Understanding urban vulnerability, adaptation and resilience in the context of climate change

Forthcoming in Local Environment: the international journal of justice and sustainability, June 2013
Pre-publication final draft deposited at Durham University Research Online, May 2013

Harriet Bulkeley* and Rafael Tuts+

*Department of Geography, Durham University, South Road, Durham, DH1 3LE

+ Rafael Tuts, Coordinator, Urban Planning and Design Branch, United Nations Human Settlements Programme, UN-HABITAT, P.O. Box 30030, Nairobi 00100, Kenya

Abstract

This paper opens a special issue of *Local Environment* that has arisen through collaboration between academic researchers and the Urban Planning and Design Branch of UN-Habitat, focused on how we can understand and respond to the challenges of urban vulnerability, adaptation and resilience in the context of climate change. The paper establishes the existing state of art in the field, and considers critical challenges that are emerging in the research-based literature. In this context, it introduces UN-Habitat's Cities and Climate Change Initiative and reflects on the lessons learnt and challenges ahead, in order to provide the context for the papers in the special issue. In conclusion, it identifies the role of international/transnational co-operation, the relation between adaptation and mitigation, issues of multilevel governance, and the ways in which change in urban socio-technical systems might be achieved as critical issues across the science/policy interface where increased dialogue and the co-production of knowledge needs to focus in order to advance this agenda.

Keywords

Climate change, vulnerability, adaptation, resilience, governance, UN-Habitat

Introduction

Since the issue first came to be a matter of scientific and policy attention in the late 1980s, debates surrounding how climate change should be addressed have focused on the challenge of mitigation – of reducing the levels of greenhouse gases in the atmosphere. International negotiations, national policies and the individual and collective efforts of cities and communities have focused on how and by whom emissions reductions should take place, and how this can be achieved in cost effective, efficient and equitable manner. These debates have proven to be complex and intractable, and while there is evidence of progress in terms of national and local successes in emissions reductions, global emissions continue to rise at an alarming rate. The continued challenge of mitigating climate change therefore remains central to any effort to address climate change. Over the past decade, however, there has been a growing recognition that alongside mitigation, issues of vulnerability and adaptation to climate change need to be addressed. At the international level, the growing engagement with issues of adaptation has emerged as a result of growing scientific consensus about the extent and impacts of climate change, on the one hand, and the shifting politics of the international regime on the other.

Given current levels of atmospheric GHG emissions and the distant prospects for significant emissions reductions in the short term, the climate science community has argued that some degree of climate change is inevitable. In their 2007 Fourth Assessment Report, the IPCC suggested that the 'warming of the climate system is now unequivocal', providing evidence of changing snow and ice coverage, sea level rise, changing patterns of precipitation and increasing temperatures (IPCC 2007). At the same time as the scientific understanding of climate impacts has evolved, as the international climate regime has shifted from one dominated by the concerns of Europe and North America, to one in which emerging economies, particularly those of India, China and Brazil, have come to the fore. In this context, and through complex and contested processes, the long-standing concerns of the least developed countries that the impacts of climate change should be taken into account have been reinvigorated. At the 2007 Conference of the Parties to the UNFCCC (COP) in Bali, adaptation was recognised as a critical pillar of any post-2012 international agreement and an Adaptation Fund established, while at the 2010 Cancun COP the Cancun Adaptation Framework was adopted, containing the declaration that "adaptation must be addressed with the same priority as mitigation and requires appropriate institutional arrangements to enhance adaptation action and support" (UNFCCC 2010: 3). While mitigation remains the dominant issue on the international agenda, it is clear that adapting to climate change has become firmly established as critical to any international response.

It is within this context of a shifting and contested international policy landscape that urban responses to the issues of climate vulnerability, adaptation, and resilience are emerging. In the early 1990s, as the international community began to develop policy frameworks, targets and mechanisms through which to address climate change mitigation, municipalities also sought to establish their own responses to the climate change agenda. As adapting to the impacts of climate change becomes recognised within scientific and policy communities as a central part of responding to the issue, so too have cities and communities sought to develop their own strategies and interventions to address these issues. Whereas initial efforts by municipalities to respond to climate change in the early 1990s often went unnoticed by the climate change research and policy community at large, over the past two decades the mobilisation of urban responses to climate change has meant that they are now recognised as a significant and legitimate part of the climate governance response (Betsill and Bulkeley 2007; Bulkeley 2010). This conjunction, of a growing recognition of the importance of urban responses to climate change and the increasing significance adaptation, raises interesting possibilities and challenges. What might climate vulnerability, adaptation and resilience mean in the urban context? How, why, by and for whom are interventions taking place to address these issues? What are the roles of different actors and agencies in responding to these issues, and what challenges do they face? Who wins, and who loses, from efforts to address vulnerability, adaptation and resilience in cities? This special issue of *Local Environment*, undertaken in collaboration between researchers at Durham, UCL and Kampala Universities and UN-Habitat, seeks to start to address these questions. Drawing on the experience of UN-Habitat and their partners in cities in Asia, Africa and Latin America, the papers explore how urban climate vulnerability, adaptation and resilience are being framed, the ways in which responses are taking place, and the consequences for the possibilities and limits of intervention. Drawing on a range of research traditions that have sought to understand the dynamics of urban vulnerability and resilience, they suggest new ways in which the challenges of climate change could be considered, and collectively contribute to the development of new research agendas in this field.

In the remainder of this paper, we set the scene for this special issue. In the first section, we consider how climate vulnerability, adaptation and resilience have emerged within the urban climate change policy agenda. We suggest that while concerns for addressing disasters in cities have a long history, the climate change agenda is creating new forms of urban response which both build upon these traditions and challenge them in important ways. In a similar fashion to early urban responses to

mitigation, a patchwork of responses, focused in some particular cities and gathering around transnational initiatives, is emerging in which the links between responding to disasters and addressing climate change are being configured in a variety of ways. There is, then, no one size fits all approach to climate vulnerability, adaptation and resilience. In the second section, we consider the different ways in which vulnerability and adaptation are being articulated across this varied landscape. Drawing on the framework advanced by Pelling (2011), we suggest that the ways in which vulnerability is being conceived is leading to a variety of framings of adaptation – as resilience, as transition, and as transformation. Each of these framings of adaptation comes with its own challenges, and we discuss how these are emerging at the urban scale. In the third section, we introduce UN-Habitat's Cities and Climate Change Initiative, the programme from which the case-studies analysed in the following papers are drawn. While the CCCI programme has made several advances in terms of addressing the urban adaptation agenda, through, for example, integration of urban climate change adaptation in urban development strategy development and in professional education curricula, significant challenges remain, including breaking through policy silos and raising awareness in countries that do not experience the dramatic impacts of climate change how to . These advances and challenges are explored in detail through the papers in this special issue. In the fourth section, we briefly introduce the papers and their core arguments, before concluding with some reflections on future research and policy challenges in this field.

Climate change adaptation: an emerging agenda?

Adapting to changing environmental conditions is "nothing new. Individuals and socio-ecological systems have always responded to external pressures" (Pelling 2011: 6). Adapting to climate change, does, however, raise new challenges. The IPCC defines adaptation as an "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC 2007b). By this account, any form of response to climatic impacts might be regarded as adaptation. However, the literature suggests that an important distinction can be drawn between those responses through which individuals and communities 'cope' with climatic (and other) risks, and adaptation. While coping involves "existing strategies that are used by urban residents to respond to climate variability and other threats" (Dodman et al. 2011: 6), adaptation requires more explicit deliberation on and efforts to change the practices and institutions through which risks are mediated and responses are framed (Pelling 2011: 21). While urban populations have a long history of coping with the risks of climate-related events, purposeful forms

of intervention which seek to reduce risk and adapt to changing climatic conditions are much more recent in origin. One means through which such interventions have been manifest is through various forms of Disaster Risk Reduction (DRR), a term used to describe the ways in which authorities and communities respond to the potential, onset and aftermath of disasters and risk (Solecki et al. 2011). Strategies and measures for DRR can either be general in scope, or focused on specific sectors and risks (e.g. flood risk measures, heatwave emergency plans). Given the common concern of DRR and climate change adaptation with addressing vulnerability to climate-related risks, some have suggested that adaptation can be regarded as simply an extension of existing DRR approaches (Mercer 2010) or regard them as interchangeable (Satterthwaite 2011). Others, however, point to enduring differences between DRR and the aspirations of climate change adaptation, suggesting for example that disaster risk planning remains based on the understanding of hazard and risk within specific locations and on the basis of the historical incidence of risk, failing to integrate longer-term horizons or the changing nature of risks in relation to climate change, while climate change risks remain rather abstract at the local scale (Birkmann and Teichman 2010; Solecki et al. 2011). Each field is also characterised by different norms concerning how and to what effect interventions should take place, and the sorts of considerations that should be taken into account in development and redevelopment efforts (Birkmann and Teichman 2010). While there are many potential areas for development and synergy between these two agendas, particularly in terms of engaging the long history within the DRR field of engaging communities (Satterthwaite 2011; Solecki et al. 2011), it is clear that assuming that urban climate change adaptation can simply be added to existing DRR agendas is problematic.

It is perhaps because of such institutional and normative differences between existing forms of DRR in cities and the emerging climate change adaptation agenda that initial urban climate adaptation responses by early adopters have not emerged from within urban DRR institutions, but have instead been generated either through the existing environmental departments of municipal authorities, the Mayor's office, or by specific institutions established to formulate adaptation responses (Anguelovski and Carmin 2011: 170; Birkmann et al. 2011: 189). Analysis of early adopters, including Boston, Cape Town, Durban, Halifax, Ho Chi Minh City, London, New York, Quito, Rotterdam, Toronto, and Singapore, who began to develop climate change adaptation strategies and measures in the early 2000s suggests the process of establishing climate change adaptation on urban agendas has often been initiated by undertaking assessments of the potential impacts of climate change in the city (Anguelovski and Carmin 2011; Birkmann et al. 2011). As Anguelovski and

Carmin (2011: 170) explain, in the absence of significant exogenous drivers for action or norms for urban planning and action, cities have tended to mimic "the sequential and inventory-based approach taken to mitigation by initiating their adaptation processes with risk and vulnerability assessments." In New York, for example, several processes have been initiated in order to assess the potential impacts of climate change on the city and to develop responses, including the 2004 New York City Regional Heat Island Initiative sponsored by the New York State Energy Research and Development Authority and in the same year the establishment by the New York City Department of Environmental Protection (NYCDEP) of a Climate Change Task Force. Both processes involved the development of collaboration between scientists and policy-makers in the city, with the goal of downscaling models of climate change in order to assess potential impacts in the city and to identify potential solutions (Corburn 2009; Rosenzweig et al. 2007).

While such assessments are a common first stage in urban adaptation responses, the ways in which strategies and measures have subsequently been designed varies significantly (Anguelovski and Carmin 2011). In some cases of early adopters, standalone strategies for adaptation have been created. In Europe, this is the case in Copenhagen, Rotterdam and London (Carter 2011: 195, and in North America, in Toronto, while in other cities, adaptation has been integrated as part of existing mitigation strategies, such as in Manchester and Madrid (Carter 2011), while in cities such as New York and Quito, adaptation has been integrated with other urban development and planning agendas (Anguelovski and Carmin 2011). In Durban, initial assessments of the impacts of climate change lead to the development of the 2006 *Headline Climate Change Adaptation Strategy* which intended to identify urban responses across a range of sectors including health, water and sanitation, waste, food security, planning, economic development and disaster risk reduction (Roberts 2010). In so doing, significant variations in interest and capacity for addressing climate change were encountered, with the result that while useful lessons were learnt "it ultimately stimulated no new adaptation actions" (Roberts 2010: 410). Rather than developing an integrated adaptation strategy, the Environmental Planning and Climate Protection Department sought instead to develop sector specific adaptation plans as a practical means through which to overcome obstacles of scarce resources and the lack of political will. In essence, rather than building an integrated approach through which to foster climate change adaptation, the goal became that of building "increased resilience one adaptation intervention at a time" (Roberts 2010: 401). Even where similar processes of developing climate change assessments, establishing leading agencies, and developing urban planning strategies have taken place, these examples suggest that amongst early adopters there is

significant variation both in terms of how climate adaptation is being framed and how responses are taking place in practice. This variation is important for it suggests that there are multiple pressures shaping the ability of cities to respond to climate vulnerability and adaptation, such that any one size fits all approach is unlikely to be successful. At the same time, by taking account of how such variation has shaped policy outcomes, it may be possible to evaluate which kinds of approach are more or less likely to be successful in achieving particular goals.

Beyond the activities of these early adopters, evidence that the climate change adaptation agenda is becoming widespread at the urban level is limited. The 2011 UN Global Report on Human Settlements concluded from its review of the state of the research field that "most of the literature on climate change adaptation and cities is focusing on what should be done, not on what is being done (because too little is being done)" (UN Habitat 2011 p.145). Nonetheless, over the past five years there is evidence of a growing interest in the adaptation agenda amongst transnational municipal networks and international agencies. In 2006, ICLEI Local Governments for Sustainability, who pioneered the Cities for Climate Protection programme in the early 1990s put the issue of climate change adaptation on their international policy agenda, and together with the World Mayor's Council on Climate Change launched a series of annual conferences on Resilient Cities in 2010. ICLEI's regional offices have also developed adaptation programmes. For example, in 2010, ICLEI Oceania launched a 'next generation' climate change programme for local authorities, which seeks to develop mitigation and adaptation in tandem and includes the development of an 'adaptation toolkit' to facilitate municipal responses to the adaptation agenda.[1] Launched in 2008 and funded by the Rockefeller Foundation, the Asian Cities Climate Change Resilience Network comprises 10 cities in India, Vietnam, Thailand and Indonesia[2] and focuses specifically on issues of adaptation and resilience. Across each of these networks, the focus is currently on the development of knowledge and capacity building for adaptation, as well as on the initiation of pilot projects through which to test new approaches and develop learning.

At the same time, there is evidence that international agencies and donor organisations, such as the United Nations, Asian Development Bank[3] and the World Bank, are beginning to engage with the urban adaptation agenda and that this is increasingly linked to other more long standing concerns.

[1] See: http://www.iclei.org/index.php?id=oceania-ccp-ia and http://www.iclei.org/index.php?id=adaptation-toolkit0
[2] Gorakhpur, Indore and Surat (India); Can Tho, Da Nang and Quy Nhon (Vietnam); Bandar Lampung and Semarang (Indonesia) and Chiang Rai and Hat Yai (Thailand).
[3] See: http://beta.adb.org/sites/default/files/pccp-information-update-03.pdf

Since 2009, the United Nations International Strategy for Disaster Reduction (UNISDR) has campaigned together with its partners to encourage disaster risk reduction action by cities and local governments. While adaptation to climate change is a key objective of the campaign, it fits within the broader framework of The Hyogo Framework for Action 2005- 2015 which aims at "Building the Resilience of Nations and Communities to Disasters" and offers solutions for local governments and local actors to manage and reduce urban risk. The campaign proposes a Ten-point checklist of Ten Essentials for Making Cities Resilient to serve as a guide for commitment by Mayors.[4] By signing up the campaign, Mayors commit, to put in place a disaster risk reduction coordination mechanism, assign a budget for disaster risk reduction, prepare risk assessments, invest in critical infrastructure, upgrade schools and health centres, enforce building regulations and land use planning principles, ensure education and training are in place, protect ecosystems, install early warning systems, and ensure the adoption of a people-centred post disaster response approach. So far, 968 cities have signed up to the campaign (22 January 2012). A monitoring system is maintained by ISDR to track the level of implementation by campaign members. While some of the commitments can be achieved relatively easy through Municipal Council resolution and budget revision, others require significant allocation of human and financial resources that has to date proven hard to come by even in those cities pioneering action in this field. One of the challenges of the campaign is to set up an effective mechanism to respond to the capacity development implications that arise from the commitments. As discussed further below, UN Habitat's Cities and Climate Change Initiative has also sought to engage a range of municipalities with the climate change adaptation agenda through developing capacity and piloting new approaches for responding to this agenda in a range of cities.

Reflecting this growing international interest, the Durban Adaptation Charter for Local Governments (Table 1) was adopted in December 2011 on the occasion of the *Durban Local Government Convention: adapting to a changing climate*[5] The Charter as initiated by South African governmental actors and ICLEI – Local Governments for Sustainability, on the occasion of the UNFCCC Durban Climate Change Conference in late 2011. The Charter was signed by 114 mayors from over 28 countries, including "New Delhi, Dar Es Salaam, Banjul, Lagos, Windhoek, Thimpu, Dakar, Vancouver, Buenos Aires and Cape Town."[6] While the 10 commitments in the Charter have certain similarities with the "Essentials" of the Making Cities Resilient campaign (assessment,

[4] The Checklist builds on the priorities identified in the *Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters* - www.unisdr.org/hfa
[5] See: http://www.iclei.org/fileadmin/user_upload/documents/Global/initiatives/LG_roadmap___COP_17_files/Durban_Adaptation_Charter_5Dec.pdf
[6] See: http://www.iclei.org/?id=12503 and http://www.capetown.gov.za/en/Pages/CityplaysleadingroleindraftingDAC.aspx

adaptation strategy, ecosystems services, etc.) the Charter is pitched at a higher, more strategic level. It includes, for instance, linkages with mitigation, international financing, measuring and multi-level governance, and an emphasis on the need for an inclusive and equitable process of decision-making. As the charter includes multi-level commitments that cannot be achieved alone by actions of individual cities, the monitoring of the Charter will necessarily also require multiple levels of monitoring.

Table 1: Durban Adaptation Charter

By signing up to the Durban Adaptation Charter, Mayors and local government leaders commit to:

- **mainstream adaptation as a key informant of all local government development planning;**
- **conduct impact and vulnerability assessments;**
- **prepare and implement integrated, inclusive and long-term local adaptation strategies;**
- **ensure that adaptation strategies are aligned with mitigation strategies;**
- **promote the use of adaptation that recognises the needs of vulnerable communities and ensures sustainable local economic development;**
- **prioritise the role of functioning ecosystems as core municipal green infrastructure;**
- **seek the creation of direct access to funding opportunities;**
- **develop an acceptable, robust, transparent, measureable, reportable and verifiable register[7];**
- **advocate for partnerships with sub-national and national governments;**
- **and promote partnerships at all levels and city-to-city cooperation and knowledge exchange.**

Together, these initiatives suggest that interest and engagement with the climate change agenda is moving beyond the initial early adopters to encompass a range of other cities. In each case, new toolkits and approaches are being developed that seek on the one hand to build capacity and on the other to standardise responses to climate change adaptation. At the same time, the long-standing distinction between climate change mitigation and adaptation is becoming blurred through the creation of common policy frameworks and the framing of urban responses in terms of climate resilience. As this new agenda for addressing vulnerability, adaptation and resilience begins to take shape, it is therefore important to consider how these critical concepts are being framed and interpreted, and the consequent implications for how, by and for whom, urban responses to climate change are being developed. The Resilient Cities Congress, organized by ICLEI in collaboration with a large group of other international partners, offers a suitable annual forum to reflect on the

[7] The idea behind this register is to monitor commitments to adaptation, and it is similar to the "MRV" spirit of climate change mitigation, i.e. to make adaptation Measurable, Reportable and Verifiable. The idea is that whereas city actions are voluntary, for these voluntary commitments to be credible they need to be MRV compliant. This is particularly important if adaptation is to become a more important part of financial resources related to climate change action. The Charter also specifies that the "MRV systems should reflect the local context in which adaptation takes place".

achievements of both the Making Cities Resilient campaign and the Durban Adaptation Charter. It remains to be seen how these two promising international advocacy initiatives can help to articulate a stronger role of cities and local governments in the emerging international climate change architecture including the adaptation window of the Green Climate Fund.

From adaptation to resilience and beyond: concepts and challenges

While the potential impacts of climate change in cities are increasingly recognised, determining their consequences entails moving beyond assessments to risk to engaging with the nature and dynamics of urban vulnerability. At one level, vulnerability can be conceived in terms of the ways in which climate change may either alter the exposure of urban populations and assets to weather-related risks or may herald new forms of risk (Hanson et al. 2011). However, vulnerability to climate change cannot be divorced from existing social, economic and environmental challenges facing cities, as vulnerability, and the capacity to adapt, is produced through the processes through which climate risks coalesce "with other stresses, such as scarcity of water or governance structures that are inadequate even in the absence of climate change" (Wilbanks et al. 2007: 373). The standard definition of vulnerability, as the "degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change including climate variability and extremes" and existing "as a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity and its adaptive capacity" adopted by the IPCC draws attention to the ways in which it is produced through the interaction of physical and social processes and to the importance of 'adaptive capacity' in determining vulnerability. Adaptive capacity, in turn, is highly varied within and between urban areas, and shaped by a range of social and physical attributes (Adger et al. 2005; Eakin et al. 2010). These in turn are regarded as "dependent on underlying structures of vulnerability such as levels of poverty, entitlements to assets and willingness to innovate" (Jones and Boyd 2011: 1263), and by what might be termed adaptation deficits, such as the absence of basic infrastructure systems and service provision, functioning governance structures, or political stability (Satterthwaite 2011). Rather than regarding urban climate vulnerability as a discrete phenomenon, this suggests that it is produced through historical and contemporary processes of urbanization. For example, in Mexico City, Romero-Lankao (2010: 111) demonstrates how successive "decisions regarding infrastructure provision have been maintained and consolidated in a manner that benefits wealthy zones and contributes to a pattern of unequal spatial access to water", in turn shaping the livelihoods, urban conditions and infrastructure systems through which the impact of climate change on water

availability and flooding are now mediated. In this volume, for example, (SI Author C) show how the impacts of climate change on local bio-physical systems will pose fundamental challenges to the urban economic development of cities in West Africa, in Kampala, (SI Author A to be added after review) shows how existing patterns of waste disposal serve to exacerbate the impacts of rainfall events, while in the Philippines (SI Author D) document the intersection between urban poverty and vulnerability. Understanding urban vulnerability under conditions of climate change is therefore not only a matter of enhancing knowledge about the potential risks and impacts posed by the changing climate system, but of engaging with the often historically complex and politically contentious factors that structure vulnerability more broadly as well as with the complex trajectories of development. At the same time, as (Author D) argue, in examining vulnerability we need to be mindful of its highly socially differentiated occurrence within and between cities.

Given the challenges of conceptualizing vulnerability, it is perhaps hardly surprising that what constitutes adaptation is subject to multiple and conflicting interpretations. Despite the growing shift away from the straightforward concern for climate impacts and towards more fundamental concerns for vulnerability, Manuel-Naverette et al. (2011: 249) argue that "international organizations and governments usually conceive adaptation to climate hazards in terms of expert-led risk management; that is, as managerial strategies to cope with hazards" and design and develop interventions accordingly. Parallel to such responses, an "alternative approach focused on reducing the vulnerability of the poor through development" is increasingly advocated by NGOs and academics and "gaining currency amongst international organizations" (Manuel- Naverette et al. 2011: 249). Where such challenges are pressing and the need for interventions that can both manage climate risk and address poverty are required, such as in the case of Kampala, it is easy to see why there are increasing calls for this kind of intervention (SI Author A to be added). Equally, the imperative of putting principles for addressing adaptation into legal frameworks may also serve to cement these sorts of approaches (SI Author B to be added). However, and despite the significant differences between these positions, Manuel-Naverette et al. (2011: 250) suggest that they are both rooted in a tradition of 'problem solving' theory, focused on delivering incremental change and failing to engage with "the possibilities for radical socio-political change." At the heart of these debates are questions about how and to what ends adaptation might be undertaken – what is it that adaptation should be seeking to achieve? At the urban level, across both the managerialist and developmental approaches to adaptation identified by Manuel-Naverette et al., there has been a growing interest in the notion of resilience as the basis for achieving adaptation, in part because it is seen as a term that can also be

used to advance mitigation agendas (Leichenko 2011: 164). The concept of resilience has intellectual roots in the study of ecological systems, but within the "broad array of urban resilience literatures" it is "typically understood as the ability of a system to withstand a major shock and maintain or quickly return to normal function" (Leichenko 2011: 164).

Yet despite these broadly common concerns, there is significant disagreement about the "characteristics that define resilience and the appropriate analytical unit for the measurement of resilience" (Leichenko 2011: 164). In its most straightforward interpretation, resilience has been considered as the "opposite of vulnerability. The more resilient, the less vulnerable" but "this belies the complexity of the conceptual relationship between these two terms" (Pelling 2011: 42). The flexibility of the intellectual origins of the term, and the diverse ways in which it has evolved, means that resilience can involve "resistance and maintenance" where political authorities seek to resist the notion that fundamental or significant change is required and maintain existing systems, "change at the margins" where risk is acknowledged and the some of the symptoms of risk are addressed in so far as they do not threaten existing orders, or "openness and adaptability" where the root causes of risk are addressed in a flexible manner that is able to address uncertainty (Pelling 2011: 43-44). Within the climate change arena, it has been the narrower version of resilience that has currently gained most currency. The IPCC, for example, refers to resilience as a system which can absorb disturbance and retain structure whilst maintaining its ability to adapt to stress and change. For Pelling (2011: 55), this suggests that resilience can be considered as one form of adaptation that "seeks to secure the continuation of a desired systems functions into the future in the face of changing context, through enabling alteration in institutions and organisational form." It is perhaps both the chameleon-like quality, and potential for accommodation between the status quo and concerns for enhancing adaptive capacity, that have lent resilience its support across a wider range of actors. However, regarded in these terms, resilience offers a largely incremental approach to adaptation.

In seeking to develop an alternative account of adaptation, Pelling identifies two additional forms of adaptation that go beyond resilience to address the more structural causes of vulnerability. Transitional adaptation "is targeted at reform in the application of governance" (Pelling 2011: 69), recognising the fundamental role that forms of governance have in structuring the ways in which problems are framed, solutions implemented, and rights and responsibilities shared. For Pelling (2011: 82) "opportunities for transition arise when adaptations, or efforts to build adaptive capacity,

intervene in relationships between individual political actors and the institutional architecture that structures governance regimes." A further form of adaptation may emerge where it operates as a "mechanism for progressive and transformational change that shifts the balance of political or cultural power in a society" (Pelling 2011 p.84). Rather than being concerned with the "proximate causes" of adaptation, such as infrastructures, livelihood planning and so on, transformation is "concerned with the wider and less easily visible root causes of vulnerability" (Pelling 2011: 86) Rather than being autonomous or contradictory forms of adaptation, Pelling conceives of resilience, transition and transformation as levels of adaptation that are interconnected so that changes at one level may create opportunities at another. Equally, he recognises that "on the ground mosaics of adaptation are generated from the outcomes of overlapping efforts to build (and resist) resilience, transition and local transformative change and remaining unmet vulnerabilities" and shift over time in response to dynamics of risk and adaptive capacity" (Pelling 2011: 24).

Such an account of adaptation is useful because it moves beyond concerns with how adaptation might be achieved, to raise more fundamental challenges about what it is that adaptation, and resilience, enable as well as their shortcomings and limitations. As discourses and interventions to address urban vulnerability and further adaptation start to engage with the notion of resilience, Pelling's analysis sounds a useful cautionary note as to whether such a vocabulary is capable of advancing approaches which move beyond problem solving approaches that seek to reduce risk and limit exposure on the one hand, or enhance adaptive capacity and address development goals on the other (Manuel-Naverette et al. 2011). Advancing more transitional or transformational approaches to adaptation may require a further engagement with a "critical adaptation agenda" one which "sees the experiencing of hazards as essentially political and tied to contingent development paths." (Manuel-Naverette et al. 2011: 250). From this perspective, understanding the limits and opportunities for adaptation entails examining "the conflicts arising between visions of development, and how these conflicts create possibilities for altering development paths, transforming governance structures, and generating coping strategies" (Manuel-Naverette et al. 2011: 250). While an 'incremental' approach to climate change adaptation does not require fundamental changes in local government planning, management and governance systems, a more 'radical' or transformative approach to climate change adaptation will require fundamental changes in these systems. This in turn suggests that if cities are to take adaptation to climate change seriously, a fundamental rethink of urban planning as a tool to support adaptation and promote sustainable development is required. Adaptation strategies such as working with urban ecosystems to prepare for increased flooding or changing urban form to cope

with urban heat island effects require fundamentally new ways of conceptualizing how cities develop and grow. Cities preparing for long term adaptation will also need to start engaging differently with communities, particularly those living in vulnerable settlements. This is particularly relevant when displacement is unavoidable to minimize risks of disasters on sites that are threatened by climate change impacts. Acting on climate change adaptation increases the urgency to address these sensitive political issues. These are radical changes, for which the implications for urban governance are profound. One implication is the necessity to improve multi-level governance systems. This is particularly important for the adaptation agenda as many adaptation measures require 'zooming out' from the city level to the city-region level, where causes and consequences of climate change impacts can be viewed more holistically. Recent events in Rio de Janeiro and Bangkok point to the necessity to consider multiple territorial scales when framing local climate change adaptation. Furthermore, a shift from an incremental to a radical approach to adaptation poses fundamental changes in the ways in which planners practice their profession and engage with policy-makers, as well as requiring significance political will and long term vision in challenging existing forms of urban development. While achieving such radical changes in how resilience is conceptualized and urban development enacted are therefore critically dependent on the nature and process of urban governance, they also need to confront other drivers of urban settlement, including migration, the nature of markets for land and labour, and the recognition afforded to informal settlements.

Addressing vulnerability, adaptation and resilience in practice: the UN-Habitat Cities and Climate Change Initiative[8]

UN-Habitat launched its Cities and Climate Change Initiative (CCCI) in 2008 to support small- and medium-sized cities in developing countries to become more resilient to climate change and embrace low-carbon growth trajectories. CCCI is developing, adapting and making available methodologies that provide city managers and practitioners with guidelines on how to cope best with climate change. In particular, it seeks to support the development of pro-poor and innovative approaches for the implementation of climate change policies and strategies in selected developing countries. The initiative was built on the urban environmental planning and management experiences and networks developed between 1992 and 2008 through the UN-HABITAT Sustainable Cities Programme and the Localising Agenda 21 Programme.

[8] This section is based on a review of selected internal UN-Habitat documents on the Cities and Climate Change Initiative. The lessons learned are based on reflections by the inter-divisional team that supports the Initiative.

The Cities and Climate Change Initiative has four key objectives: (1) to promote active climate change collaboration between local governments and their associations; (2) to enhance policy dialogue so that climate change is firmly established on the agenda; (3) to support local governments in making climate-sensitive changes; and (4) to foster awareness, education, and capacity-building strategies that support the implementation of climate change strategies. CCCI emphasizes practical initiatives and governance issues for municipalities and their citizens. To achieve its objectives, climate change networks at the global, regional, national and city levels are supported. The networks include national governments, local government associations, non-governmental bodies, universities, the private sector, and UN organizations. They help to enhance awareness of climate change issues and the dissemination of knowledge among key actors. CCCI also supports education, capacity building and the localization and implementation of national adaptation and mitigation strategies. In particular, CCCI works with local authorities to strengthen their capacities to integrate climate change concerns in local and city-wide planning and budgeting for cost-effective policy responses.

Implementation of the CCCI started in 2008 with four pilot cities: Esmeraldas in Ecuador, Kampala in Uganda, Maputo in Mozambique and Sorsogon City in the Philippines. It has since grown to include work with cities in more than 20 countries. These cities have carried out assessments of their vulnerabilities to climate change as well as greenhouse gas emissions profiles. This includes an analysis of the existing institutional framework to address climate change and an analysis of the stakeholders currently involved in addressing climate change. Based on these assessments, climate change action plans have been developed and are being implemented, addressing a wide range of issues, including landslides, flooding, see level rise, mobility, housing, livelihoods and disaster risk reduction. The aim of CCCI is to move in a participatory manner from initial broad-brush assessments of climate change risks, to in-depth assessments of priority topics such as flood risk, to climate change strategies, to demonstration projects and institutional mainstreaming. CCCI also shares knowledge related to secondary cities in developing countries with decision-makers and researchers, supports local officials in lobbying for improved climate change frameworks, collaborates with other organisations in proposing global standards, and promotes improved education for planners and capacity-building for local officials on the topic of cities and climate change.

To carry out its activities, the Initiative has mobilised funding from various sources (including Norway, Sweden, UN Development Account, Cities Alliance, etc.) for a total of about US$ 7 million covering the period 2008-2011. Some examples of the achievements include the following:

- Building on a pilot initiative in Sorsogon, CCCI has supported the Government of Philippines to implement those aspects of its Climate Change Act that pertain to local governments, while mainstreaming climate change into the national urban planning framework
- Maputo is adopting a more thorough urban environmental approach to managing environmentally sensitive areas in the city
- Lami City in Fiji is preparing for sea level rise and storm surges through integrating an ecosystems based approach to adaptation in its urban planning and management systems
- Capacities of urban youth groups in Kampala, Mombasa and Kigali were strengthened and livelihood prospects were improved through applying 'green teams' approach to climate change adaptation.
- Encouraged by CCCI, three new countries in Africa have launched Green Building Councils to promote environmentally sustainable building practices
- Drawing on UN-Habitat experiences, the Africa Association of Planning Schools has developed and is using the curriculum "Climate Change and African Cities in Planning Education".
- The World Bank, UN-Habitat and UNEP jointly launched a common Urban Risk Assessment Methodology as part of a Joint Work Programme supported by the Cities Alliance

Throughout this process, challenges have been encountered and valuable lessons have been learnt. A first set of issues concerns how climate change is placed on local agendas and the ways in which assessment of climate change risks is undertaken. The CCCI has found that climate change concentrate minds on addressing issues of urban risk and vulnerability in some cities more than in others. Sorsogon City in the Philippines, for example, suffers from frequent cyclones of devastating magnitude. In a small coastal city like this, climate change will capture attention. In an inland city like Kampala, Uganda, on the other hand, climate change may be lower on the policy agenda. In such cities finding additional entry points for promoting sustainable urban development may be necessary. Given these different political priorities, and the challenges of data availability and impact assessment, developing useful climate change assessments which can be acted upon is at least a two-step process. It seems to work better, firstly, to carry out a broad-brush assessment which identifies major issues, and then, secondly, to carry out in-depth follow-on assessments in areas that the initial assessment identified as priorities and which may also suit local political agendas.

A second set of issues relates to how climate change is integrated into existing forms and structures of multilevel urban governance. Integrating climate change within land use and development plans at the urban level requires strong links with national climate change and planning policy, and the development of a clear framework. This in turn means that consultation over adaptation at the urban level also needs to include selected national stakeholders. These processes can act as a useful means of bridging communities of experts and policy-makers who work on climate change and urban policy, who are often undertaking decision-making in policy 'silos'. CCCI and similar programmes can play a useful role in fostering better communications across these communities, leading to improved policy frameworks for addressing the urban aspects of climate change. At the same time, international frameworks for addressing climate change are evolving rapidly, and improved forms of multilevel and transnational communication can assist municipalities in engaging with important new institutions that are framing debates and funding opportunities for cities, including the Adaptation Fund, the National Adaptation Plans and the Green Climate Fund.

Beyond issues of assessment and the development of appropriate forms of multilevel governance, the CCCI found a third set of challenges and opportunities. There is a need to promote awareness of climate change among the general public and stakeholders in order to foster political support for action. Furthermore, it is crucial for the business sector to engage with climate change agendas, for they play a vital role in providing green building technology development and in promoting risk-resilient communities through the use of appropriate and innovative technologies in housing and infrastructure development. Galvanising this kind of engagement means that in addition to supporting reform of laws and practices, it is critical to identify and support change agents, across the public and private sectors, who can innovate and develop responses through, for example, building construction and water management. Finally, the experience of CCCI suggests that it is often unwise, and frequently impossible, to divorce mitigation actions from adaptation measures. This has significant implications for current structures of global funding where such distinctions are the norm. Urban realities suggest instead that the two agendas are much more closely intertwined. The ecosystems services provided by a wetlands or forest close to an urban area may yield both mitigation and adaptation benefits. Likewise if new houses are being built to better withstand flooding, it also makes sense to ensure that those structures also encourage more efficient use of water and energy. Based on these initial experiences, CCCI has identified the following niche areas within the field of cities and climate change where it can offer most added value in the coming years:

- ***Integrate disaster risk reduction and climate change adaptation considerations.*** Cities' interest in participating in CCCI is mostly driven by their need for disaster reduction. This is echoed in the global trend to converge policies of disaster risk reduction and climate change adaptation. This would require intensified collaboration with other agencies, including UN-ISDR on coordinated and comprehensive strategies that integrate disaster risk reduction and climate change adaptation considerations.
- ***Assisting small- and medium-sized cities in developing countries to address climate change.*** Small- and medium-sized cities represent some of the most rapidly growing urban areas on the planet. While climate change will affect such cities just as severely as larger conurbations, the capacity of the smaller cities to respond generally will be more limited. This niche of small- and medium-sized cities in developing countries is relatively neglected by other agencies.
- ***Using urban planning and management as entry points to tackle climate change.*** Urban planning and management provide a suite of tools to confront climate change. Urban planning helps to put a long-term developmental lens on disaster preparedness and response efforts. Building codes encourage the use of mature technologies to reduce GHG emissions and increase the flood resistance of buildings. Multi-sectoral participatory planning can effectively underpin and integrate sectoral investment.
- ***Addressing the urban poverty aspects of climate change.*** CCCI pays particular attention to those who are most vulnerable to climate change: the urban poor. Poor families are more likely to live in vulnerable areas, but enjoy less access to adaptive resources than do other populations. Some other programmes, concerned with different aspects of climate change adaptation, overlook the urban poverty dimension.
- ***Facilitating city access to adaptation funding.*** Another area where CCCI perceives a need is in helping cities link up with funding agencies to access resources for climate change adaptation measures. Given that the rules and requirements for adaptation funding are still to be determined, the playing field for providing assistance in this area fairly open compared to that for helping developing countries finance mitigation projects. At the same time cities find it difficult to navigate through the evolving financial landscape to obtain funds. There is therefore an opportunity and a need to consider alternative funding mechanisms.
- ***Supporting national-local policy dialogue.*** As a UN agency with a dual operational and normative mandate, UN-Habitat sees an important role to play in supporting national-local policy dialogue, to help ensure that law-makers carve out a substantial role for cities in climate

change-related legislation. UN-Habitat is well positioned to feed lessons learned at the local level into global policy dialogue related to climate change.

- ***Using climate change adaptation as an entry point to promote broader innovation in urban planning.*** Support to climate change adaptation should go beyond sectoral and conventional actions. It should question the prevailing urban planning and design practices in specific countries. In many countries, current urban development patterns are locking in significant future adaptation costs that could be reduced by re-thinking urban spatial structures, investing in green and blue infrastructure, and exploring synergies between urban water, food and energy systems. UN-Habitat is well placed to build partnerships with other agencies to advocate for such a broader approach to urban adaptation planning.

Conclusions: towards a collaborative research and policy agenda

In this opening paper of a special issue of *Local Environment* dedicated to the themes of urban vulnerability, adaptation and resilience, we have outlined the contours of existing debates and policy initiatives. In conclusion, we reflect on the core issues that are emerging at the intersection of these fields, and consider their implications for research and policy agendas. First, we can clearly identify the growing international momentum surrounding urban climate change adaptation. Transnational municipal networks that have historically been engaged with issues of climate change mitigation, basic urban services and disaster risk reduction have come to regard adaptation as central to their work, while international agencies are increasingly promoting urban adaptation and climate resilience. On the one hand, this holds much promise, in the form of initiatives to develop capacity, funding opportunities, and political support. On the other hand, the plethora of initiatives coupled with the rapidly shifting national and international contexts within which urban responses are being forged will mean that municipal governments and other urban actors are developing adaptation responses in an ever more complex landscape. Previous research has suggested that as transnational municipal networks gain momentum, they can become dominated by particular 'leaders' in the field, offering support and opportunity to a relatively small number of cities (Kern and Bulkeley 2009). Given the importance of working across municipal divides at the city-region scale and of engaging with small and medium sized cities where capacity constraints and adaptation challenges may be severe, it is important that the international policy and research communities consider how such

forms of support can be developed in a manner that does not become dominated by the usual suspects.

Second, as the experience of CCCI to date has found, the divide between adaptation and mitigation may be both unwise and impossible on the ground as different actors seek to advance new forms of 'climate resilient' urban development. As (Author C to be added) show, long term strategies that seek to address both mitigation and adaptation are emerging on the ground and have achieved some policy traction. However, at the national and international levels these divisions are strong and hardwired into political negotiations and funding opportunities. To date, it has been mitigation, with the possibilities of more readily quantifiable targets and actions, that has attracted the most significant resources. Understanding how adaptation agendas may be advanced through similar approaches, and the ways in which mitigation actions may also offer adaptation benefits is an important research and policy task. At the same time, it is critical to realise the implications for both mitigation and adaptation of this focus on interventions that can be readily measured: in other words, to consider what it is that is *not* being done that ought to be being addressed because of the dominance of the quantification and verification agenda.

Third, the body of research that has developed around the question of urban responses to climate change has drawn attention to the importance of the multilevel governance context in which this is taking place (Bulkeley and Betsill 2003; Bulkeley 2010; Corfee-Morlot et al. 2011). The experience of UN-Habitat's CCCI in seeking to advance urban adaptation and resilience is no exception. There are significant challenges here, given that international and national adaptation agendas are largely dominated by concerns regarding rural adaptation, and because of the close relation between forms of urban and rural resilience (Author D to be added). This suggests that simply opening up better channels of communication between existing urban, national and international policy arenas will not be sufficient, but rather that some new institutional forums may be needed that bring together a range of urban interests operating across scales and between neighbouring municipalities (see also SI Author A to be added after review). As (Author B to be added) show, the integration of principles of climate change adaptation into national frameworks can provide a progressive context for urban responses, but it can also serve to disempower local responses. At the same time, it is clear that while existing government institutions are vital to creating the capacity for urban adaptation they may also serve to maintain the existing interests in urban political economies that obstruct more transformative, radical forms of adaptation. While extensive processes of community consultation

and engagement are evident across the cities discussed in this special issue (Author C), the extent to which this can be really empowering depends on whether it is possible to challenge existing power relations. Here, there is a critical role for external organisations, including universities, international agencies, private and civil society organisations, to work with municipalities to transform principles and practices of urban planning and development in order to enable more radical approaches to emerge.

A final, related, issue concerns how change and transformation can be fostered at the urban level. UN-Habitat's CCCI has identified the important role of 'change agents', in public and private organisations, in catalysing novel approaches and ways of intervening in cities and towns that promote climate change adaptation. Likewise, the Urban Transitions and Climate Change project at Durham University has also identified 'climate change experiments' as central to urban responses to both mitigation and adaptation (Bulkeley and Castan Broto 2012). These findings suggest that rather than focusing only on *policy* change, municipalities and other actors concerned with urban climate change responses need to recognise that the possibilities for achieving adaptation and resilience can come in many forms. These can include technical and social innovations that may not be ready to be formally regulated, but can have a significant effect on norms and social practices within an urban area, or particular projects or technologies that can spread through peer-to-peer learning within professions or through markets. Understanding and leveraging such change agents is a critical policy and research agenda. As (Author D) argue, it may be that where such interventions are focused on 'quick wins' they detract attention from the broader scale challenges of responding to climate change. This in turn means that it will be critical to develop our understanding of the long term and systemic impacts of these sorts of interventions, and crucially to investigate the ways in which they may contribute to more transformative forms of climate resilient urban development.

Bibliography

Adger, W.N., Arnell, N.A., Tompkins, E.L. (2005) Successful adaptation to climate change across scales. Global Environmental Change 15 (2): 77–86

Anguelovski, I. and Carmin, J. (2011) Something borrowed, everything new: innovation and institutionalization in urban climate governance, *Current Opinion in Environmental Sustainability*, 3:169-175.

Betsill, M. and Bulkeley, H. (2007) 'Looking Back and Thinking Ahead: A Decade of Cities and Climate Change Research.' Local Environment: The International Journal of Justice and Sustainability 12(5): 447 - 456.

Birkmann, J. and von Teichman, K. (2010) Integrating disaster risk reduction and climate change adaptation: key challenges – scales, knowledge, and norms *Sustainability Science* 5: 171- 184.

Birkmann, J., Garschargen, M., Kraas, F. and Quangm N. (2011) Adaptive urban governance: new challenges for the second generation of urban adaptation strategies to climate change *Sustainability Science* 5: 185- 206.

Bulkeley, H. (2010) Cities and the governing of climate change, Annual Review of Environment and Resources, 35: 229–53.

Bulkeley, H. and Betsill, M. M. (2003) *Cities and Climate Change: Urban Sustainability and Global Environmental Governance*. London: Routledge.

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

Corburn, J. (2009) Cities, Climate Change and Urban Heat Island Mitigation: localising global environmental science *Urban Studies* 46 (2): 413- 427.

Corfee-Morlot J, Cochran I, Hallegate S, and Teasdale P. J. (2011) Multilevel risk governance and urban adaptation policy *Climatic Change* 104: 169-197.

Dodman, D. Kibona, E. and Kiluma, L. (2011) *Tomorrow is too Late: Responding to Social and Climate Vulnerability in Dar es Salaam*, Tanzania, Case study prepared for Cities and Climate Change: Global Report on Human Settlements 2011, Available from http://www.unhabitat.org/grhs/2011 (accessed January 2012)

Eakin, H., Lerner, A.M. and Murtinho, F. (2010) Adaptive capacity in evolving peri-urban spaces: responses to flood risk in the Upper Lerma River Valley, Mexico, *Global Environmental Change*, 20:14-22.

Hanson, S., Nichols, R., Ranger, N. Hallegate, S., Corfee-Morlot, J., C. Herweijer , C. and J. Chateau (2011) A global ranking of port cities with high exposure to climate extremes, *Climatic Change* 104: 89–111

IPCC (2007a) Synthesis Report: summary for policy-makers 1, online: http://www.ipcc.ch/publications_and_data/ar4/syr/en/spms1.html (accessed January 2012)

IPCC (2007b) Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability – Glossary A-D, online: http://www.ipcc.ch/publications_and_data/ar4/wg2/en/annexessglossary-a-d.html (accessed January 2012)

Jones, L. and Boyd, E. (2011) Exploring social barriers to adaptation: insights from Western Nepal, *Global Environmental Change*, 21: 1262-1274.

Leichenko, R. (2011) Climate change and urban resilience *Current Opinion in Environmental Sustainability* 3: 164-168.

Manuel-Navarette, D., Pelling, M. and Redclift, M. (2011) Critical adaptation to hurricanes in the Mexican Caribbean: development visions, governance structures, and coping strategies, *Global Environmental Change*, 21: 249-258.

Mercer, J. (2010) Disaster risk reduction or climate change adaptation: Are we reinventing the wheel? *Journal of International Development*, 22 (2): 247-264

Pelling, M. (2011) *Adaptation to Climate Change: from resilience to transformation* London: T and F Books

Roberts, D. (2010) Prioritizing climate change adaptation and local level resilience in Durban, South Africa, *Environment and Urbanization*, 22(2): 397-413.

Romero-Lankao, P. (2010) Water in Mexico City: what will climate change bring to its history of water-related hazards and vulnerabilities? *Environment and Urbanization*, 22(1): 157-178.

Rosenzweig, C., Major, D.C., Demong, K., Stanton, C., Horton, R. and Stults, M. (2007) Managing climate change risks in New York City's water system: assessment and adaptation planning, *Mitigation and Adaptation Strategies for Global Change*, 12: 1391- 1409.

Satterthwaite, D. (2011) Editorial: why is community action needed for disaster risk reduction and climate change adaptation? *Environment and Urbanization*, 23 (2): 339-349

Solecki, W., Leichenko, R. and O'Brien, K. (2011) Climate change adaptation strategies and disaster risk reduction in cities: connections, contentions, and synergies, *Current Opinion in Environmental Sustainability*, 3:135-141.

UNFCCC (2010) Report of the Conference of the Parties on its sixteenth session, held in Cancun from 29 November to 10 December 2010, available online: http://unfccc.int/adaptation/items/4159.php (accessed January 4th 2012)

UN-HABITAT, www.unhabitat.org/ccci

UN-HABITAT, Cities and Climate Change Initiative (CCCI): Prepared by CCCI Technical Support Team, Early Lessons, 2009

UN-HABITAT, Cities and Climate Change Initiative (CCCI): *A Round-up of New Lessons*, Prepared by CCCI Technical Support Team, 2010.

UN-HABITAT, Cities and Climate Change Initiative (CCCI): Adaptation Finance: Are Cities in Developing Countries Slipping Through the Cracks? 2011

Wilbanks, T.J., Romero Lankao, P., Bao, M., Berkhout, F., Cairncross, S., Ceron, J. P., Kapshe, M., Muir-Wood, R. and Zapata-Marti, R. (2007) Industry, settlement and society, in Parry, M .L., Canziani, O. F., Palutikof, J .P., van der Linden, P. J. and Hansen, C. E. (eds) (2007) *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 University Press, Cambridge, pp 357-390.