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CLIMATE CHANGE AT THE CITY SCALE

Impacts, mitigation and adaptation in Cape Town

Edited by Anton Cartwright, Susan Parnell, Gregg Oelofse and Sarah Ward

Climate Change at the City Scale

Climate change impacts are scale and context specific, and cities are likely to bear some of the greatest costs. Against the backdrop of the tardiness displayed by nation-states in committing to emissions reductions, some cities have begun to craft their own climate change responses.

Climate Change at the City Scale presents a fresh contribution to climate change literature, which has largely neglected the role of cities in spite of their increasingly important role in the global economy. The book focuses on the impacts of climate change in the rapidly evolving city of Cape Town, and captures the experiences of the Cape Town Climate Change Think Tank, a hybrid knowledge partnership that has produced research on a range of urban governance, impacts, mitigation and adaptation challenges confronted by the City.

Cape Town has long been acknowledged as an innovator in the area of urban environmental management, notwithstanding its limited resources to manage the demand for a more resilient and equitable future. By documenting the work and experiences of the City's efforts to define its own climate future, the book provides a provocative case study of the way in which the science-policy interface can be managed to inform urban transformation.

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Chapter 1

Climate at the city scale[1]

The Cape Town Climate Think Tank

Anton Cartwright, Gregg Oelofse, Susan Parnell and Sarah Ward

'If this was easy we would have been finished long ago. This is complex!' exclaimed United Nations Framework Convention on Climate Change (UNFCCC) chair Christiana Figueres midway through the Conference of Parties (COP17) gathered in Durban in December 2011. The Durban conference served as a reminder that, while the goal of tackling climate change is clear, the process of realising the necessary objectives is complex and contested. While COP17 failed to deliver the required ambition from nation-states, one of the new themes to emerge was the important role of cities in adapting to climate change and in reducing greenhouse gas emissions. The increasing focus on cities is in many ways a natural process, resulting from the growing number of people living in cities, the contribution of cities to the global economy and the fact that cities increasingly have independent, internationally recognised political, ecological and economic identities.

Action to counter the impacts of climate change is potentially easier at the local or city level. Cities, especially in developing countries, are places of flux and opportunity. The fluid nature of the fast-growing and relatively unbuilt cities of China, India, Indonesia, South Africa, Nigeria and Brazil necessitates changes to their spatial form and operations, regardless of whether or not climate change is accepted as a risk. In these rapidly expanding settlements, the need to transform the modes of construction and management brings with it opportunities to constrain emissions and reduce climate change impacts. The task of simultaneously slashing greenhouse gas emissions and coping with the consequences of unavoidable social, economic and biophysical changes will reconfigure the international competitive advantage. In the process a new set of urban winners and losers (political, corporate and individual) will be created, for it is already clear that cities which manage their transition to a low-carbon and resilient development pathway will generate new competitiveness and new pathways out of poverty (UNEP 2011). In this contest for competitive advantage lies a paradox; while individual cities are taking locally appropriate action, no city acting in isolation can adequately address the cause of climate change. The need is for greater consensus around the urban climate change agenda, and while the C40 cities of the Global North have taken some initiative in this regard, the real challenge lies in how cities of the Global South respond.

The stakes, then, are high. While there may be certain advantages to focusing responses to climate change at the local level, the realisation that global and national targets for climate mitigation cannot be met without a fundamental transformation of how cities are planned, built and managed undoubtedly compounds the complexity of the global climate change challenge.

Few middle-income cities have been as quick or as engaged in defining a climate change programme as Cape Town, South Africa, but while the 'solution' to climate change in Cape Town hinges on effective political and administrative leadership, the process of change needs to extend beyond government. Urban climate change solutions require the best available information and intelligence – about cities, about climate and about the diverse domains in which climate change will have a major impact, such as buildings, public finance, coastal zones and places of biodiversity. Traditionally the type of knowledge considered useful in the context of climate change has been generated and codified in the Global North, where science and its affiliated 'experts' have been seen as 'upstream' of urban decisions (Ziman 2000). In Cape Town, scientists have historically transferred knowledge to city practitioners in technical reports and peer-reviewed literature in the hope that it would be assimilated and applied. It was an arrangement that led to predictable and well-documented disconnects: academics were seen as operating at inappropriate spatial and temporal scales, focusing on personal curiosities, lacking appreciation for application contexts and being poor communicators, while officials were seen to be adopting a day-to-day perspective, operating within their practitioner silos and being reluctant to engage complexity (Schon 1995; Boyer 1996; Harriss 2002). On the occasions that consultants have played the role of knowledge brokers between scientists and officials, they in turn have been prone to a lack of appreciation for the processes that see knowledge turned into policies, programmes and actions.

The limits of the traditional approach are particularly acute against the spectre of climate change, as specialist scholarly knowledge is generally too narrowly conceived to be immediately applicable to the systemic nature of climate change risk. At the city scale, climate change impacts have their origins in complex social and institutional structures, and appropriate responses demand an inter-disciplinary response and a knowledge agenda that can lead to implementation. In this arena it is not possible for universities or researchers to divorce themselves from the problem or its solution (Checkoway 1991). On the contrary, unless local institutions and systems inform the characterisation of research questions and the formulation of research findings, climate change 'solutions' at the local level remain facile, piecemeal, difficult to implement and even contradictory (Evans and Marvin 2006). As a minimum, meaningful climate change research requires a two-way flow of knowledge between officials and 'experts' and perspectives from an array of academic disciplines and socio-economic contexts if it is to elicit the required socio-economic and governance responses.

There is no linear relationship between more and better climate knowledge and improved action in cities. In a certain sense, the more city officials understand about climate change and its consequences, the more difficult decisions become. On the one hand, climate-adaptation theory suggests that increasing uncertainty requires a greater emphasis on flexibility, iterative progress, reflection and continual learning as information becomes available (Dessai *et al.* 2008; Hallegatte *et al.* 2011). At the same time, city officials and politicians are being called upon to demonstrate proactivity in defining alternative modes of urban management. There is thus a tension between carefully engaging the science so as to create policy that will cope with uncertainty on the one hand, and the call for bold and transformative leadership on the other (Stern *et al.* 2006; UNEP 2011). It is unsurprising, then, that some city-scale decision-makers find themselves uneasy about taking climate change decisions in a systematic and responsible manner. The fact that climate change is only one of the competing imperatives – alongside critical issues such as poverty reduction and economic growth – demanding the attention of city officials and politicians makes defining the right action even more contested.

To their credit, officials and politicians within the City of Cape Town recognised the centrality of information and knowledge to the process of change and conceded the limitations of conventional knowledge production and transfer in the context of local climate change. In response they sought to reconfigure the relationship between the academy and practitioners. They found a willing ally in the African Centre for Cities (ACC) at the University of Cape Town which, through its CityLab programmes, was seeking to engage alternative points of knowledge formation within local government and civil society (Parnell *et al.* 2009), including in the area of urban climate change response. The ACC has been at the forefront of a shift that recognises the considerable knowledge that sits outside of universities, and has promoted an activist intellectual agenda in which universities respond more directly to societal problems in order to retain intellectual keenness. Drawing from Max-Neef (2005), the ACC leadership endorses the notion that any hope of understanding or tackling a problem such as climate change requires meaningful application and effort from diverse disciplines and multiple knowledge bases. Funded by the Mistra Urban Futures programme, which shares this commitment to the co-production of knowledge, staff in the ACC have been able to engage in an open-ended search for the knowledge and knowledge partnerships that would foster a more climate-resilient city.

The result was the formation of the city of Cape Town's Climate Change Think Tank and a process that set out to create an 'institution with a memory that outlasts the political and economic cycle' (Lorentzen *et al.* 2009: p. xiii). Forty members drawn from the academic, business, non-governmental organisation (NGO) and academic communities were invited to research climate-related questions or knowledge gaps. The specific focus of this research was established jointly by academics and officials based on problems that City officials had identified as being both critical and constraining on their day-to-day efforts to address climate change risks. The same 40-member community reviewed and shaped the research as it progressed.[2]

The machinations of the Think Tank involved steering committee meetings and periodic feedback on 14 pieces of commissioned research. The end products of this research are captured in the chapters of this book. The book itself was produced at the insistence of the academic partners, who pushed for a durable, peer-reviewed product that would provide a resource for urban professionals and a legitimate resource for global processes such as IPPC reporting. By virtue of the manner in which they were generated, the chapters contain the type of information that the City of Cape Town can use. Certain chapters collate perspectives from very different disciplines while other chapters remain largely true to a specific discipline, but the technical reports that preceded these chapters were reviewed and discussed by peers from a range of disciplines, both in small groups and in plenary. The plenary, attended by the 40 invited participants, convened every two months to listen to presentations from the respective research teams and to challenge the content as it emerged from these teams. Small groups emerged organically to debate specific detail and agree on the content of technical reports.

Of course, the broader goal went beyond applied, better scrutinised, collaborative research and networking. Although not explicit, Cape Town's Climate Change Think Tank resonates with notions of the 'triple-helix' (Leydesdorff and Etzkowitz 1998), 'connecting for value' (Després *et al*. 2004) and 'consilience' (Wilson 1998)[3] that are understood to be important for innovation. This is no coincidence. In many respects the Think Tank represents an innovative response to climate change, both in the knowledge it provides and in the ways in which it generates this knowledge. The Think Tank's members formed a new and diverse community of climate change thinkers that included Cape Town's own officials. Drawn from an array of perspectives, the collective insight into the city's most pressing climate change questions, in conjunction with the challenged, enhanced and increasingly concordant use of language, modes of analysis and standards of validation, created a climate-adaptation resource for the City.

While the Think Tank sought to span disciplines, it was not a simple case of lumping together people from different disciplines. Interdisciplinary applied research was a by-product of the peer-review process, rather than an explicit goal. Similarly, the inter-profession interactions (between politicians, lawyers, scientists and economists) were at least as significant as the traditionally construed benefits of interdisciplinary encounter. The commissioned research teams typically contained a mix of academics, consultants, NGO representatives and officials. Initially distinctive roles were largely maintained: academics contributed literature, posited theories that would influence thinking and documented the process; officials grounded the research in the operations of the City, provided case studies, coordinated different research projects and identified local needs; civil society challenged assumptions, contributed perspectives from their respective interest groups, and raised concerns and opportunities from the perspective of social and ecological justice; consultants contributed perspectives from a wide range of professional engagements. Over time, however, there was a discernible blurring of these roles and an appreciation of a wider spectrum of experience and knowledge. This was characterised by increasing insight into, and empathy for, the constraints under which different Think Tank members worked. For academics, the rigours of the political process of local government, with its joint political and administrative structures, were exasperating, intense and demanding because of the implied short-term imperatives. For practitioners, recognition involved an acknowledgement that the knowledge held in the 'ivory towers' of universities and by specialist professionals is essential in defining a climate-resilient development path and in training the next generation of professionals. Downing and Dyszynski (2010) call this 'socio-institutional learning' – a process that equips the city to take a wide range of complex decisions in an accountable and coherent manner, and allows a level of confidence in the ability to take good decisions.

Knowledge reorientation was not automatic. It required a reworking of the academic canon and the freeing up of practitioners and consultants for the writing of academic publications. The process occasionally destabilised the assumptions held by technocrats and other members, but the Think Tank sought to create an environment in which it was safe and acceptable to interrogate assumptions and explore the definitive questions; indeed, rational enquiry by commissioned teams tended to provoke constructive reflection by people outside of the group, and vice versa.

Nor were the workings of Think Tank always easy or uncontested. The Think Tank's success, buoyed by growing public awareness around climate change, generated its own challenges. Activists both within the group and outside of it complained that the implicit agenda (and by association the membership) was deliberately too conservative and restricted. While the Think Tank's existence demonstrated that knowledge development and public participation are interrelated in a democratic society (Checkoway 1991), finding a suitable balance between participation and knowledge development presented an ongoing challenge; it is always possible to increase the former but this does not necessarily lead to more useful knowledge. Similarly, businesses in the City sought to influence the research themes to address their private concerns, while politicians, appreciating the potential for profile and electoral currency, began insisting on special meetings and specific research themes to coincide with electioneering strategies. City officials frequently found themselves caught between the ambitious, unfettered and at times critical findings emerging from the Think Tank and their accountability to their political counterparts and time-honoured modes of taking city-scale decisions. In these ways, and others, closer collaboration inevitably highlighted both shared interests and differences. The Think Tank, even while creating insight into the working environments of respective members, did not obviate the claims that academics were out of touch with City issues, that consultants were intellectually expedient, that officials were myopic in their understanding of their responsibilities and that politicians were opportunistic. That the Think Tank sat outside of the City, the University or any given NGO, and was free to criticise the respective institutions and transcend the political and economic cycle, was key to its rigour and continuity.[4] At times it failed its own exacting standards of independence, critical reflection and inter-disciplinarity, but it always managed to maintain sufficient momentum and autonomy so as not to fall prey to the vagaries of its respective members' institutions.

Different participants contributed their time and energy to the Think Tank for different reasons. For the City a key rationale involved the desire to focus academic research and to take stock of the various, and at times fragmented, research projects taking place within the city. For academics, there was the desire to broaden the knowledge community and the allure of greater insight into, and proximity to, City functions. For NGOs and the business community, there was the potential to be drawn into the workings of the City and to gain profile within the associated professional networks.

The chapters of the book reflect the products of the Think Tank's commissioned research. The respective contributions are as varied in their scale of analysis, their technical content, their subject matter and their mode of analysis as the experiences of climate change itself.

- Tadross *et al.* (Chapter 2) draw on down-scaled general circulation models to provide an overview of climate dynamics and projections for the city region. The chapter highlights that it is the underlying climate system that generates much of the climate change risk and uncertainty for Cape Town.
- Cartwright *et al.* (Chapter 11), who focus on decision-making, point out the profound implications for planning and decision-making when the past no longer represents a good proxy for the future. Significantly, given that this book in no way purports to provide a best-practice handbook for city-scale climate action, they are unable to provide a blueprint for the processes that support effective climate change decisions at the local level.
- In an attempt to isolate city-specific dynamics, Borchers and Lewis (Chapter 5) draw on South Africa's national mitigation scenarios to describe a range of mitigation options and their respective consequences for the City. The need for mitigation is established by Lewis and Jooste (Chapter 6), who identify Cape Town as a carbon intensive city.
- The cluster of legal chapters signals that not all climate change action flows from conventional climate science; that even if there was perfect information on the science or politics of cities facing climate change, this would not necessarily ensure appropriate responses at the city scale; and that when working at the city scale to address climate change, the devil is in the detail – fiscal, legal and institutional. Within the legal chapters, De Visser (Chapter 7) points to the consequences of Cape Town's conservative interpretation of national public finance legislation for the type of decisions required by climate change. He makes a case for a different interpretation of what the legislation refers to as 'financial economic benefit', embracing a new legal interpretation to deal with the ambiguity in law and science.
- The three chapters related to sea-level rise address very different aspects of this threat to the City's coastline. Brundrit and Cartwright (Chapter 3) provide a high-level assessment of changes in the 300-kilometre coastal zone that is under the city's administration. Colenbrander *et al.* (Chapter 10) draw on personal experience to outline the complexity that defines coastal zone management. Harris *et al.* (Chapter 4) provide a site-specific study of the complex interactions between marine and freshwater systems on the edge of Cape Town's CBD. They draw on the best available down-scaled climate data and a sophisticated technical analysis, but stop short of a prescriptive

conclusion that would allow a definitive management of its consequences, even though the work is being used by the City of Cape Town in defining its storm-water policies.

- Ziervogel and Parnell (Chapter 12) describe the varied strategies for initiating institutional change for climate action, providing a fitting context for the work of the Think Tank that is captured in this book.

Interestingly, all chapters point to uncertainty and complexity. While the information contained in the chapters is necessary for better local decisions, actually taking these decisions requires a novel form of negotiated process. By bringing practitioners, politicians and academics together to co-produce the knowledge in this book, the Think Tank aimed to create a process that is empowering of these decisions. Time will tell how effective it has been in this regard; the City of Cape Town's Climate Change Think Tank, which is in part represented by the chapters of this book, involves an ongoing institutional experiment. It draws on the available theory around knowledge communities (Boyer 1996; Després *et al.* 2004; Parnell *et al.* 2009), interdisciplinarity and institutional change (Harriss 2002; Evans and Marvin 2006; Barry *et al.* 2008) in an ambitious participatory approach that does not shy away from the structural complexity of the challenge. While much of the information contained in the chapters is already being used by City officials, there are also longer term acts of change and practical implementation that in time might be attributed to the stimulus of the Think Tank.

What is already clear is that collectively the chapters of this book provide an optimistic message for city decision-makers. Without dismissing the need for a global climate change agreement, the book points to critical decisions and actions that fall within the day-to-day remit of city management and have a profound impact on the way in which rising mean atmospheric temperatures impact upon cities. For example, sea-level rise is caused by powerful forces, manifesting over long timeframes, over which city planners and residents have little control, but the demarcation of coastal zones and preparedness in times of storm surges greatly influences the damage caused by these surges; similarly while few causes of climate change are 'illegal', the law offers considerable leverage in preventing adverse climate change impacts. This book, it is hoped, provides insight into how this local influence can be understood and deployed, to the benefit of the global effort to tackle climate change.

Notes

1 In this book 'the City' refers to the local government structures of a city, e.g. the City of Cape Town, and 'the city' refers to Cape Town itself.

2 The first phase of the Climate Change Think Tank ran from 2009 through 2011. During this period the Think Tank was financially administered by Sustainable Energy Africa (SEA); chaired by an ACC academic; jointly run by the city, SEA and the African Centre for Cities (ACC) at the University of Cape Town; and was funded directly by Danida's Urban Environmental Management Programme and Mistra Urban Futures (through the ACC). The Think Tank drew extensively on city resources and leadership.

3 Wilson (1998: 7) talks about 'consilience' as 'literally a jumping together of knowledge by the linking of facts and fact-based theory across disciplines to create a common groundwork of explanation'.
4 Most but not all meetings were held outside the Council buildings.

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Chapter 2

Understanding Cape Town's climate

Mark Tadross, Anna Taylor and Peter Johnston

To assess the potential disruptions, risks or opportunities that changes in the climate may present in an urban and peri-urban environment, it is often critical to first understand how the current climate shapes metropolitan activities and how possible future climate conditions may alter the way those activities are undertaken. To do this requires an understanding of the local climate, how it is modulated through the annual cycle (the changing seasons) and how the local climate is influenced and driven by the large-scale atmospheric circulation. It is important to clearly distinguish between weather and climate patterns. While weather constitutes the atmospheric conditions experienced locally over short time periods (measured over hours and days), climate refers to the average atmospheric conditions over much longer timescales (the average of measurements taken over 30 years or more). It is noteworthy that, unlike the case in most European cities, a significant body of academic work on Cape Town's urban climate does not exist. This chapter presents some background information on how the current climate of Cape Town and its environs is shaped by local topography (variations in the land surface height) and proximity to the ocean (see Figure 2.1), and how the climate may be expected to change in the future, given anthropogenic climate change.

The current climate of Cape Town

The current climate of Cape Town is dominated by two major atmospheric systems, which together drive the seasonal cycle. During winter, periodic mid-latitude cyclones/storms approach from the west, bringing rain, north-westerly winds and cooler weather. During summer the south Atlantic high pressure system keeps the city drier and hotter, with winds predominantly from the south-east (see Figure 2.1). Together these systems produce a Mediterranean-type climate with wet winters and dry summers (see Figure 2.2).

In addition to these dominant processes that produce typical summer and winter conditions, and are a direct result of hemispheric processes influencing the seasonal cycle, several other large-scale systems have an important influence on the climate of the city. These systems are generally less persistent and frequent than the high and low pressure systems mentioned above, and occur mostly at particular times of the year.

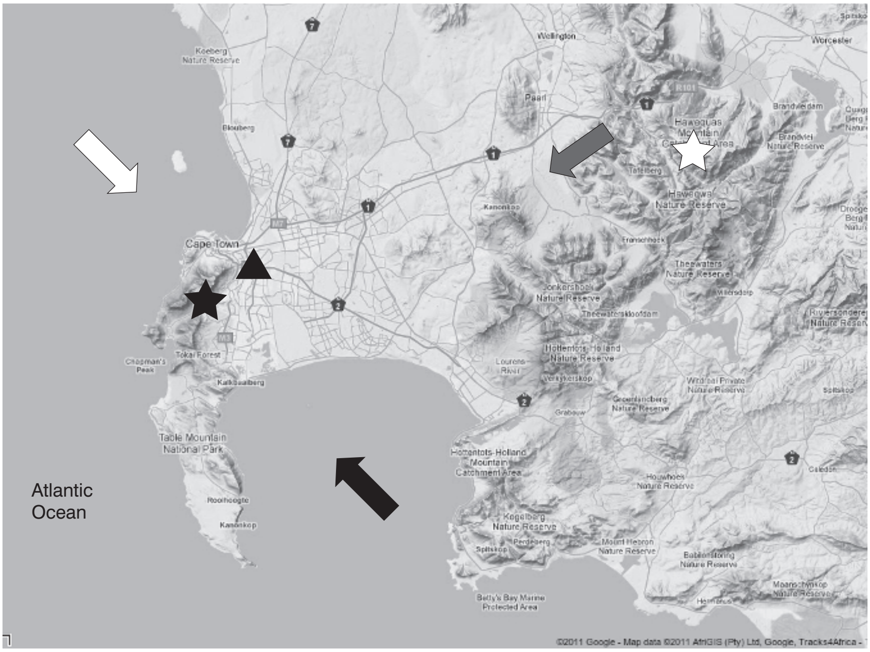

Figure 2.1 The city of Cape Town, local topography and proximity to the ocean

Notes: Table Mountain (black star) is approximately 1,085m high; some peaks in the Hawequas mountains (white star) are over 1,800m high. Dominant wind directions during winter storms are shown by the white arrow, summer high pressure conditions are shown by the black arrow, and continental offshore (berg) wind conditions are shown by the grey arrow. The approximate location of the South African Astronomical Observatory and Groote Schuur are indicated by the triangle.

Source: Google, AfriGIS, Tracks4Africa (2011)

Coastal lows

These are low-pressure systems that develop along the west coast to the north of Cape Town and move south, following the coast. They are generally shallow, weak systems which are accompanied by a hot and dry offshore flow of air (from the continental interior) which raises the temperature in and around the city. After passing the city the flow turns onshore and may bring moist marine air which results in rainfall, particularly over the mountainous areas.

Cut-off lows

These are deep low-pressure systems which are generated from westerly waves (associated with mid-latitude storms) in the south Atlantic and which become detached from the main westerly flow. They may become stationary over a certain area, drawing tropical moisture from the north which can result in very heavy

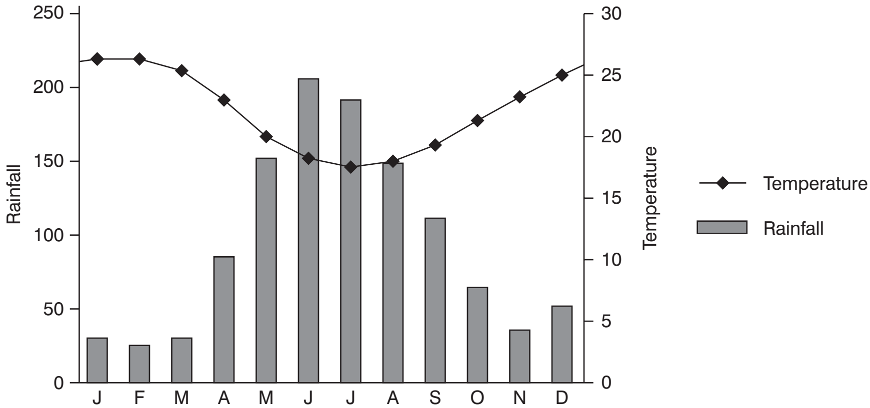

Figure 2.2 The seasonal cycle of rainfall (mm/month) and temperature (°C) at Groote Schuur, 1980–2000
Source: South African Weather Service

rainfall, e.g. the Laingsburg floods in 1981. These largely unpredictable systems are more frequent during spring, winter and autumn and may be associated with high storm surges along the coast.

Berg winds

These are offshore winds drawn from continental inland areas (often associated with coastal lows) which are generally hot and dry. These systems are more prevalent during late winter and early spring.

Thunderstorms

During summer, convective activity due to increased temperatures and moisture (usually from the north and continental areas) can lead to thunderstorms, especially over high ground. These systems may bring isolated heavy rainfall incidents during the summer months.

Marine fog

This is generally found when moist air is transported horizontally over cold water – often from the west. The development of fog under such conditions is promoted by a cold and stratified atmospheric boundary layer or elevated temperature inversion which suppresses vertical mixing of the air masses. Marine fog is most often found during autumn.

Whilst these large-scale atmospheric processes explain the general climate of the city, there are marked differences in the local response to these processes in different parts of the city and its surroundings. This is particularly true in areas influenced by topography, especially near Table Mountain, which dominates the climate of the central city and its surrounding suburbs. For example, during winter, storms bearing moisture-laden air from the (north-)west strike Table Mountain and characteristically deposit more rainfall on the eastern (lee) side of the mountain than on the western side – resulting in high rainfall in places such as Kirstenbosch Botanical Gardens and Groote Schuur (see Figure 2.2). During summer, moist south-east winds can also bring rain to mountainous areas, though not usually for lower elevations, and thunderstorms often preferentially form over mountainous interior regions. There are, consequently, a large range of weather conditions that affect Cape Town and its immediate vicinity, some of which are locally generated and others driven by larger scale processes influencing southern Africa and beyond. The resulting distribution of rainfall (and temperature due to elevation) in turn affects local vegetation, river flows, groundwater recharge, dams and allocations of water for agriculture and urban use (Midgley *et al.* 2005; Mukheibir and Ziervogel 2006: 67).

Climate trends in Cape Town and surrounding regions

Historical trends in climate can offer useful insights into how the climate of a region may be changing in response to anthropogenic climate change. However, it is important to remember that these trends may also be a response to natural variability on decadal timescales, and so do not 'prove' that anthropogenic climate change is affecting the regional climate. Nevertheless, if observed trends are consistent with projected changes for several decades in the future (see below) there are grounds for suggesting that these trends may continue and adaptation to these trends is a worthwhile exercise (as long as one continues to monitor whether these trends are changing). If historical trends are, however, different to projected changes, it is possible that:

- historical trends are due to other sources of variability on, e.g., decadal timescales;
- projected future changes are modelled inconsistently – there are high levels of uncertainty;
- knowledge of the regional climate system and how it responds to external forcing is lacking, e.g. knowledge of how gravity waves influence rainfall in and around Table Mountain;
- the timing of projected future changes is unclear, i.e. when the climate change signal will be apparent relative to natural variability is not known.

In such circumstances there may be little evidence of change, and decisions about whether to adapt or adopt more climate-resilient approaches are based on existing vulnerabilities and impacts to natural climate variability. Historical changes in the climate of the Western Cape and Cape Town have been noted as follows.

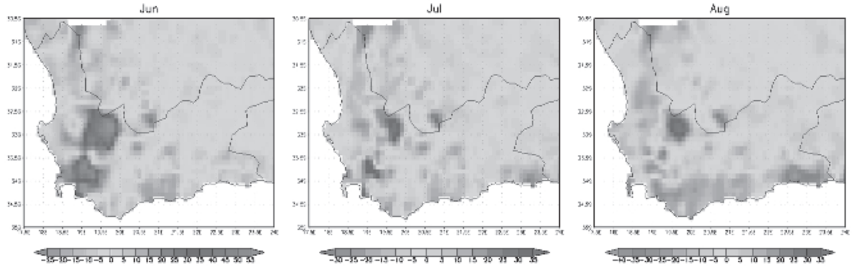

Figure 2.3 Total change in monthly rainfall (mm) between 1950 and 1999 for the core months of the winter rainfall season (June, July and August)
Source: Midgley *et al*. (2005)

Rainfall

Rainfall trends are notoriously difficult to detect, mostly because rainfall is a highly heterogeneous variable which is often under-sampled by the current spatial distribution of weather stations. Stations with a long record (1910–2004) near Cape Town indicate statistically insignificant trends for extreme rainfall indices (Kruger 2006), though the anthropogenic influence on climate trends is not expected to be observable until after 1960, when human influence on the global temperature record is detectable. The work of Hewitson (Midgley *et al*. 2005), however, indicates that trends in rainfall for the years 1950–99 are dependent on the time of year and location. In particular, rainfall trends during the winter months are different for low (negative trend) and high (positive trend) altitudes (see Figure 2.3). So whilst rainfall has been increasing over the mountainous regions, it has been decreasing at lower altitudes.

Temperature

Temperature trends are generally easier to detect as temperature tends to vary in a similar manner (with differences due to altitude) between nearby locations. During the last 30–40 years of the twentieth century, weather stations spread across the Western Cape have clearly indicated warming of both maximum and minimum temperatures (many statistically significant at the 95 per cent confidence interval), with average minimum temperatures rising across all months and maximum temperatures rising most during autumn and spring (Midgley *et al*. 2005). Similar analyses for Cape Town and Cape Point also find statistically significant increases in both minimum and maximum annually averaged temperatures of approximately 0.16°C per decade between 1960 and 2003 (Kruger and Shongwe 2004). These changes are consistent with the future projections of climate change from both global and regional models.

Wind and atmospheric systems

Whilst there has been little work to identify trends and changes in atmospheric circulation (which could be related to the changes in temperature and rainfall noted earlier), a study of pan evaporation and related aspects of climate for stations spread across the Western Cape revealed that both evaporation and wind run (the distance wind travels in a defined period – analogous to wind speed) had declined significantly between 1974 and 2005 (Hoffman *et al.* 2011). The physical cause of the declining wind run has yet to be determined, though it may be related to increases in vegetation (increasing surface drag) or noted changes in the atmospheric circulation (Midgley *et al.* 2005).

The future climate of Cape Town and surrounding regions

The basis for all simulations of the long-term (10+ years) future climate of Cape Town are General (or Global) Circulation Models (GCMs). These models simulate the land-ocean-atmosphere system of the planet at spatial resolutions of the order of several hundred kilometres. They incorporate the exchange of heat, moisture and energy, as defined by fundamental physical equations, between the main components of the earth system. Globally there are approximately 20+ formulations of these models, which have been developed by scientific research organisations around the world, and all have been shown to accurately represent the global climate of the last century (IPCC 2007). Emissions scenarios which describe the likely anthropogenic emissions of gases, including carbon dioxide and sulphates, along with natural causes of variability (e.g. solar cycles), are used in the GCMs to simulate the future global climate.

GCMs are useful for simulating large-scale changes in climate, such as changes in the global Walker and Hadley circulations, the position and intensity of the sub-tropical high pressure systems, and the average position of the mid-latitude cyclone tracks. However, the scales at which GCMs represent topographic features, coastlines, lakes and vegetation make them unsuitable for simulating the local response to large-scale changes in climate, and it is often information on this local response that urban planners and local governments require in order to start planning for the negative impacts of climate change. For this reason 'downscaling' methods are often used to derive changes in local climate, though it should be noted that even these methods may not be able to provide useful information at a scale required by planners and government. Whilst some Regional Climate Model (RCM) simulations do exist for the Cape Town area, these are often limited to one or two downscalings of a limited number of GCMs, though recently the international COordinated Regional climate Downscaling EXperiment (CORDEX)[1] and Council for Scientific and Industrial research (CSIR)[2] have started generating ensembles of RCM downscalings of multiple GCMs. For this reason we concentrate on a statistical downscaling of multiple GCMs in the following discussions.

Global model simulations

When estimating changes in future climates it is important to use as many different models (called an 'ensemble') or ways of estimating the future as possible in order

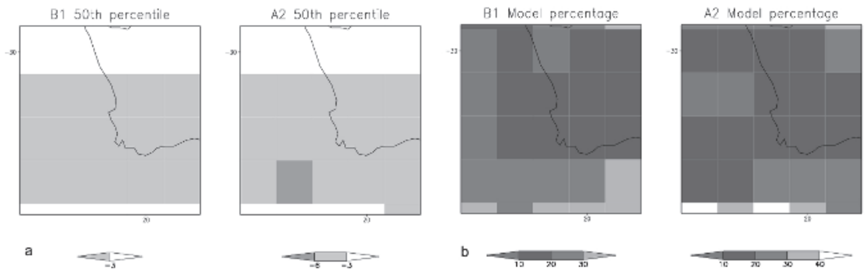

Figure 2.4 Changes in precipitation for the 2040–2060 period relative to the 1960–2000 period, under the B1 and A2 emissions scenario; (a) mean change (mm/month) and (b) percentage of models indicating a positive change, for 15/13 GCMs (A2/B1 scenario).

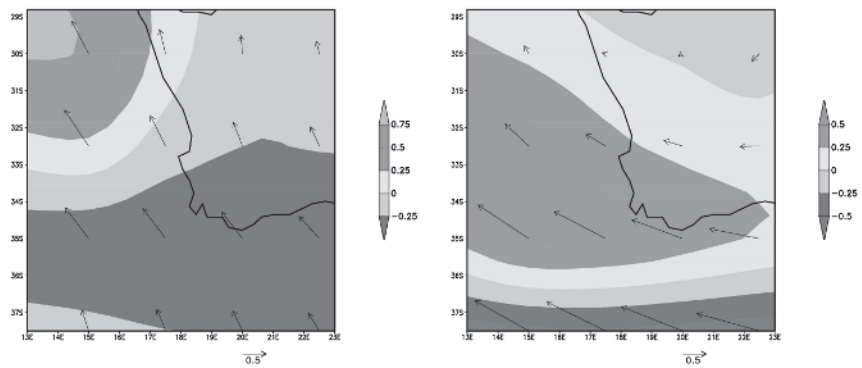

Figure 2.5 Average change in 10m winds for 15 GCMs under an A2 emissions scenario, June–August (left), December–February (right)

Note: Shading indicates changes in wind speed (m^{s-1}).

to sample the range of confidence/uncertainty when making estimates. Ideally a probabilistic approach would be taken with thousands of simulations, but in their absence we use measures of the median/mean model to indicate the tendency of the ensemble of models, with an indication of the spread of the ensemble as a measure of the confidence/uncertainty.

Average changes in precipitation for the June–August period by 2040–60 are shown in Figure 2.4, as is the percentage of models showing a positive change. Under both A2 and B1 emissions scenarios[3] the average model change is for a reduction in rainfall, and the percentage of models indicating positive/negative change is approximately 15/85 per cent. This indicates reductions in rainfall during the peak of the current rainfall season, though during other seasons there is less consistency in the modelled changes. Accompanying increases in surface temperature are of the order of 1–3°C, with higher increases inland than near the coast (changes will depend on elevation and the influence of coastal vs continental climate).

Figure 2.5 gives an indication of the changes in the atmospheric dynamics that are responsible for these changes in rainfall and temperature; surface (10m) wind changes