha.2010.09.002

Heltberg, R., & Bonch-Osmolovskiy, M. (2011). Mapping vulnerability to climate change *Policy Research Working Paper Series*: The World Bank.

Hennessy, K., Fitzharris, B., Bates, B.C., Harvey, N., Howden, S.M., Hughes, L., Salinger, J., & Warrick, R. (2007). Austrailia and New Zealand. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C. E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 507-540). Cambridge, UK: Cambridge University Press.

Huang, C., Vaneckova, P., Wang, X., FitzGerald, G., Guo, Y., & Tong, S. (2011). Constraints and Barriers to Public Health Adaptation to Climate Change: A Review of the Literature. *American Journal of Preventive Medicine, 40*(2), 183-190. doi: http://dx.doi.org/10.1016/j.amepre.2010.10.025

Huq, S., & Ayers, J. (2007). Critical list: the 100 nations most vulnerable to climate change. London: IIED Sustainable Development Opinion.

Huq, S., & Toulmin, C. (2009). Three eras of climate change. IIED sustainable development opinion. http://www. iied. org/pubs/pdfs/11060IIED

IPCC (2009). *Chapter Outline of the Working Group II Contribution to the IPCC Fifth Assessment Report.* Paper presented at the Thirty-first Session of the IPCC, Bali

IPCC. (2009). *Scoping Meeting for the IPCC 5th Assessment Report.* Paper presented at the AR5 Scoping Meeting, Venice, Italy.

International Council for Science (ICSU). (2010). Regional Environmental Change: Human Action and Adaptation - What does it take to meet the Belmont Challenge? (23pp). Paris.

Kiem, A.S., & Austin, E.K. (2012). *Barriers to effective implementation of positive climate change adaptation: Disconnects between science, policy and stakeholders.* Paper presented at the Climate Change 2012: Water and Climate: Policy Implementation Changes; Proceedings of the 2nd Practical Responses to Climate Change Conference, 1-3 May 2012, Canberra.

Klein, R.J.T. (2009). Identifying Countries that are Particularly Vulnerable to the Adverse Effects of Climate Change: An Academic or a Political Challenge? *Carbon & Climate Science Law Review, 3*, 284-291.

Klein, R.J.T., & Möhner, A. (2011). The Political Dimension of Vulnerability: Implications for the Green Climate Fund. *IDS Bulletin, 42*(3), 15-22. doi: 10.1111/j.1759-5436.2011.00218.x

Laczko, F., & Warner, K. (2008). *Research Priorities and Gaps: Migration & the Environment.* Paper presented at the Conference on International Migration and Development, New York, NY.

Lahsen, M., Sanchez-Rodriguez, Lankao, P.R., Dube, P., Leemans, R., Gaffney, O., Mirza, M., Pinho, P., Osman-Elasha, B., & Smith, M.S. (2010). Impacts, adaptation and vulnerability to global environmental change: challenges and pathways for an action-oriented research agenda for middle-income and low-income countries. *Current Opinion in Environmental Sustainability, 2*(5–6), 364-374. doi: http://dx.doi.org/10.1016/j.cosust.2010.10.009

Laukkonen, J., Blanco, P.K., Lenhart, J., Keiner, M., Cavric, B., & Kinuthia-Njenga, C. (2009). Combining climate change adaptation and mitigation measures at the local level. *Habitat International, 33*(3), 287-292. doi: http://dx.doi.org/10.1016/j.habitatint.2008.10.003

Leemans, R., Asrar, G., Busalacchi, A., Canadell, J., Ingram, J., Larigauderie, A., Mooney, H., Nobre, C., Patwardhan, A., Rice, M., Schmidt, F., Seitzinger, S., Virji, H., Vorosmarty, C., & Young, O. (2009). Developing a common strategy for integrative global environmental change and outreach: The Earth System Science Partnership (EESP). *Current Opinion in Environmental Sustainability, 1*(1), 4-13. doi: 10.1016/j.cosust.2009.07.013

Leighton, M. (2010). Climate Change Migration: Key Issues for Legal Protection of Migrants and Displaced Persons (12pp).

Lubchenco, J. (1998). Entering the Century of the Environment: A New Social Contract for Science. *Science, 279*(5350), 491-497.

Ludwig, F., Droogers, P., van der Valk, M., van Schaik, H., & Kabat, P. (2012). *Climate change adaptation in the water sector*: Routledge.

Magrin, G., Gay Garcia, C., Cruz Choque, D., Gimenez, J.C., Moreno, A.R., Nagy, G.J., Nobre,C., & Villamizar, A. (2007). Latin America. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 581-615). Cambridge, UK: Cambridge University Press.

Mansur, E.T., Mendelsohn, R., & Morrison, W. (2008). Climate change adaptation: A study of fuel choice and consumption in the US energy sector. *Journal of Environmental Economics and Management, 55*(2), 175-193. doi: http://dx.doi.org/10.1016/j.jeem.2007.10.001

Meehl, G.A. (2009). *ESM Perspectives on IAV and Coordination with Other Groups.* Paper presented at the Workshop on Climate Change Impacts, Adaptation and Vulnerability (IAV) Community Coordination, Boulder, CO.

Moss, R.H., Edmonds, J. A. , Hibbard, K.A., Manning, M.R., Rose, S.K., van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F., Nakicenovic, N., Riahi, K., Smith, S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P., & Wilbanks, T.J. (2010). The next generation of scenarios for climate change research and assessment. *Nature, 463*, 747-756. doi: 10.1038/nature08823

Norman, B. (2009). Principles for an intergovernmental agreement for coastal planning and climate change in Australia. *Habitat International, 33*(3), 293-299. doi: http://dx.doi.org/10.1016/j.habitatint.2008.10.002

O'Brien, K., Pelling, M., Patwardhan, A., Hallegatte, S., Maskrey, A., Oki, T., Oswald-Spring, U., Wilbanks, T., & Yanda, P.Z. (2012). Toward a sustainable and resilient future. In C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.K. Plattner, S.K. Allen, M. Tignor & P.M. Midgley (Eds.), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* (pp. 437-486), Cambridge, UK: Cambridge University Press.

Palutikof, J. (2009). *Some TSU reflections on the AR4 and onward.* Paper presented at the Workshop on Climate Change Impacts, Adaptation and Mitigation (IAV) Community Coordination, Boulder, CO.

Pandey, R., & Jha, S.K. (2012). Climate vulnerability index - measure of climate change vulnerability to communities: a case of rural Lower Himalaya, India. *Mitigation and Adaptation Strategies for Global Change, 17*(5), 487-506. doi: 10.1007/s11027-011-9338-2

Pelling, M. (2010). *Adaptation to climate change: from resilience to transformation*: Taylor & Francis US.

Pelling, M., High, C., Dearing, J., & Smith, D. (2008). Shadow spaces for social learning: a relational understanding of adaptive capacity to climate change within organisations. *Environment and Planning A, 40*(4), 867-844. doi: 10.1068/a39148

Perrson, A., & Klein, R.J.T. (2008). Mainstreaming Adaptation to Climate Change into Official Development Assistance: Integration of Long-term Climate Concerns and Short-term Development Needs (16pp). Stockholm: Stockholm Environment Institute.

Reid, W.V., Chen, D., Goldfarb, L., Hackmann, H., Lee, Y.T., Mokhele, K., Ostrom, E., Raivio, K., Rockström, J., Schellnhuber, H.J., & Whyte, A. (2010). Earth System Science for Global Sustainability: Grand Challenges. *Science, 330*(6006), 916-917.

Romero-Lankao, P. (2009). *IAV: challenges and future steps.* Paper presented at the Workshop on Climate Change Impacts, Adaptation and Vulnerability (IAV) Community Coordination, Boulder, CO.

Rosenzweig, C., Casassa, G., Karoly, D.J., Imeson, A., Liu, C., Menzel, A., Rawlins, S., Root, T.L., Seguin, B., & Tryjanowski, P. (2007). Assessment of observed changes and responses in natural and managed systems. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 391-431). Cambridge, UK: Cambridge University Press.

Rosenzweig, C. (2009). *IAV Directions and Challenges: NAS Workshop Perspectives.* Paper presented at the Workshop on Climate Change Impacts, Adaptation and Vulnerability (IAV) Community Coordination, Boulder, CO.

Roser-Renouf, C., & Maibach, E. (2010). Communicating climate change. *Encyclopedia of Science and Technology Communication*, 141-147. Salzman, J., & Ruhl, J.B. (2013). Climate Change Meets the Law of the Horse. *Duke Law Journal, 62*(5), 975-1027.

Samson, J., Berteaux, D., McGill, B.J., & Humphries, M.M. (2011). Geographic disparities and moral hazards in the predicted impacts of climate change on human populations. *Global Ecology and Biogepgraphy, 20*(4), 532-544. doi: 10.1111/j.1466-8238.2010.00632.x

Scherler, D., Bookhagen, B., & Strecker, M. R. (2011). Spatially variable response of Himalayan glaciers to climate change affected by debris cover. *Nature Geoscience, 4*(3), 156-159.

Schneider, S.H., Semenov, S., Patwardhan, A., Burton, I., Magadza, C.H.D., Oppenheimer, M., Pittock, A.B., Rahman, A., Smith, J.B., Suarez, A., & Yamin, F. (2007). Assessing key vulnerabilities and the risk from climate change. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 779-810). Cambridge, UK: Cambridge University Press.

Smith, J.B., Schneider, S.H., Oppenheimer, M., Yohe, G.W., Hare, W., Mastrandrea, M.D., Patwardhan, A., Burton, I., Corfee-Morlot, J., Magadza, C.H.D., Füssel, H.M., Pittock, A.B., Rahman, A., Suarez, A., & van Ypersele, J.P. (2009). Assessing dangerous climate change through an update of the Intergovernmental Panel on Climate Change (IPCC) "reasons for concern". *Proceedings of the National Academy of Sciences*. doi: 10.1073/pnas.0812355106

Snoussi, M., Ouchani, T., & Niazi, S. (2008). Vulnerability assessment of the impact of sea-level rise and flooding on the Moroccan coast: The case of the Mediterranean eastern zone. *Estuarine, Coastal and Shelf Science, 77*(2), 206-213. doi: http://dx.doi.org/10.1016/j.ecss.2007.09.024

Stark, J., Mataya, C., & Lubovich, K. (2009). Climate Change, Adaptation, and Conflict: A Preliminary Review of the Issues (40pp): United States Agency for International Development.

Suarez, P., Anderson, W., Mahal, V., & Lakshmanan, T.R. (2005). Impacts of flooding and climate change on urban transportation: A systemwide performance assessment of the Boston Metro Area. *Transportation Research Part D: Transport and Environment, 10*(3), 231-244. doi: http://dx.doi.org/10.1016/j.trd.2005.04.007

Thomalla, F., Downing, T., Spanger-Siegfried, E., Han, G., & Rockstrom, J. (2006). Reducing hazard vulnerability: towards a common approach between disaster risk reduction and climate adaptation. *Disasters, 30*(1), 39-48. doi: 10.1111/j.1467-9523.2006.00305.x

Tin, T., Ainley, D., Barnes, J.N, & Hajost, S. (2010). Climate Change and Ecosystems. In A.A. Perez, B.H. Fernandez & R.C. Gatti (Eds.), *Building Resilience to Climate Change: Ecosystem-based adaptation and lessons from the field.*

United Nations Framework Convention on Climate Change. (2007a). *Climate change: impacts, vulnerability and adaptation in developing countries* (68pp).

United Nations Framework Convention on Climate Change. (2007b). Synthesis of outcomes of the regional workshops and expert meetings on adaptation under decision 1/CP.10. Bonn.

United Nations Framework Convention on Climate Change. (2012a). *Implementing adaptation: Calendar of workshops and meetings*. Retrieved December 24th, 2012, from http://unfccc.int/adaptation/implementing_adaptation/items/3582.php

United Nations Framework Convention on Climate Change. (2012b). *Nairobi work programme on impacts, vulnerability and adaptation to climate change (NWP) - Understanding Vulnerability, fostering adaptation*. Retrieved December 24th, 2012, from http://unfccc.int/adaptation/nairobi_work_programme/items/3633.php

United Nations Framework Convention on Climate Change. (2012c). Sixth Compilation and synthesis of initial national communications. *Compilation and Synthesis Reports*. Retrieved December 24th, 2012, from http://unfccc.int/national_reports/non-annex_i_natcom/compilation_and_synthesis_reports/items/2709.php

United Nations Framework Convention on Climate Change (2012d). *Panel Discussion on Climate Methods and Tools: availability, applicability, accessibility and training opportunities*.

United Nations General Assembly. (2008). Background Paper-Climate Change and the Most Vulnerable Countries: The Imperative to Act (8pp): United Nations.

United Nations High Commissioner for Refugees. (2011). Climate Change and Displacement: Identifying Gaps and Responses Expert Roundtable (4pp).

United Nations Institute for Training and Research (UNITAR). (2010). *Environmentally Induced Migration and Climate Change*, New York, NY.

United Nations Women Watch. (2009). F*act Sheet: Women, Gender Equality and Climate Change.*

Urwin, K., & Jordan, A. (2008). Does public policy support or undermine climate change adaptation? Exploring policy interplay across different scales of governance. *Global Environmental Change, 18*(1), 180-191. doi: 10.1016/j.gloenvcha.2007.08.002

Verner, D. (2010). *Reducing Poverty, Protecting Livelihoods, and Building Assets in a Changing Climate*. Washington, DC: The World Bank.

Visser, M.E. (2008). Keeping up with a warming world; assessing the rate of adaptation to climate change. *Proceedings of the Royal Society of Biological Sciences, 275*(1635), 649-659. doi: 10.1098/rspb.2007.0997

Wheeler, D. (2011). Quantifying vulnerability to climate change: implications for adaptation assistance.

Center for Global Development Working Paper (240).

Wilbanks, T.J., Romero Lankao, P., Bao, M., Berkhout, F., Cairncross, S., Ceron, J.P., Kapshe, M., Muir-Wood, R., & Zapata-Marti, R. (2007). Human health. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 357-390). Cambridge, UK: Cambridge University Press.

World Meteorological Organization. (2008). Future Climate Change Research and Observations: GCOS, WCRP and IGBP Learning from the IPCC Fourth Assessment Report-Workshop and Survey Report (57pp).

World Meteorological Organization. (2009). High-Level Taskforce towards the Global Framework for Climate Services (GFCS). Retrieved December 25th, 2012, from http://www.wmo.int/hlt-gfcs/

Yohe, G.W., Lasco, R.D., Ahmad, Q.K., Arnell, N.W., Cohen, S.J., Hope, C., Janetos, A.C., & Perez, R.T. (2007). Perspectives on climate change and sustainability. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 811-841). Cambridge, UK: Cambridge University Press.

Zhang, L., Luo, R., Hongmei, Y., & Tyler, S. (2008). *Climate Adaptation in Asia: knowledge Gaps and Research Issues in China Final Report to IDRC and DFID* (40pp): Centre for Chinese Agricultural Policy (CCAP), Chinese Academy of Sciences (CAS), Institute for Social and Environmental Transition (ISET), Institute of Geographic Sciences and Natural Resources Research (IGSNRR).

The Programme of Research on Climate Change Vulnerability, Impacts and Adaptation (PROVIA) is a global scientific initiative seeking to provide direction and coherence at the international level for research on climate change vulnerability, impacts and adaptation (VIA). Launched with the support of leading scientists and decision-makers, PROVIA responds to the urgent call for a more cohesive and coordinated research approach and the critical need to harmonize, mobilize and communicate the growing knowledge-base on VIA. PROVIA also acts as a growing network of scientists, practitioners and decision-makers working towards identifying research gaps and meeting policy needs in climate change VIA research. PROVIA is a component of the World Climate Programme.

The PROVIA Secretariat is currently hosted by the United Nations Environment Programme in Nairobi, Kenya.

www.unep.org/provia

provia@provia-climatechange.org

UNEP

PROVIA
PROGRAMME OF RESEARCH ON CLIMATE CHANGE VULNERABILITY, IMPACTS AND ADAPTATION

PROVIA PROGRAMME OF RESEARCH ON CLIMATE CHANGE VULNERABILITY, IMPACTS AND ADAPTATION

www.unep.org

United Nations Environment Programme
P.O. Box 30552 - 00100 Nairobi, Kenya
Tel.: +254 20 762 1234
Fax: +254 20 762 3927
e-mail: uneppub@unep.org
www.unep.org

UNEP

To respond to the demand for better coordination of research, PROVIA has led the development of a set of Research Priorities on vulnerability, impacts and adaptation in consultation with both experts and policymakers. The Research Priorities include new and emerging topics, the importance of which is now coming into focus, and topics that have long been recognized as important but for which research is still required. The Priorities reflect the balance between research 'supply' from experts and research 'demand' from policymakers.

www.unep.org/provia

United Nations Environment Programme
PROVIA SECRETARIAT
P.O. Box 30552, Nairobi 00100, Kenya · Tel: +254 20 7623231
E-mail: provia@provia-climatechange.org

IISBN: 978-92-807-3317-4
Job Number: DEW/1631/NA