Observations on

ENVIRONMENTAL Change in South Africa

SECTION 2





Editor | LARRY ZIETSMAN

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Observations on Environmental Change in South Africa

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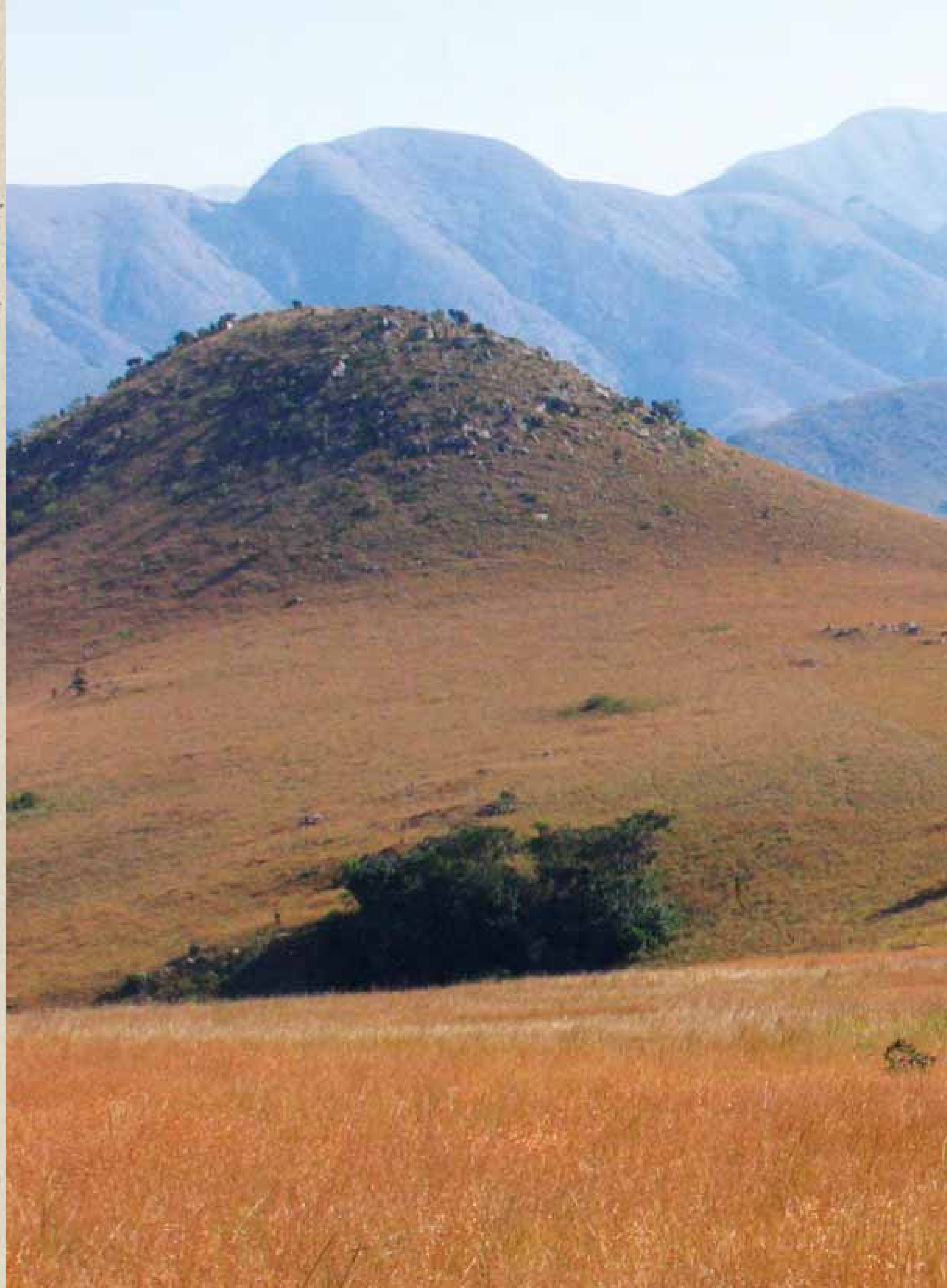
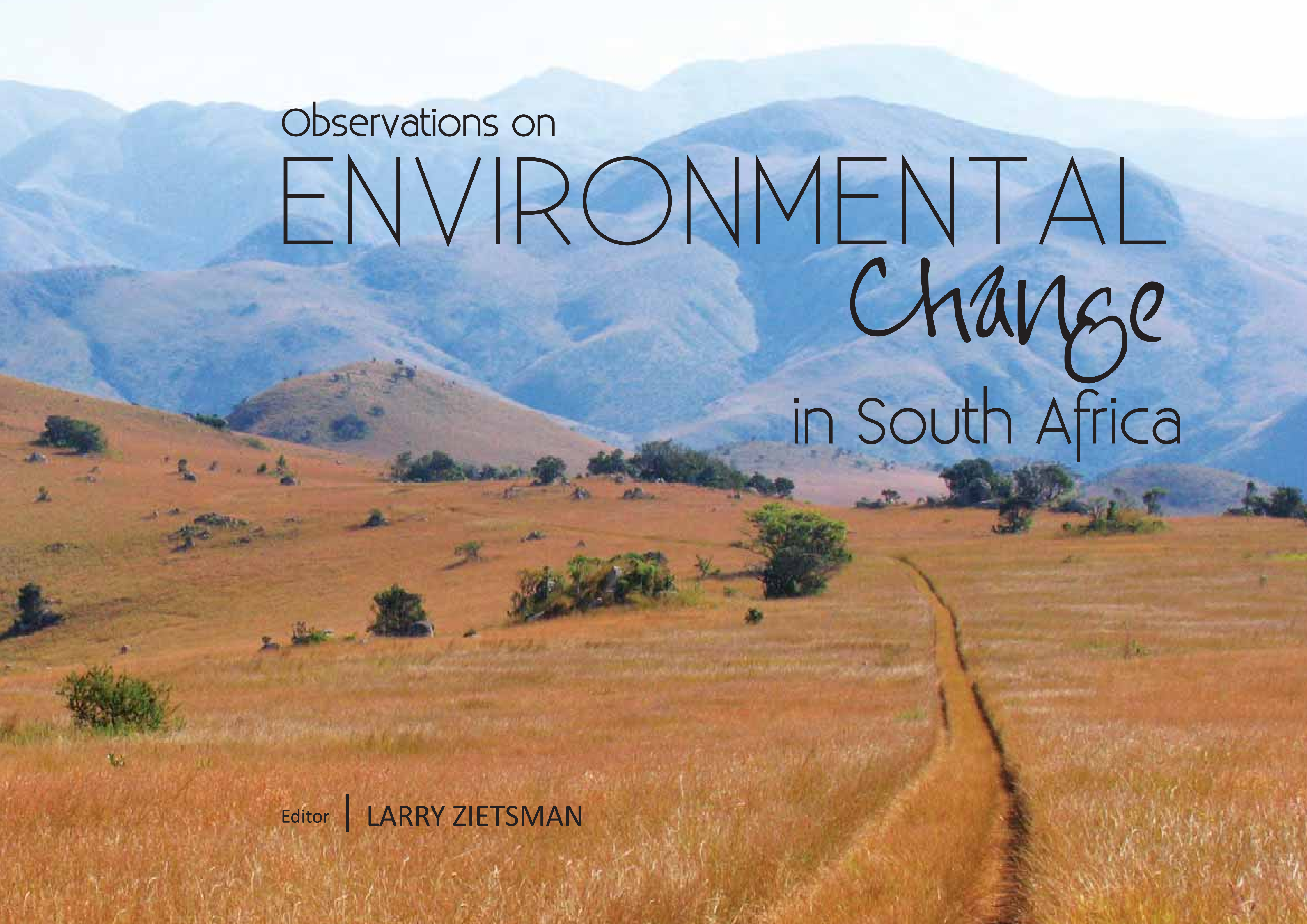
RIGHT Grasslands [Barend Erasmus]





Observations on ENVIRONMENTAL Change in South Africa

Editor | LARRY ZIETSMAN

Editorial Committee

RIGHT African Reed Frog [Barend Erasmus]

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The mandate of the South African Environmental Observation Network (SAEON) is to establish and maintain state-of-the-art observation and monitoring sites and systems; drive and facilitate research on long-term change of South Africa's terrestrial biomes, coastal and marine ecosystems; develop and maintain collections of accurate, consistent and reliable long-term environmental databases; promote access to data for research and/or informed decision making; and contribute to capacity building and education in environmental sciences. Its vision is: A comprehensive, sustained, coordinated and responsive South African environmental observation network that delivers long-term reliable data for scientific research, and informs decision-making for a knowledge society and improved quality of life. SAEON's scientific design is adaptively refined to be responsive to emerging environmental issues and corresponds largely with the societal benefit areas of the intergovernmental Group on Earth Observations (GEO).

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The vision of the Department of Science and Technology (DST) is to create a prosperous society that derives enduring and equitable benefits from science and technology. Our mission is to develop, coordinate and manage a national system of innovation that will bring about maximum human capital, sustainable economic growth and improved quality of life.

We are guided by the corporate values of professionalism and competence. We will strive to deliver top-class, quality products and services, seek innovative ways to solve problems and enhance effectiveness and efficiency.

The DST strives toward introducing measures that put science and technology to work to make an impact on growth and development in a sustainable manner in areas that matter to all the people of South Africa.

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Acknowledgements

The idea for this book came from Albert van Jaarsveld. He discussed the possibility of a 'coffee table book' showing 'before and after' images of environmental changes in South Africa with Johan Pauw, who saw the relevance and necessity for such a book and its value for promoting the work of the South African Environmental Observation Network (SAEON), especially amongst politicians and decision makers, who by the nature of their work may not have much time to delve into the intricacies of scientific papers on environmental change, but need to advance sustainable policies for development. Together with Konrad Wessels, they developed the idea and approached me to act as project co-coordinator and to test the feasibility of the idea and set out a proposed table of content. Together we drafted a document listing broad topics or themes to be addressed and then went about listing potential contributors from the scientific and research community in South Africa. I then drafted a document formulating the goals that we would like to achieve and the approach to be followed by contributors to the proposed book. The potential authors were contacted and invited to participate in writing a book on 'Earth observation and environmental change in South Africa'. The scientific and research community responded positively to the idea and a set of guidelines were sent to those willing to contribute to this publication. These authors sent in proposed titles and abstracts of what they had in mind. Their submissions were evaluated and most were accepted for inclusion. The vast majority of these authors honoured their commitments and submitted their full texts within a reasonable timeframe. A tentative table of contents was drawn up and circulated. Valuable inputs, especially from Sue Milton, led to a revised, restructured and reordered table of content very similar to the final version. Barend Erasmus, Charles Griffiths, Lauri Laakso, Johann Lutjeharms, Matlala Moloko, Sue Milton, André Theron, Rudie van Aarde, Brian van Wilgen and Alan Whitfield generously supplied supplementary photographs.

The book that has materialised from this process is probably not quite what Albert van Jaarsveld had in mind. It took on a life of its own, in spite of my best efforts to keep it in line with out initial intentions! Although every effort was made to ensure that it would be '... an attractive, richly illustrated and easily readable book on the causes consequences and responses to environmental changes in South Africa', its scientific nature became much more prominent. We now have a publication '... conveying scientific evidence based on local case studies using examples to graphically illustrate these trends and impacts with a variety of satellite imagery, photo's, maps and other illustrative materials.'

The book gives a picture of environmental change and proposed responses on a range of themes and topics. It draws together work from as many scientific disciplines as possible, extracts the most pertinent information and presents it in a condensed format. As such this book should be very useful to inform the general public and senior political and public executive officials involved in policy formulation and decision making on environmental issues and implications of policies as initially intended. However, it will undoubtedly also be of value to lecturers and students at institutions of higher education.

I would like to acknowledge the time and efforts of all the authors and co-authors who graciously contributed their work without remuneration in the interests of science and our fragile environment. I also thank the editorial committee (Johan Pauw, Albert van Jaarsveld and Konrad Wessels) for their foresight, confidence and support in helping to bring this publication to fruition.

Hendrik L Zietsman
Editor
December, 2010

Foreword

MRS G.N.M. PANDOR, MP

South Africa has a rich history of scientific excellence and of undertaking pioneering work in the environmental sciences. This richly illustrated publication is yet another valuable contribution to that heritage. According to a report by Thomson Reuters, between 2004 and 2008 South Africa ranked above average in the scientific fields of Environment and Ecology, contributing 1,29% of world output, with a citation rate averaging above 5 per paper.

South Africa can also be proud of its strong tradition of exploiting scientific knowledge to support effective policy and practice in sustainable development. Supported by my department, the South African Environmental Observation Network (SAEON) emerged from that tradition to establish six strategic nodes that jointly cover South Africa and its adjacent oceans. These nodes function as observation systems and platforms that enable the environmental sciences community to perform longitudinal studies of environmental change, and ultimately to support sustainable development objectives. This work has made a valuable contribution to science-based initiatives such as the Southern African Millennium Ecosystem Assessment in identifying possibilities for improving human wellbeing, taking into account the capacity of ecosystem services to support these improvements.

South Africa continues to face crucial social and economic challenges. A set of 12 priority outcomes has been identified for focused attention over the next few years. Effective management of our natural environment and assets is not only a key outcome in its own right, but also has an important contribution to make in supporting outcomes such as a long and healthy life for all South Africans, food security for all, and sustainable human settlements.

The natural environment is a complex system with many interconnected strands. A range of human pressures combine with natural processes resulting in many and varied impacts and responses. Science investments are vital for the development of a knowledge base that can assist decision-makers to make sense of the complexity and to respond through policy measures and interventions. Science investments range from the development of long-term environmental observation capabilities, the effective integration of new and existing datasets and the initiation of longitudinal studies, to ensuring maximum exploitation of the data through appropriate knowledge products such as forecasts, early warning systems and impact maps.

Notwithstanding the strong foundation in environmental observation and research that already exists in South Africa, the Department of Science and Technology continues to prioritise this area for further development and investment within the context of its Innovation Plan. For example, we have committed to the development of satellites that will provide fine resolution and space-based data that we can exploit for areas ranging from environmental management to early warning systems for better disaster management.

Over the next 10 years, through the Space Science Grand Challenge, we will be investing in satellites as well as supporting infrastructure that will constitute a stronger earth observation system. Coupled to these efforts are a range of other initiatives, under the umbrella of the Global Change Grand Challenge, which will support analysis and research on the basis of the available observation data sets as well as building a new generation of skilled scientists and practitioners.

I would like to take this opportunity to congratulate the National Research Foundation, SAEON and the many scientists who contributed their time and expertise to this publication and to the work being done to maintain and strengthen our environmental science heritage.

More importantly, I would like to acknowledge the attempts being made to enhance the accessibility of complex and technical scientific material in ways that empower all sections of society.

Naledi Pandor

Mrs G.N.M. Pandor, MP
Minister of Science and Technology
December, 2010





Introduction

Johan C. Pauw
Hendrik L. Zietsman
Albert S. van Jaarsveld
Konrad J. Wessels

Environmental conditions on earth are changing rapidly. The degree to which these changes are human-induced could be debated, but the fact that changes are taking place is indisputable. As custodians of finite natural resources we do not have the luxury of being complacent. This highly illustrative book provides a glimpse into the environmental changes that have been observed. It is not a compendium of all changes, as that would require numerous volumes. The book highlights some pertinent aspects of environmental change and introduces ways in which satellite technologies and other observation systems are used to measure and monitor some of these changes. In many cases, the book describes the principle problems and discusses why these issues are considered problematic. The book also describes the main drivers of these changes, how the environment is responding, and how these problems can be solved. In addition, the book outlines the potential consequences of failing to act.

Why a book about environmental change in South Africa?

The key understanding that the reader will gain from reading this book is that scientific observation of environmental change is ubiquitous in South Africa and that these changes are progressively affecting the future of South Africans through their combined impacts on human livelihoods, security and prosperity. A conscious effort is made to distinguish 'environmental change' from 'natural environmental variability' in order to determine if the root causes of environmental change may be considered attributable to human activity. Natural environmental variability is normally of a periodic nature whereas environmental change can be experienced as a directional trend; either gradual or drastic, but with a high probability of being irreversible.

From the above, it follows that both the public and private sectors should rapidly mainstream environmental considerations and trends into their policy making, strategic planning, operations and market positioning. Consequently, the primary audiences for this book are decision makers and advisors at all levels of society, from government to civil society. The purpose is to provide them with a snapshot of pertinent scientific evidence to assist them in formulating intelligent and responsible policies and practices for the betterment of our society and to ensure the long-term futures of South Africans. Yet, the scope, breadth and depth of subject matter covered also renders this text useful reading for teaching and for further studies in related disciplines.

Making sense of environmental complexity

The natural environment is often illustrated as a spider's web consisting of interconnected strands. Although each strand is fragile on its own, the intricate and beautiful web structure provides it with resilience against external forces. Similarly, global-scale earth systems (i.e. biogeochemical cycles of the atmosphere, oceans and land) can be viewed as nested and multi-scaled ecosystems integrated through interactive processes. These systems are systemically afflicted by natural and human forces that act at multiple scales.

Amidst the obvious complexity of ecosystem studies, a standardised conceptual model of ecosystem function has emerged over time. This model was adopted by the United Nations Commission on Sustainable Development in 1995 and forms the basis of most state of environment reports, including those from South Africa [1]. The model is called the Driver-Pressure-State-Impact-Response (DPSIR) model (See Figure A) and it forms a golden thread that permeates the work presented in this book.

Batho Pele

Batho Pele – 'People First' – is the well-known slogan of the South African Government. It is therefore appropriate that the opening section of this book addresses issues of 'People and Environmental Change'. The subsequent chapters describe a variety of pertinent environmental issues grouped into broad large-scale ecosystem topics spanning the atmosphere to the oceans. The book ends with a concluding chapter.

South Africans, across the board, are dependent on these vital life-supporting systems and what is presented should serve as a reality check about the status of these systems. From our understanding of environmental change, people are collectively and rapidly transforming the environment for short-term economic and lifestyle gains, whether by choice or purely in order to survive. Yet, it should be clear that the longer-term impacts of irreversible environmental change will undermine the quality of human livelihoods and may compromise the essential life-support benefits derived from ecosystem services. In most instances, due to disparate access to resources, services, education and infrastructure, it must be anticipated that environmental justice and equality will suffer in the face of environmental change.

Environmental change is a global concern and requires ongoing observation, interpretation and responses from South African government and civil society. This book is therefore a bona fide 'science for society' contribution.

The GEO-4 CONCEPTUAL FRAMEWORK

The GEO-4 conceptual framework (Figure A) enhances our understanding of the relationships between the environment and development and how these affect human well-being and vulnerability. The main components of the framework are 'Drivers', 'Pressures', 'States', 'Impacts' and 'Responses'.

'Drivers' or driving forces are the fundamental processes in societies that motivate certain decisions and activities which lead to changes in the environment. Examples of drivers include demographic, economic, technological, institutional and political patterns and systems.

'Pressures' emanate from emissions, waste, inputs, modifications, extractions and other activities that lead to environmental change. Examples are pollutants, fertilisers, irrigation, resource extraction, deforestation and land-use changes.

'State' includes trends and pertains to natural conditions and induced changes in the environment. These changes are often linked in subtle ways, so that changes in one part of the system lead to changes in another part. Examples of natural processes are those that operate in the physical, chemical and biological systems. These are monitored by measuring levels, concentrations, compositions and movements such as solar radiation, temperature, moisture, gasses, chemicals, land use, species and services.

'Impacts' are the effects that these environmental changes have on human well-being, social and economic sectors or environmental services, whether negative or positive.

'Responses' refer to the policies, legislation, regulations, programmes and projects undertaken to reduce human or natural vulnerability, reduce or mitigate negative effects, or strengthen positive consequences to environmental change.

The conceptual framework also shows that these components are interrelated, scale and location dependant and operate differently at different scales (local, regional and global), in different geographical and social contexts.

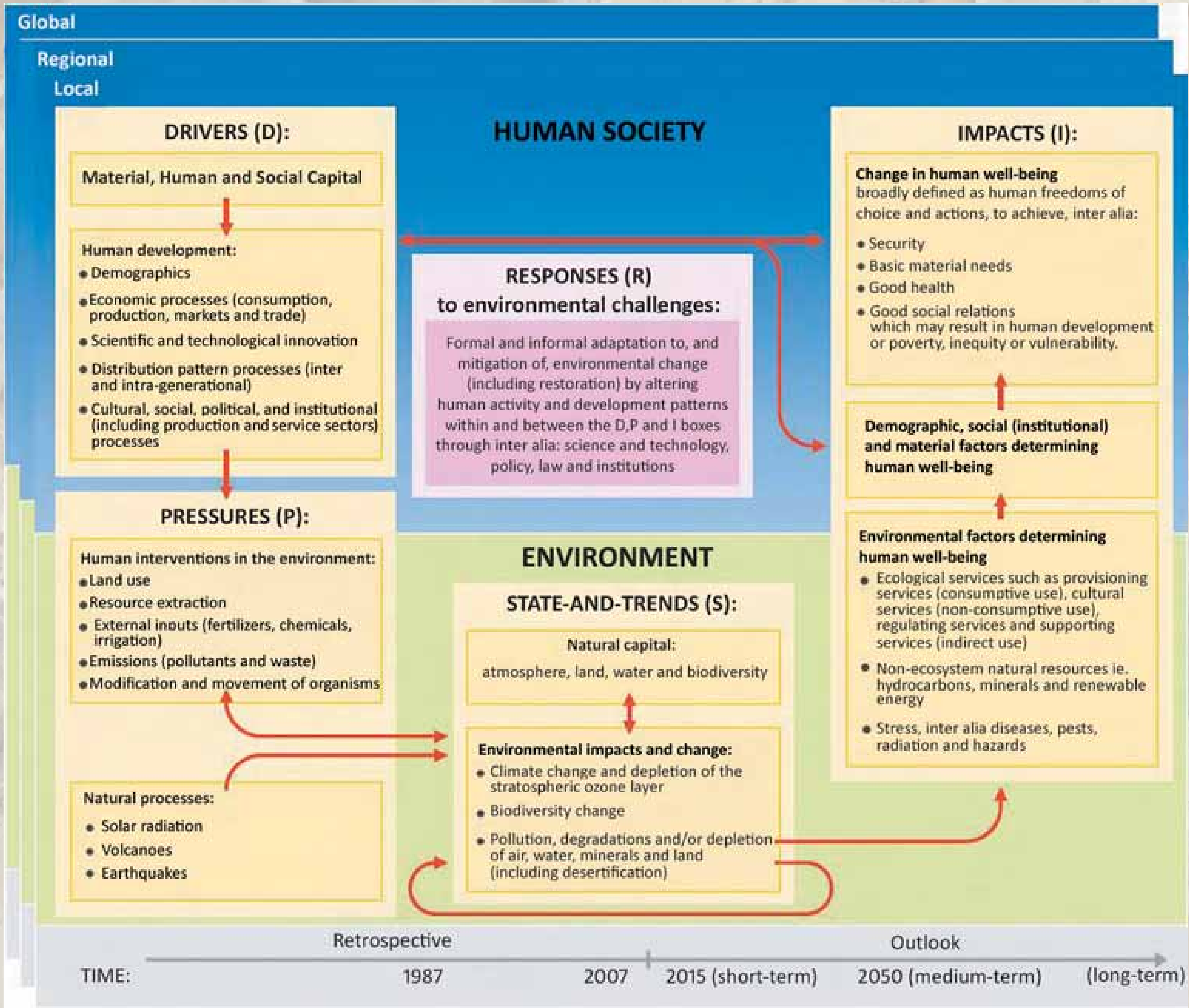

Figure A GEO-4 DPSIR conceptual framework. [Reproduced with permission from the United Nations Environment Programme. Global Environment Outlook – environment for development (GEO-4 Report, 2007). United Nations Environment Programme: New York]

Extensive non-sustainable low-density urban residential development in Maun, Botswana. [Barend Erasmus]

SECTION 2

Atmospheric system and climatic changes

Introduction

Stuart J. Piketh

The atmosphere is a thin skin of gases, liquids and solids (78,08% nitrogen) that surrounds the earth protecting its inhabitants from harmful solar radiation – mostly ultra violet radiation. It also absorbs terrestrial energy that heats the atmosphere to current temperatures. The presence of oxygen in the atmosphere (approximately 20,9%) is essential for the development and sustenance of life, so life on the planet would not be possible without the atmosphere. It is only the bottommost layer of the atmosphere, the troposphere, with which humans interact. This is also the layer in which all weather occurs.

The atmosphere serves as an important integrating medium between the lithosphere and hydrosphere within the biosphere. Emissions from land and ocean surfaces enter the atmosphere and are mixed together while being transported a few meters to several thousand kilometres over the globe. Nitrogen, oxygen and carbon dioxide in the atmosphere are representative of biogeochemical interactions which later links to other spheres of the global system.

The movement of air in the atmosphere, or atmospheric circulation, is driven by differential heating of the planet by the sun. The atmosphere and oceans are constantly driven to balance the excess energy received at the equator with the deficit of energy at the North and South Poles. The day-to-day weather experienced around the world is a consequence of this process. However, the atmosphere is not independent of the underlying land and ocean surfaces. For example, significant differences exist between the circulation in the Northern and Southern Hemispheres. This is a largely a function of the change in distribution of land and water masses between the two hemispheres. The Southern Hemisphere has a larger water component and is often referred to as the 'Water Hemisphere'.

Emissions into the atmosphere occur from natural and anthropogenic sources. The anthropogenic sources are potentially the most harmful to the natural environment, climate system and human health. Greenhouse gas emissions from anthropogenic fossil fuel combustion over the past century are currently thought to be driving increases in global average temperatures. It is believed that these temperature increases are likely to result in more severe weather conditions being experienced in the future. Over the past three decades, scientists have worked hard to understand the role that the atmosphere plays in the process of global warming. It has become evident from these efforts that the atmosphere, and its interaction with other global processes, is extremely complex. Global Climate Models (GCMs) have been developed to simulate the impacts of various changes in the atmosphere. These models (based on scenarios from past climate records and future predictions) aid in forecasting possible climate changes, help to identify vulnerable areas and can assist in response strategies.

It is extremely important that we obtain a good understanding of the drivers of atmospheric processes. This will ensure appropriate and sustainable management practices in the future. This chapter considers the role of the atmosphere and its interactions within the biosphere and the resulting impacts on climate system. The chapter also looks at emissions into the atmosphere and considers their consequences and management.

LEFT Atmospheric pollution. [Lauri Laakso]

Air pollution by residential coal fires. [Lauri Laakso]

Air pollution and the interactions between atmosphere, biosphere and the anthroposphere

Lauri Laakso
Jakobus J. Pienaar

Air pollution in southern Africa poses a serious risk to nature and human well-being. The high pollutant concentrations from domestic and industrial sources, combined with numerous wild fires, are enhanced by a specific meteorology that promotes long residence times and reduced vertical mixing. However, atmospheric pollution is a combination of natural and man-made sources, and to direct the reduction procedures efficiently, one has to know the contribution of different sources. For this estimation, good and updated emission inventories and background measurements are needed. The inventories and measurements are also imperative for regional air pollution and climate change modelling, and the validation of satellite observations. At administrative level, structural changes are needed to improve the authorities' capacity to implement the current legislation.

What is air pollution?

Air pollution is typically defined as the human-made part of atmospheric trace gases and particles, having a potential adverse effect on nature and human health. The same gases and aerosol particles are a natural part of the atmosphere and originate from natural sources like sea, vegetation and volcanoes. However, due to human activities like industry, domestic burning, traffic and increased wild fires (Figure 2.1), these trace compounds reach levels far beyond those natural levels adapted to by nature and vegetation over millennia. As the human-induced disturbances take place over short periods– much shorter than is needed for structural and genetical adaptation – humans and nature may not accommodate the changing environment.

Figure 2.1 Biomass burning (a) and industrial activities (b) are major regional sources of air pollution in southern Africa. [Lauri Laakso]

This changed environment affect humans and vegetation in several different ways. For example, higher-than-natural sulphuric compound levels increase the acidity of the soil. This changes the bacteria and nutrition balance and damages the cells responsible for photosynthesis and leads to, for example, reduced harvests. For humans, the same sulphuric compounds, when inhaled, irritate the lung surfaces and cause small but continuous stress to the body's immune system leading to respiratory and cardiovascular diseases. To highlight the economic burden of health impacts, Scorgie *et al.* estimated that in 2002 annual air pollution health related costs in the Vaal triangle area alone amounted to almost R300 million [1]. In a national context, approximately 2 000 children die annually due to lung-related illnesses, making it the sixth largest killer of children.

Another example of pollution with significant impact on nature and human well-being is the soot released in incomplete burning which, for example, occurs in domestic coal burning and wild fires. This black carbon has adverse effects on human health when inhaled. It also influences global climate, and black carbon is estimated to be the second most important driving force in climate change [2].

Because the concentrations of atmospheric tracers defined as pollutants are a combination of natural and anthropogenic sources (Table 2.1), it is not possible to discuss the anthropogenic part of the pollutants separately from the natural part [3].

Meteorological characteristics relevant for air pollution in South Africa

To be able to understand the behaviour and the interactions of the atmosphere, one has to understand some specific meteorological and seasonal characteristic unique to South Africa.

South Africa as a country is located in a latitude with large-scale down-welling air due to global atmospheric circulation. This downward motion, combined with a significant number of cloudless days and nights, creates a vertical atmosphere structure with several stable layers which reduces the vertical mixing (Figure 2.2a). The phenomenon is clearly visible during cold winter evenings when smoke from domestic burning remains close to the ground. The increased evening (and morning) pollution concentrations are a combination of two processes: increased emissions due to human activity and smaller mixing volume due to reduced mixing [4].

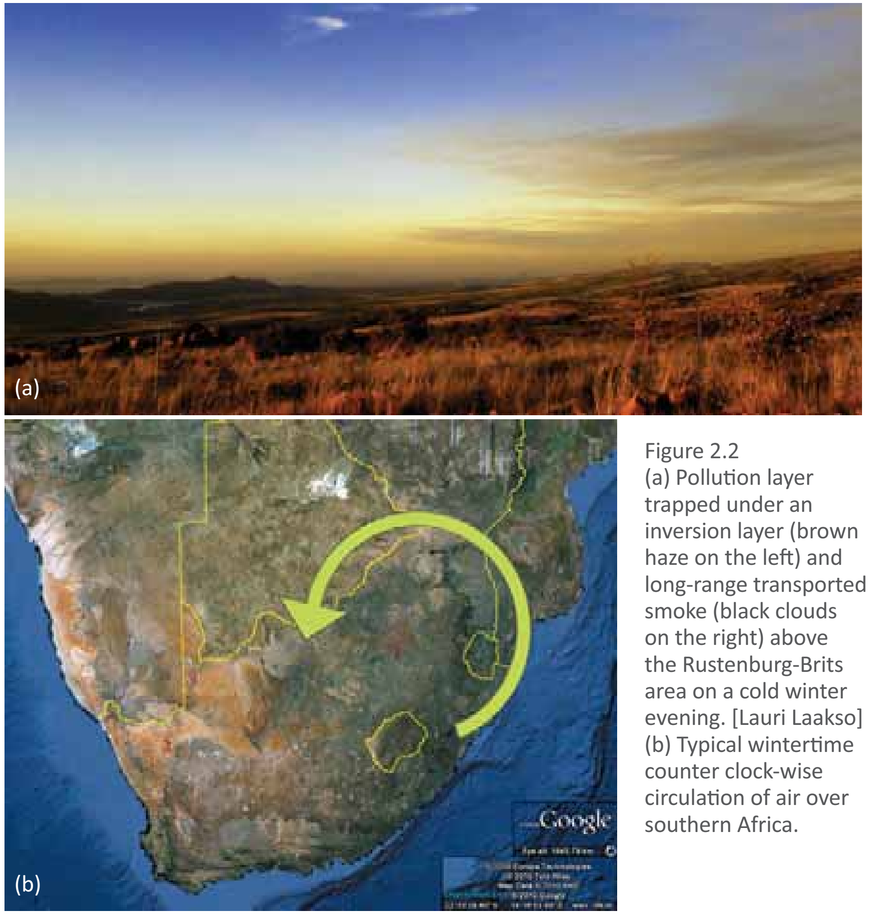

Figure 2.2
(a) Pollution layer trapped under an inversion layer (brown haze on the left) and long-range transported smoke (black clouds on the right) above the Rustenburg-Brits area on a cold winter evening. [Lauri Laakso]
(b) Typical wintertime counter clock-wise circulation of air over southern Africa.

The second important meteorological phenomenon characterising the atmospheric motion is the frequent (especially during the winter) counter-clockwise circulation which makes the same air gyrate above southern Africa [5]. This condition can prevail for several weeks at a time (Figure 2.2b). This re-circulation leads to a gradual increase of pollution levels in the air until the synoptic conditions change and pollution is blown away from central southern Africa.

The third important phenomenon is the significant variation in precipitation between the warm and humid summer months and dry and cold winter months (Figure 2.3). This variability affects the emissions from vegetation, the frequency of wild fires and the amount of pollution in the air – as the rain cleans the air, it brings the pollutants down to soil and rivers.

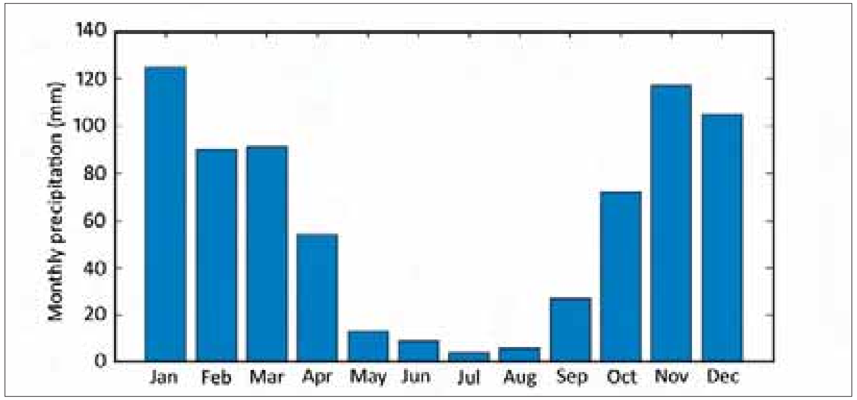

Figure 2.3 Average monthly precipitation in Johannesburg. [6]

Major pollutants and their sources in southern Africa

Table 2.1 lists some relevant air pollutants in the South African context together with major sources and impacts.

The first column in the table contains some of the most important pollutants. The next two columns describe the major anthropogenic and natural sources of these pollutants and the two last columns show the adverse effects on humans and vegetation.

Table 2.1 Most important pollutants relevant to South Africa, their sources and some adverse effects.

Pollutant	Anthropogenic sources	Natural sources	Effects on humans	Effects on vegetation and environment
Particulate sulphates and SO_2	Energy production, domestic coal burning, metallurgy	DMS from oceans, volcanoes	Adverse health effect when inhaled	Acidification of soil and aquatic systems; direct damages to plants
NO_x	Combustion processes (biomass, industry, wild fires, traffic)	Biological activity	Adverse health effect when inhaled	Acidification of soil and aquatic systems; direct damages to plants
O_3	Chemical reactions of anthropogenic hydrocarbons	Chemical reactions of biogenic hydrocarbons	Adverse health effect when inhaled	Direct damages to plants
VOC_s	Industry, especially petrochemical	Vegetation	Some species harmful to humans	Adverse effects especially on fauna
Aerosol particles	Industry, wild fires, domestic burning, traffic	Dust, sea salt, vegetation	Adverse health effects when inhaled on respiratory and blood-vascular system; toxic compounds like heavy metals	Effects on climate and precipitation; deposition of harmful compounds like heavy metals
CO_2	Coal-based power production, traffic, domestic burning	Decomposition, other natural processes	Impacts on climate change	Impacts on climate change

How and why atmosphere, humans and nature are linked to each other

The atmosphere-vegetation-anthroposphere is a linked system (Figure 2.4), and if all the parts are not properly understood, it is not possible to understand how the total system, and especially the indirect influences on humans and nature, functions in general. This general understanding is needed to comprehend the long-term responses caused by changes in human activities, and even more importantly, changes caused by climate change.

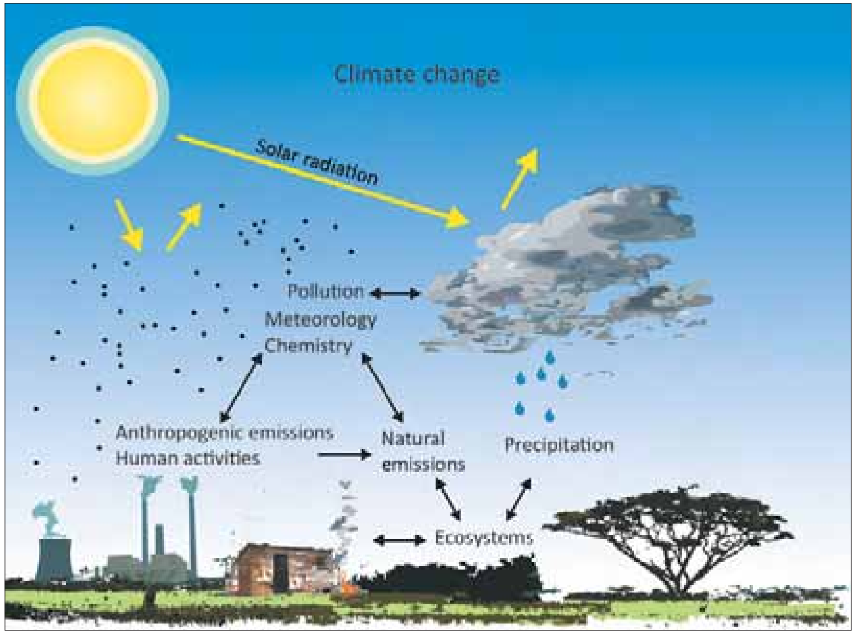

Figure 2.4 Interactions between the vegetation, humans and atmosphere. Natural and anthropogenic emissions affect the regional air pollution, precipitation and global climate, and these affect the natural emission and vegetation with several different feedback mechanisms. [Reproduced with permission from Martin Smit]

Typical human activities release dust, sulphate and nitrogen compounds, organic vapours (VOCs) and soot. However, a significant fraction of particulate mass originate from organic vapours emitted from vegetation, which after a chain of chemical reactions, condense on existing particles and affect the NOx and ozone (O_3) chemistry (Table 2.1).

The particulate matter, and especially the smallest particle sizes, affects the amount of solar radiation penetrating to the earth's surface, partly by directly reflecting the solar radiation back to space and partly by affecting the properties of clouds and precipitation. Precipitation and solar radiation affect the vegetation, and even small changes in precipitation may be fatal to very sensitive ecosystems like Karoo [7]. In a regional context, these changes affect the food production potential and may lead to human emigration.

Suggestions on what should be done

South Africa has new air pollution legislation with internationally comparable pollution limits. This legislation is aimed at reducing the pollution levels to concentrations relatively safe for humans and the environment. However, many of the aims are currently not being reached resulting in serious health problems due to direct pollution exposure and enrichment of certain pollutants in the food chain. Added to this, food production is reduced due to direct plant effects.

Despite some problems with legislation, the main problem is that governmental and provincial authorities lack the capacity to implement existing legislation. Most of the technical capacity resides in industry and consulting companies. As a result, the authorities are forced to buy services without having enough knowledge to negotiate fair contracts or to adequately evaluate results.

As we have argued, the air pollution issue is a complex mixture of meteorology, physics, chemistry, human activities and natural ecosystem processes. It is not possible to have general suggestions that address all aspects of the problem.

This section approaches some particular aspects of air pollution from two different points of view: what should be the practical focus of the authorities; and what are the long-term scientific questions to be addressed? The suggestions for the authorities are more practical and short-term oriented whereas the scientific questions are important and vital for long-term sustainability. The section concludes by discussing some cost-efficient ways to reduce air pollution.

Short-term considerations

Currently, municipalities are required to monitor air pollution. This approach is not cost-efficient and does not provide high-quality data with correct interpretations. The problems include the following:

(a) The data interpretation and technical skill often resides with one or two individuals.

(b) Many of the instruments need continuous maintenance. It is not cost efficient to have workshops, specific tools and spare parts at municipal level. On the other hand, ordering spares only after a problem has arisen takes time and creates disruptions in time-series data of up to several months. In addition, most instruments need at least monthly calibrations. It is not cost efficient to have different sets of calibration instruments in each municipality.

(c) Related to the previous point, technical personnel at the municipal level very rarely encounter a specific technical problem and thus lack experience and specialist skills to service instruments.

(d) The small number of air quality officers cannot become sufficiently knowledgeable to negotiate on an equal level with industrial companies and service providers. The problems are especially pertinent when related to technical matters.

(e) Often the companies provide air pollution monitoring solutions, like specific data formats and visualisation programmes, which are bound to the products of a specific company. In some cases the same company provides instrumentation, training and continuous maintenance services. Proper training of the governmental employees reduces the need for consulting services and this may lead to a conflict of interests.

A solution to the problems listed is to develop a stronger role for provincial consortiums and academic institutions that have enough knowledge about pollution problems and can provide good technical solutions, as well as the technical capacity for servicing the instruments. This technical capacity should include provincial level workshops with technical support and calibration facilities available to all members of the consortiums. The interaction with educational institutes will also provide government with new well-educated personnel and help in interpreting results through theses and other academic work. This kind of consortium could also relieve capacity constraints as the data interpretation and quality assurance can be done efficiently by specialised people to help solve potential problems rapidly.

Long-term considerations

One of the major hindrances in air pollution reduction work in South Africa is the lack of updated regional emission inventories. The only scientific quality inventory currently available is from the SAFARI 2000 campaign. Without inventories, trustworthy pollution modelling work is impossible and the emission reduction procedures cannot be implemented in a cost-efficient way.

Another hindrance to air pollution studies is the lack of background observations. Part of the pollutants originates from natural sources; part of them from anthropogenic sources. The background measurements help in explaining the sources of pollution in urban areas. In an ideal case, the human contribution is the concentration of pollutants within a specific city minus the concentration of pollutants measured on a clean background area upwind from the city.

Another need for background observations arises from long-term changes in ecosystems caused by climate change, changes in land use, changes in power production capacity, and such like. If the monitoring site is in the vicinity of pollution sources, small long-term changes are hidden by changes in individual nearby sources dominating the concentrations of pollutants. Observations far away from individual sources provide information on regional and global changes in atmospheric composition and radiative balance. Such measurements are also imperative for regional air pollution and climate change modelling, and the validation of satellite observations.

South Africa, as the most developed country in Africa, has a leading responsibility to monitor long-term changes of the atmosphere. The Global Atmospheric Watch station at Cape Point is the most important monitoring station in Africa. However, in addition to this marine station, a new background station in a remote part of the savanna region of central South Africa is needed. The scientific aim of this station should be to monitor the long-term changes in air pollution and responses of the savanna ecosystem to climate change.

Cost-efficient possibilities to reduce air pollution

There are several cost-efficient ways to reduce the pollution levels with limited investments. From a health effects point of view the focus should be on emissions taking place in proximity to people – in their home environment, work places and in urban environments. Some emission sources with easy reduction potential are as follows:

(a) The domestic burning practices in informal settlements. An easy way to reduce the emissions from such burning is to start the fire from the top of the fuel instead of the bottom, as is traditionally done.

(b) Pollution from car exhausts. The inspection of engines should provide more feedback on badly serviced motors. Properly serviced engines save money as they last longer and use less fuel with the additional benefit of reduced air pollutant emissions.

(c) South Africa is improving existing and creating new power production capacity based on coal. As it is not realistic to convert to other options, despite significant green house gas emissions, the new capacity built should be equipped with emission reduction technology and the emission reduction technology on existing capacity improved during routine maintenance operations.

(d) Wild fires and grass burning in general should be controlled more strictly and more attention should be given to increase public awareness of the adverse effects of wild fires.

(e) More effort should be put on mine dump emission control as the dust from these dumps negatively affects the well-being of a significant number of workers and nearby residents.

The South African Air Quality Information System (SAAQIS)

Peter Lukey
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Over the past decade much energy has been expended on reviewing and modernising the air quality legislation in South Africa. In 2004, the new National Air Quality Management Act was passed and replaced the Air Pollution Prevention Act of 1969. The effectiveness of any legislation is measured by the manner in which it is rolled out and implemented. In 2007, a National Framework for Air Quality Management was published to guide the implementation of the new law. Information management has been identified as a critical component of this process. This chapter outlines the role of information management in the effective enforcement of the new legislation. The existing infrastructure that has been developed, the South African Air Quality Information System (SAAQIS), as well as plans for future developments are described in detail.

Introduction

On 11 September 2007, government published the 2007 National Framework for Air Quality Management in the Republic of South Africa [1]. The National Framework introduced the 'Environmental Governance Cycle' as illustrated in Figure 2.5. The 'information management' component is often considered to be the engine that drives this cycle as 'informed decision making' is regarded as being fundamental to good governance. In other words, decisions can only be well informed if decision makers have ready access to accurate, relevant, current and complete information.

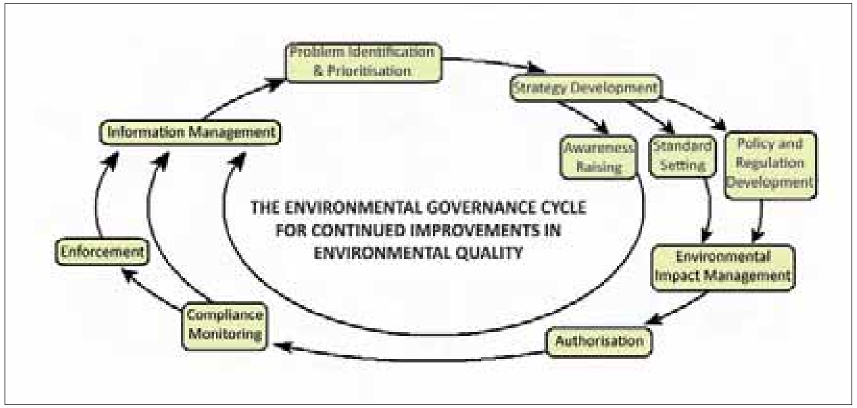

Figure 2.5 The Environmental Governance Cycle introduced in the 2007 National Framework for Air Quality Management.

Given government's clear acknowledgement of the importance of information management, it is hardly surprising that the National Environmental Management: Air Quality Act (No. 39 of 2004) (hereinafter 'the AQA') makes numerous references to information and information management requirements, including, among others:

- the inclusion of national norms and standards for air quality information management within the National Framework,
- public access to air quality information, and
- the consideration of sound scientific information when declaring a Controlled Emitter or a Controlled Fuel.

The AQA also includes an entire section on national monitoring and information management standards.

With respect to the AQA's information management standards, the section dealing with 'National monitoring and information management standards' requires that the national framework must establish national standards for: (a) municipalities to monitor (i) ambient air quality, and (ii) point, non-point and mobile source emissions; (b) provinces to monitor (i) ambient air quality, and (ii) the performance of municipalities in implementing this Act; and (c) the collection and management of data necessary to assess (i) compliance with the Act, (ii) compliance with ambient air quality and emission standards, (iii) the performance of organs of state in respect of air quality management plans and priority area air quality management plans, (iv) the impact of, and compliance with, air quality management plans and priority area air quality management plans, (v) compliance with the Republic's obligations in terms of international agreements, and (vi) access to information by the public.

The AQA's requirement for national standards for information management relating to compliance with the Republic's obligations in terms of international agreements includes information management requirements relating to greenhouse gas emissions under the United Nations Framework Convention on Climate Change (UNFCCC) and information on ozone-depleting substances under the Montreal Protocol on the Protection of the Ozone-Layer.

In order to meet the information requirements for good air quality governance and ensure full compliance with the AQA, the Department of Environment, together with the South African Weather Service (SAWS), have been developing the South African Air Quality Information System (SAAQIS) and the National Ambient Air Quality Monitoring Network (NAAQMN) since the promulgation of the AQA in early 2005.

South African Air Quality Information System

In essence, the SAAQIS is an electronic web-based information management system that has the stated objective of providing stakeholders with easy access to all relevant information about air quality in South Africa. The SAAQIS further provides different stakeholders with different useful on-line applications to support the effective and efficient management of air quality. The NAAQMN, which consists of a network of government-owned automatic ambient air quality monitoring stations located around the country, collects and feeds information into the SAAQIS.

Both the SAAQIS and the NAAQMN are already in operation, but both systems are 'works in progress' and should continue to grow in size, scope, utility and complexity over the next few years.

As far as the SAAQIS is concerned, the SAAQIS Phase I Development Project has established the basic SAAQIS architecture (see Figure 2.6 and www.saaqis.co.za).

This basic functionality includes interactive maps that may be zoomed into for more detail (metadata) on the ambient air quality monitoring stations that feed information into the SAAQIS – location, photographs of the stations, sources and types of pollution monitored, and so forth (Figure 2.7). The interactive maps also provide a direct link to a tool that generates useful graphs of what the station is measuring (Figure 2.8).

The SAAQIS also provides access to all available air quality-related documentation including government policies, legislation, regulations, Government Notices, air quality management plans and the National Air Quality Officer's Annual report. There is also a contact list and an electronic means of submitting air quality-related complaints (Figure 2.9).

Figure 2.6 The SAAQIS home page.

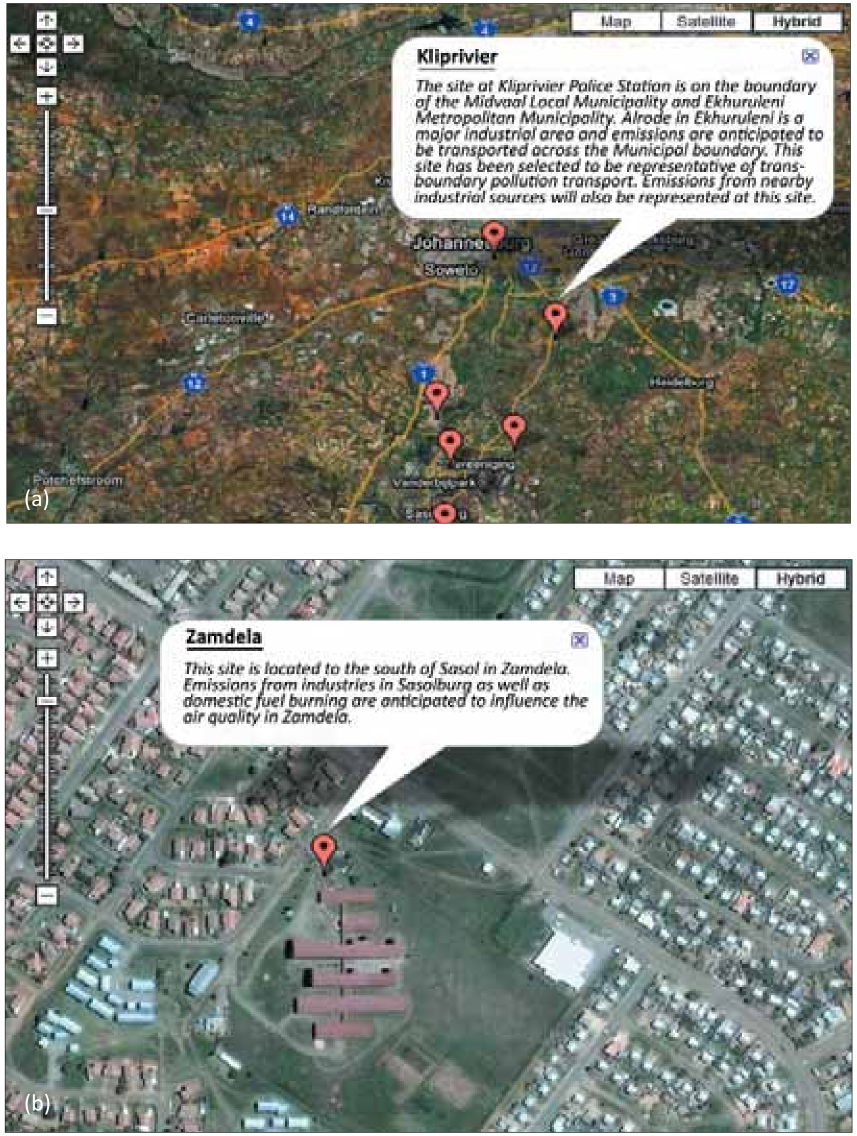

Figure 2.7 Two examples of the information provided by SAAQIS interactive maps.

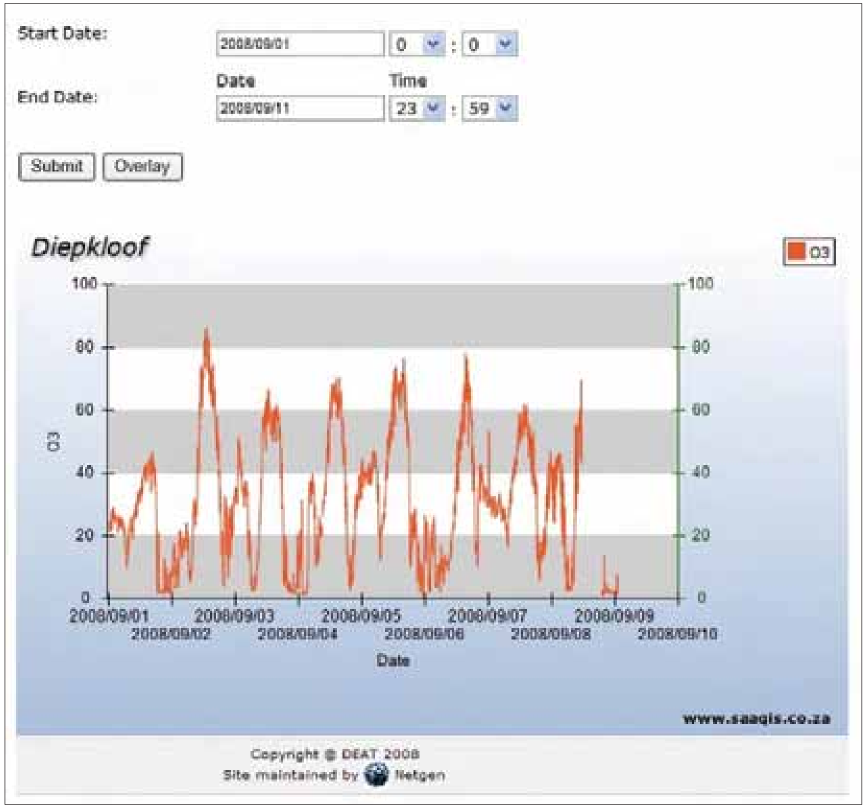

Figure 2.8 An example of a graph generated by the SAAQIS illustrating monitoring data from a particular station.


Complaint Details

For air quality related complaints please fill in all the details in the form below. This form will be submitted to the relevant air quality department. If you have entered your email address you will receive an email confirming that your query has been logged in the SAAQIS system and that the query has been forwarded to the relevant department. You will also receive a reference number for this query

First Name:
Surname:
Cell Number:
Email Address:
Confirm Email:
Province: <Select Province>
Town/Municipal Area:
Incident Location:
Complaint Type: Poor Air Quality
Description Of Complaint:
Date Of Complaint: 23/10/2008
Have you reported this before?
No Yes
Submit Reset

Figure 2.9 The SAAQIS complaint form.

In the second phase of SAAQIS development, to be initiated in early 2010, the system will be expanded to incorporate a national atmospheric emission inventory, including greenhouse gas emissions. This inventory will provide for the periodic submission of emission data by various information holders as detailed in atmospheric emission monitoring and reporting regulations to be published in terms of the AQA once the system has been established and tested in late 2011. This information will allow SAWS to fully deploy its air pollution forecasting services within the SAAQIS that is already under development.

In further phases of SAAQIS development, the department also hopes to develop access to free air quality modelling software for use in, among others, specialist air quality studies associated with environmental impact assessments (EIAs) and any required Atmospheric Impact Reports as contemplated in the AQA.

As far as the NAAQMN is concerned, the first networks of national government owned stations were established in the areas declared as National Priority Areas, or air pollution hot-spots, in terms of the AQA, namely, the Vaal Triangle Air-shed Priority Area and the Highveld Priority Area. The Vaal

Triangle Air-shed network consists of six monitoring stations established in 2007 and the Highveld network consists of five stations established in 2009. These 11 stations feed data to the SAAQIS and this information is available in user-friendly forms on the SAAQIS website.

Although this national network of monitoring stations is planned to grow to cover all current and potential air pollution hot-spots over the next ten years, there are already over 80 other stations owned by provincial government departments and municipalities around the country (Figure 2.10). Over the next few years, these stations will also start providing data to the SAAQIS.

A - DEAT Vaal Triangle Priority Area
B - DEAT Highveld Priority Area
C - Gauteng Province
D - Western Cape Province
E - Kwazulu-Natal Department of Agriculture and Environmental Affairs
F - Mpumalanga Department of Agriculture and Land Administration
G - North West Province
H - Rustenburg Municipality
I - Limpopo Province
J - City of Johannesburg
K - Ekhuruleni Municipality
L - City of Cape Town
M - eThekwini Municipality
N - Nelson Mandela Bay
O - Tshwane
P - Msundusi Municipality
Q - Mangaung Municipality
R - Buffalo City, East London

Figure 2.10 National, provincial and municipal air quality monitoring networks with detail of the City of Cape Town's network (inset).

Furthermore, a number of privately owned monitoring stations and networks already provide data to the SAAQIS.

The City of Cape Town's network (see inset in Figure 2.10) is a good example of a municipal owned and operated ambient air quality monitoring network. Cape Town has a well-established network of twelve AQM stations spread across the Greater Cape Town area. This network has been built up over the past twenty-five years and is run in-house by well-trained and experienced staff to US EPA requirements. Four of the stations are subsidised, to various extents, by local industry. Gas analysers are mostly Teledyne API units while PM-10 analysers are TEOM 1400A/Bs. The analysers are regularly calibrated using dilution calibrators and Cape Town's Athlone AQM station is accredited to ISO 17025. It is the only SANAS accredited station in the national, provincial and local government operated networks. Data collected by LINUX based loggers can be exported in CSV format [2].

Conclusion

The overall objective of SAAQIS is to provide a well-structured database that integrates the various sources of data and information on air quality into one easily accessible virtual place. The system will ultimately be the focal point for managers of polluting industrial sources to provide information to fulfil their legal reporting requirements, local governments to make available the status or air quality within their designated boundaries, and central government to manage and provide information relative to air quality management. SAAQIS will always be a work in progress as new ideas and technologies are integrated into the software. The success of SAAQIS depends on a few key factors. The first is political will to successfully address the problem of air quality in South Africa. Currently this political will is alive and vibrant and much progress has been made in establishing and implementing the new air quality regulations. Second, there must be increased responsibility and willingness from all stakeholders to improve air quality in South Africa. Finally, there needs to be effective dissemination of information on all aspects of air pollution. SAAQIS will go a long way in assisting to address these important components of air quality management.

Marion Island's disappearing ice cap

K. Ian Meiklejohn

One of the most visible consequences of climatic warming has been the disappearance of permanent snow and melting of a fossil ice cap on Marion Island. In 1966, approximately 10% of the Island's 293 km² was covered by permanent snow and ice; today, only a few isolated patches remain. Between 1948 and 2009, it is estimated that approximately 42 million cubic meters of ice melted from the ice cap, and its surface area was reduced from 107 Ha to approximately 7 Ha. Recent evidence indicates that the pace of melting has continued the current ice cap is losing between 1 m and 1.5 m of ice over its surface area every year.

Geology and geomorphology of Marion Island

Marion and Prince Edward Islands are part a Hawaiian-Type, intra-plate, shield volcano situated in the Southern Ocean, over a mantle plume [1]. The islands, with aerial extents of 293 km² and 46 km² respectively, are geologically young with oldest dated basalt lavas on Marion Island being in the region of 450 000 years old [1]. Basalts from the earliest eruptions are the densest on the Island, which are from massive basalt flows that are called "grey lavas". Between the first eruptions and the present day, there have been as many as eight periods of volcanic activity. The more recent eruptions that commenced between 13 000 and 10 000 years ago and, which still episodically occur, are basalts that are less dense, called "black lava", comprised by aa, pahoehoe and blocky lavas similar to those found in Hawaii, as well as scoria [1]. Between volcanic episodes, Marion Island experienced glaciations during the stadials (cold parts) of the current Ice Age. The interbedding of the glacial sediments with basalt, which bares testament to this, is clearly visible in the strata of Marion. However Prince Edward Island, only just over 20 km away from Marion, does not exhibit any glacial evidence [2]. This is thought to be because the smaller island is too small and has too low an altitude for an ice cap to develop [2]; the highest point on Marion Island is 1231 m.a.s.l. and that of Prince Edward Island is 672 m.a.s.l.

It has been suggested that there may be a link between glaciation and volcanism on Marion Island [3]. This was particularly the case following the Last Glacial Maximum, where the rapid loss of ice that took place when the Island warmed and because of isostatic rebound, local crustal movement resulted in substantial volcanism. It is this last volcanic period that has had the greatest impact on the current visible landscape, in the form of lava flows and over 130 scoria cones [2] (see Figure 2.11). The last Glacial Maximum, 18 000 years ago represents the greatest aerial extent of glaciation on Marion Island [4]; only the areas of highest relief were not covered by ice [5].

The Marion Island ice cap and its surroundings

The last remnant of ice on Marion, called the Ice Plateau, is found in a basin in the centre of the Island at just over 1000 m.a.s.l. and is only a fraction of its original size. Early reports at the time of the annexation of the Prince Edward Islands by South Africa in 1948 indicated a substantial ice cap and permanent snow cover [6]. The permanent snowline was first estimated to have been 600 m.a.s.l., while aerial photographs taken in 1961 showed permanent snow existing down to between 650 and 800 m.a.s.l. [6] (Figure 2.1). The most striking evidence of the loss of ice is from repeat photography; the earliest photograph of the Ice Cap (Ice Plateau) is from 1966 [7] and when compared to the most recent images from 2009, it is clear that the landscape has been altered considerably (Figure 2.12).

In the present-day, apart from the tiny remnants of ice, the only permanent snow is found in shaded sites at the highest altitudes on the Island. The rest of the interior of Marion is devoid of vegetation and has a distinct periglacial environment, with the ground freezing seasonally to a depth of only 20 cm at 1000 m.a.s.l. [5]. It is difficult to imagine how glacial ice could survive in such a "warm" environment.

New digital elevation data and high resolution QuickBird satellite imagery (50 cm resolution) has facilitated remapping of the ice and snow extents. In addition, much of the geology in the interior of Marion Island comprises

Figure 2.11 Satellite Image of Marion Island with an interpreted permanent snow and ice cover for 1965 [7] and the location of the 1980 lava flows [8]. (Image: Courtesy of NASA).

scoria, which has a low density and is easily moulded by ice, and it is possible to distinguish the boundary of ice cap when it was at a maximum, or else when it was stable for a long period of time (Figure 2.13). Other features, from satellite imagery and field observations that were used to model the position of the ice cap included moulded surfaces (Figure 2.13), striations on rock surfaces and moraines. From the earliest reports [6], it is apparent that this ice level approximately corresponds to that at the time of annexation. The boundaries of the ice were mapped, together with interpreted contour lines, using Geographic Information Systems technology and used to create a 3-dimensional landscape surface (Figure 2.14). It is now possible to compare the modelled Ice Plateau surface with the current DEM (Digital Elevation Model) (Figure 2.14).

The amount of ice-lost in the last 50 years amounts to a maximum depth of 90 m (Figure 2.14), a total volume loss of just more than 42 million cubic metres (38 million tons), and a reduction in aerial extent from 107 Ha to approximately seven hectares in 2009. It is difficult to accurately determine the current extent of the ice as it is all covered by ash-like scoria. A further impact of the melting of ice cap as well as the previously frozen slopes of the Ice Plateau has been slumping on the slopes, which is also visible on satellite images (Figure 2.13).

It would be easy to ascribe the loss of ice to melting that has taken place through climatic amelioration. In support, other studies have shown that the air temperatures at the Meteorological Station increased by approximately 1.2°C between 1966 and 1999 [5]. However, aerial photography from 1988 shows that most of the ice had already melted by then. The last major volcanic eruption on Marion took place in 1980 [8] and it possible that in addition to climatic warming, geothermal heating may have been responsible for a large part of the loss of ice. Nevertheless, an observed annual lowering of the floor of the basin that is the Ice Plateau of between one and one and a half metres between 1996 and 2009, is clear evidence that warming through climate change is resulting in changes to the landscape of Marion Island.

Consequences of climatic warming on the Marion Island landscape

In addition to melting the Marion Island ice cap, climatic warming will also have other impacts on the landscape. The higher temperatures are likely to reduce the extent and length of seasonal freezing of the ground. As many of the slopes in the interior of Marion Island comprise scoria, and their stability in winter depends on them being frozen, warming is likely to result in instability and result in slumping and sliding on the steeper slopes. However, while the average temperature warms, the reduced cloud-cover predicted, and already being observed, on the Island will result in a loss of nocturnal long-wave radiation and colder minimum ground temperatures [5]. This will increase diurnal frost activity in the ground and result in disturbance that may impede colonisation by plants [5].

As indicated earlier, the exact extent and depth of the remaining ice on Marion Island is not possible to determine. However, there is little doubt that the ice will continue to melt and provide a further example of a changing environment on Planet Earth. While other influences, such as geothermal heating may contribute, the current observed increasing temperatures are recognised as one of the major causes of the current reducing Ice Plateau.

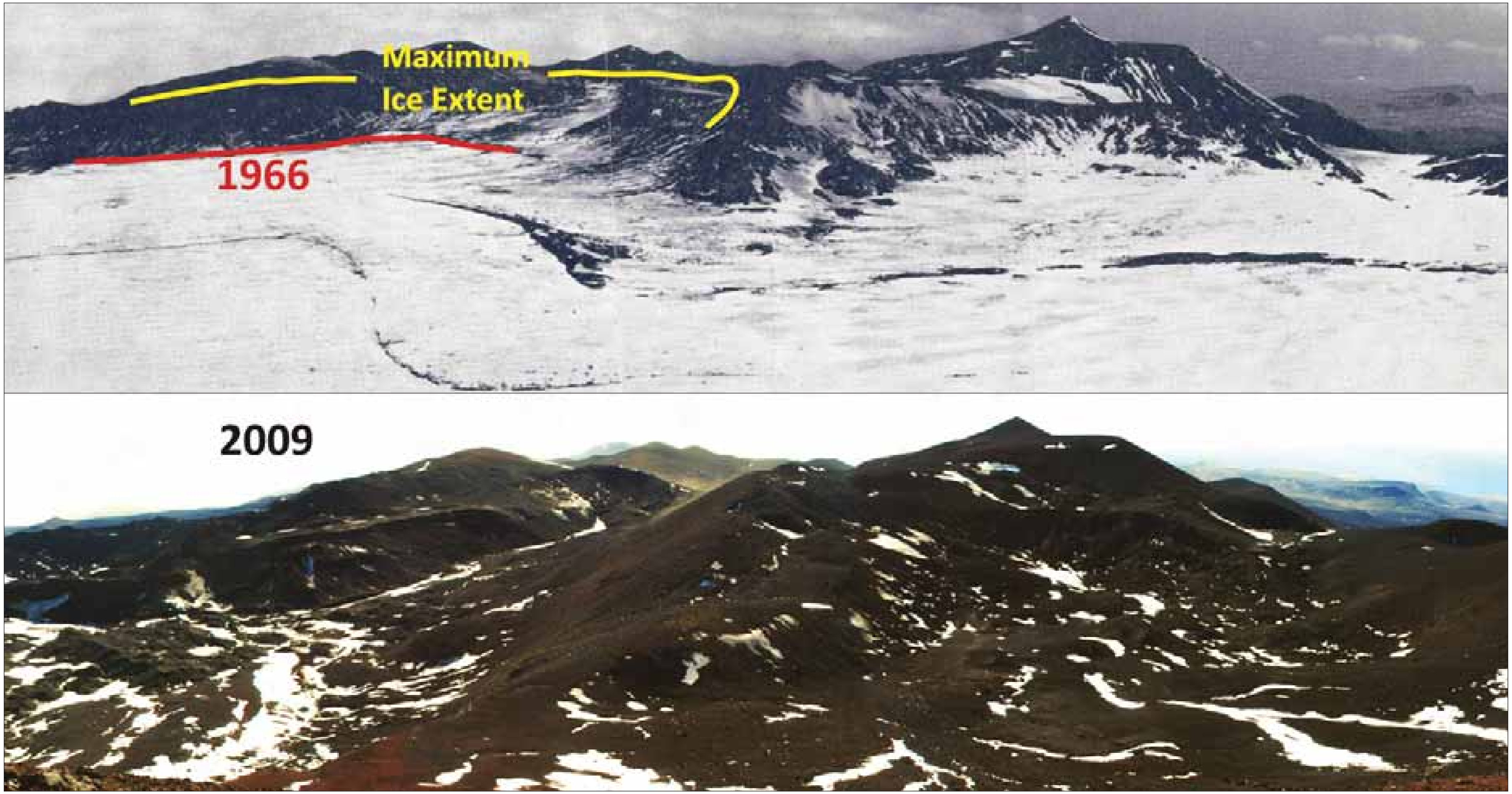

Figure 2.12 Comparative imagery showing the Marion Island Ice Cap (Ice Plateau) in March 1966 [Van Zinderen Bakker EM, 1971] [7] and then again in April 2009.

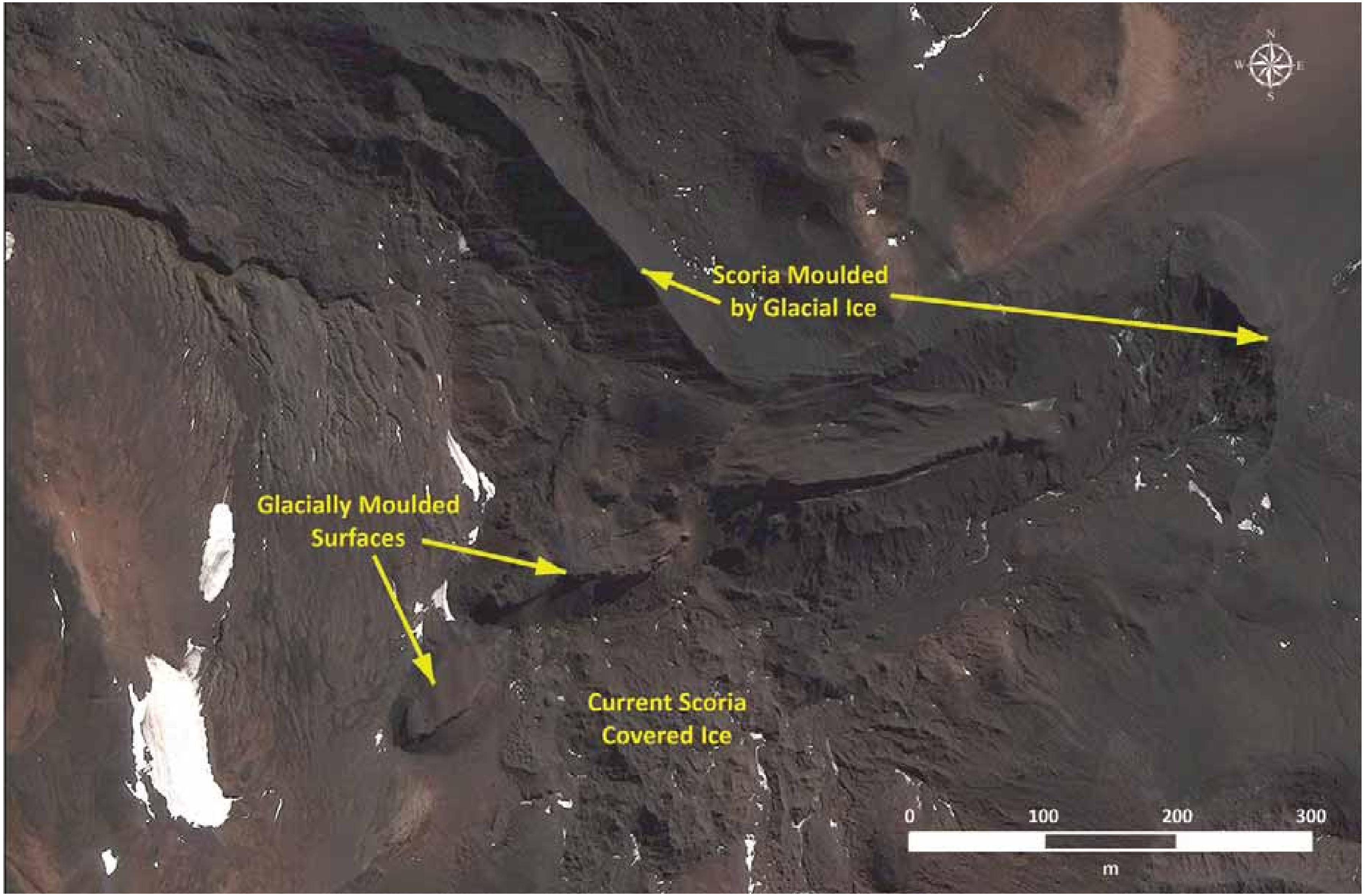

Figure 2.13 Topography of the Marion Island Ice Plateau area showing moulded landforms and breaks in slope that were used to model the maximum position of the ice cap (Imagery: QuickBird images from Digital Globe).

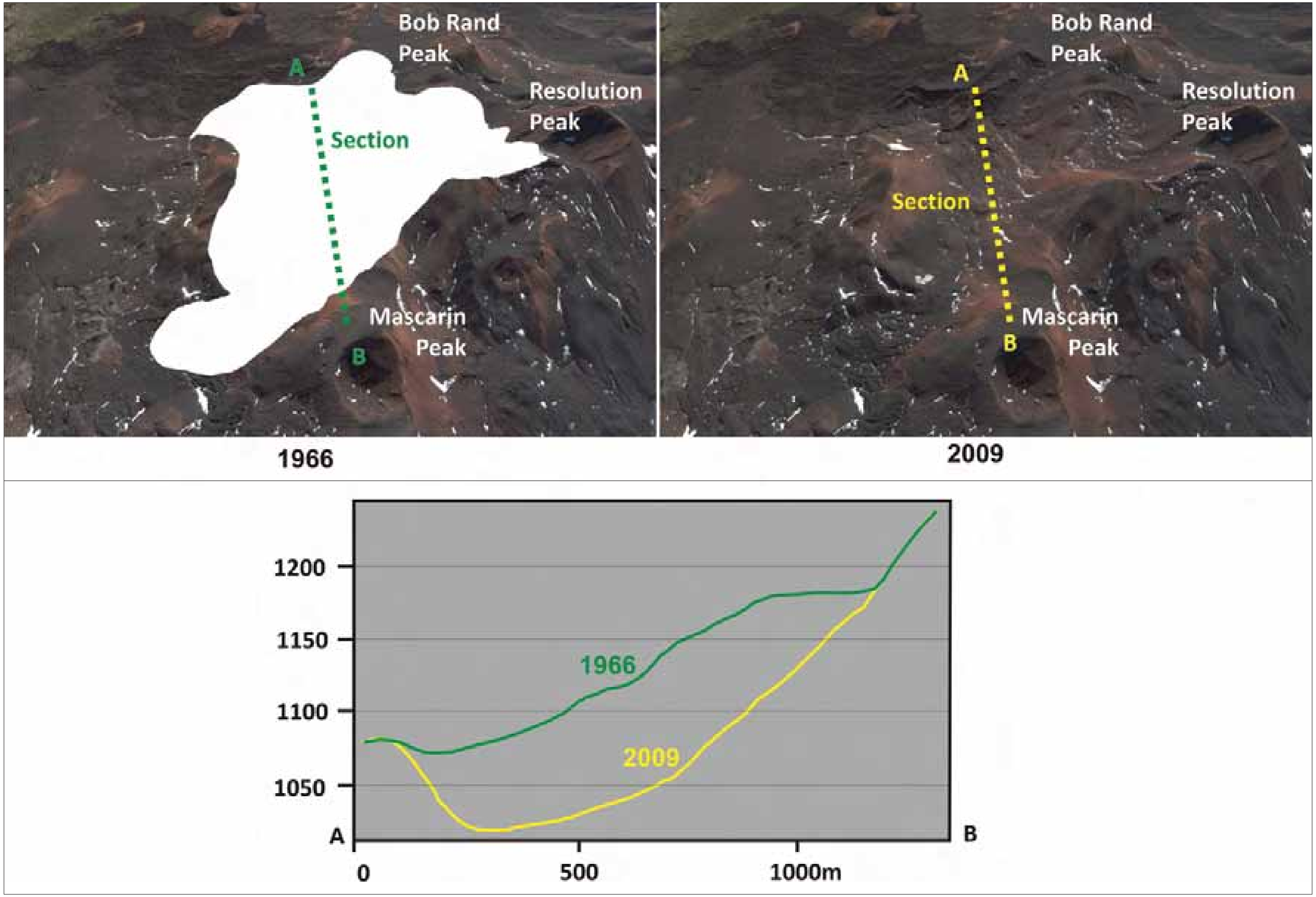

Figure 2.14 Modelled orthographic images of the Marion Island ice-cap (Ice Plateau) in 1965 and in 2009, together with profiles for the same periods. (Imagery: QuickBird images from of Digital Globe).

Climate change, species and ecosystems

Why systematic observation is critical for a predictive understanding of South African ecosystems and biodiversity

GUY F. MIDGLEY

Credible projections of impacts of climate change and other important pressures on ecosystems and their biodiversity (often called 'global change') are challenging. This is because the scientific tools available are lacking, because the country has high levels of biodiversity, and because of gaps in our understanding of how these ecosystems function. Systematic observation provides efficient reality checks of projections for refining or even rejecting current approaches. The next decade of apparently unavoidable climate change could allow projections of modelling and experimental approaches to be tested if adequately monitored. The information derived will be important for climate policy and adaptation measures.

Introduction

In its fourth assessment report, the Intergovernmental Panel on Climate Change (IPCC) concluded that the there is high confidence (a greater than 90% chance) that the activities of human society, which have increased greenhouse gas concentrations in the atmosphere, had very likely caused at least half of the global temperature increase recorded since the mid-20th century [1]. The burning of fossil fuels (coal, oil and natural gas) and to a lesser extent the transformation of ecosystems by land use (primarily through tropical deforestation), have now been shown to have caused a significant increase in the level of greenhouse gases (mainly carbon dioxide, but also methane, nitrous oxide and industrially-synthesised gases) in the atmosphere.

Apart from changing the heat balance of the atmosphere, with associated impacts on macro-climate, changes in CO_2 directly affect some of the most important natural processes on land. These include increasing plant photosynthesis and the productivity of vegetation. Climatic effects will include warming and changes in rainfall patterns that are projected to affect a multitude of biological and ecological processes on land. It is now a major challenge to biological scientists to assess what the potential impacts of these atmospheric and climate changes might be on natural ecosystems and their biodiversity, and how these impacts might best be managed to reduce adverse impacts on human society.

The challenge of projecting these impacts is compounded in this country. South Africa is noted for exceptionally high levels of terrestrial biodiversity, both in terms of its species richness and endemic species numbers, emerging as well above average in global analyses [2, 3]. There is also a high dependence on and demand by society for the services derived from natural ecosystems (with sometimes high rates of land surface change) and ongoing changes in these demands in response to national and international socio-economic drivers, which have important effects on ecosystems and biodiversity.

Several recent analyses suggest that projected climatic and atmospheric change may result in significant spatial shifts in preferred climate conditions for southern African species [4] and may change the structure of ecosystems (for example, by changing a grassy landscape into one dominated by trees) [5-9].

The modelling and experimental tools available to biologists to make credible projections of these changes over the next several decades are in active development and thus provide only a part of the picture necessary for useful planning responses. If we accept that some level of climate change over the next few decades is unavoidable (as suggested by the IPCC), it seems that this period of climatic change provides a unique opportunity to gain as much understanding as possible.

Consequently, systematic observation of the responses of species and ecosystems to the initial phases of climate change in conjunction with other stresses placed on ecosystems, including the impacts of extreme events, will prove crucial in testing the predictive capability of models and modelling approaches that are being used and are under development to address climate change impacts projections. In this chapter, I briefly outline how systematic observation could be optimally used in conjunction with other approaches to improve our understanding and suggest that the biological science community could usefully aim to co-ordinate their activities in a comprehensive programme to make better use of all of these approaches.

Projections for South African ecosystems and biodiversity under climate change

The majority of South Africa's natural biomes [10] are dominated to some extent by grasses with varying cover of woody elements [5], either shrubs (Nama-Karoo Biome), trees (Savanna Biome), or simply grass (Grassland Biome). However, two highly species-rich biomes of the winter rainfall region (Fynbos and Succulent Karoo) seldom show grass dominance. It is noteworthy that transitions between these distinct ecosystem structural 'states' (represented by biomes) occur over quite short distances. These transitions may often be determined by climate, or interactions between climate and disturbance regime. The implication is that changes in climate (and related changes in disturbance) may cause shifts in ecosystem state and related biodiversity changes in many parts of the country. This perspective contrasts with the dominant current view pervasive in Northern Hemisphere ecology that such changes due to climatic shifts will be driven by species shifts in geographic range that will occur individualistically!

Despite the significant land cover transformation that has been associated with land-use change over decades to centuries, many of the ecosystems of southern and South Africa retain relatively intact communities of animals and plants [11]. The indigenous and endemic biota have thus far displayed remarkable resilience to human impacts on the landscape. A key question to ask is whether climate change impacts could act to alter or even exceed the limits of this resilience in any way.

Recent projections, summarised for the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4), show an increase of between roughly 3 °C and 5 °C by the end of this century, but lack agreement even on the sign of rainfall change over much of southern Africa [1]. There is an emerging consensus for annual rainfall changes in South Africa of 10% or less towards the end of this century, with slightly increased mean annual rainfall for some of the summer rainfall regions of South Africa, but decreased rainfall in the winter rainfall zone of the southern Cape and western summer rainfall areas [12]. It is likely, therefore, that the diverse biomes and ecosystems of South Africa will experience a wide range of different future scenarios, similar only in the projected increase in temperature country-wide and associated increased evaporative demand of the air.

Triangulation towards a predictive understanding

How do we maximise our predictive understanding of this complex issue? Triangulation is a method often used when map reading and attempting to identify one's geographic position. This method involves using independent directional indicators of position. A similar concept is useful in building scientific knowledge of a complex problem. Three independent ways to explore impacts of climate and atmospheric change on ecological systems present themselves, namely experiment-, modelling-, and observation based. Each approach has its advantages and drawbacks that cause us to face trade-offs between three considerations – precision and control, realism and complexity, and predictive capability. Ultimately, it is beneficial to use insights from all three to build understanding of complex ecosystem responses to a changing climate and atmosphere.

Experimental approaches that manipulate several explanatory variables are challenging and expensive, but have provided useful insights into mechanisms that might control ecosystem change. Modelling approaches have developed considerably in the past few years. Species 'niche-based' modelling approaches utilise knowledge of species geographic distributions to infer climate control of the species. With this knowledge and modern geographic information systems, it is possible to 'redraw' species distributions to account for changes in climate. Unfortunately, this approach ignores important drivers of change, such as changes in wildfire frequency, and other important effects on species. Another approach that can account for these drivers, is called 'dynamic global vegetation modelling' (DGVM). This form of modelling simulates changes in ecosystem structure (such as the balance between grasses and trees). Nonetheless, these approaches do not consider many of the species interactions that make ecosystems 'tick', and so remain limited.

It is clear then that observation-based approaches ultimately provide the real-world test of our understanding, as the real-world situation incorporates the impacts of forcing factors that may not have been initially included in the conception of even the most insightful experiment or modelling solution. Most importantly, these might include the impact of extreme events that are often not expressly considered in experimental approaches, as well as complex interactions that may not be considered in models that attempt to capture and abstract reality through simplifying assumptions. There is no substitute for astute observation of individuals, species and processes under field conditions.

Case studies using modelling-based approaches

Species-based approaches have been used for many plant and animal species of all South Africa's biomes, generally projecting reducing geographic ranges for the species modelled (with some exceptions). Modelling of almost one thousand endemic plant species of a range of life forms over southern Africa [13] showed that on average the endemic flora of southern Africa could be reduced by about 40% in habitat-specific species richness, even under an optimistic scenario of greenhouse gas emissions.

Climate change has even been shown to be potentially more important in increasing the risk status of endemic Protea species than projected land transformation over a time as short as two decades [14]. Impacts of climate change and land transformation on species in regions of high risk of biome loss [15] used 28 Proteaceae species to show that most species experienced potential range contractions (17 of 28). Five of these species showed range elimination, but several species (11 of 28) showed potential range expansions. For species whose ranges contracted, current land transformation had less impact on future potential ranges than did climate change, because ranges tended to shift to higher altitudes with less land transformation pressure.

Similarly, studies on multiple animal species show range contractions and range shifts, generally resulting in the gravitation of species towards higher altitude, cooler regions in the interior of the country. These studies identify a need for migration to allow the persistence of species, and efforts to address this need by designing effective links between protected areas using corridors have shown that this might be achievable [16], though they are highly dependent on climate scenario and thus need to be strongly generalised for conservation implementation.

However, studies such as those discussed above are limited by the assumptions of niche-based modelling, with the particular concern that they lead to overestimates of the impacts of climate change on species persistence and community change. This shortcoming requires that experimental and ongoing monitoring programmes are designed to test the evolution of the early impacts of climate change to allow confirmation of this threat and to improve the modelling approaches.

The mechanistically-based DGVM approach has, until recently, been relatively poorly developed in South Africa. Do such studies provide evidence that fire and atmospheric CO_2 drivers ignored by niche-based approaches are important? This certainly appears to be the case. In a series of related papers, Bond *et al.* [17], Higgins *et al.* [18] and Scheiter and Higgins [19], have indeed concluded that both rising atmospheric CO_2 and wildfire are important determinants of vegetation structure, especially in savanna ecosystems where trees and grasses exist in a dynamic equilibrium. The natural geographic distribution of these biomes, and local to regional dominance of dominant plant growth forms, is determined largely by interactions between climate and disturbance regime, and may be critically mediated by atmospheric CO_2 level [6]. The projected increase of desert plant cover and savanna tree cover by the DGVM approach stands in contrast to the projections of correlative modelling. Although the implications are significant for South and southern Africa, there is not a single field experiment to test these ideas in the country or the region.

Case studies using experimental approaches

Relatively few experimental studies testing climate change impacts on South African plant or animal species have been conducted, either under controlled or field conditions. The few studies published address impacts of drought, warming, and elevated CO_2 and UV-B radiation, and have focused on the Succulent Karoo Biome (UV-B, drought and warming experiments), and Fynbos, Savanna and Grassland Biomes (Elevated CO_2 experiments). In general, these studies support the mechanistic understanding that underlies the DGVM approach described, but with some useful additional insights to be gained.

Experiments are often required to test accepted wisdom that may be based on causal observation and assumption. For example, drought experiments, some in the field, surprisingly reveal that succulent species, which dominate the species rich desert environments of the Succulent Karoo, show a sensitivity to extended drought, and that the non-succulent shrubs are more drought-tolerant in their adult phases [20]. Likewise, warming experiments show that succulents are susceptible to daytime heat-induced mortality [21]. Greenhouse and early field-based studies have confirmed positive CO_2 impacts on grassland water-use efficiency [22-25]. These findings show how important it is that South African biologists do not import accepted wisdom from foreign ecosystems and continents, but rather develop their own knowledge sets.

Case studies using observation approaches

There are remarkably few observation-based studies of climate change impacts on species and ecosystems. This is in contrast to hundreds of studies in European and North American regions. In only one case has sufficient evidence been collected to suggest a potential species range shift response to recent climate change in southern Africa. The desert tree succulent *Aloe dichotoma* (quiver tree) shows unsustainable mortality in the warmer parts of its range in Namibia, but high rates of recruitment and population expansion in the cooler parts of its range in South Africa [26]. Other studies have however documented population impacts of climate change. A comprehensive study of census records (1977-96) for 11 ungulate species in South Africa's Kruger National Park showed severe population declines in seven species that could not be explained by ENSO forcing and its effects on annual rainfall [26], but were correlated with an extreme reduction in dry season rainfall, interpreted as a possible fingerprint of regional climate change. Model projections suggested that local near-extinction of three ungulate species could happen under recurring dry summer conditions [27].

The future role of systematic observation

Given the wealth of biodiversity in southern Africa, this region seems to offer excellent opportunities to utilise a national network of systematically observed sites for changes in abundance and/or species distributions that may confirm or refute expected responses to trends in climate. The region has also developed a significant store of species distributional databases (though recognising the considerable taxonomic bias thereof and the poor quality of invertebrate databases) and excellent climate and substrate spatial information. This represents a powerful dataset to guide focused monitoring efforts at the national scale, especially if combined with future modelling efforts that should develop projections for changes in ecosystem processes (such as fire and biological invasions) and species range shifts. The advances in experimental and modelling approaches described above also provide a good opportunity to serve as a guide for the positioning of observation sites and the identification of key species and processes that could be monitored.

Systematic observations could, and must, provide a sensitive test of the projections of modelling and experimental approaches by monitoring ecosystems and biodiversity change over time. There is a lack of credible evidence that climate change is affecting biodiversity and ecosystems either positively or negatively, or that predicted effects are being realised. If this continues, the lack of evidence will undermine a key voice for climate policy and adaptation measures in South Africa.

In summary, while climate change impacts detection is only one of several major objectives, the invigoration of systematic observation provides an excellent opportunity to co-ordinate this important activity country-wide. The cost of co-ordinating observations and linking these to experimental and modelling activities, as suggested, is not likely to be much higher, and could be even less than that of completely independent modelling, experimental and observation programmes. A focus on climate change detection in SAEON could sharpen the focus of monitoring activities over the next decade or more, especially when this is seen against the backdrop of the limited current understanding, inadequately developed tools for projection, and the fact that a certain amount of climate change is virtually guaranteed over this time period.

Rangelands in a low rainfall environment
are ecologically sensitive. [Rudi van Aarde]

Environmental changes are progressively affecting the future of South Africans through their combined impacts on human livelihood, security and prosperity.

This book is about environmental change in South Africa, its causes, trends, implications, suggested solutions and the technologies and methodologies of observation and analysis. It draws together work from as many scientific disciplines as possible to inform not only the private sector and political decision makers, but also the general public on current environmental issues and challenges.

Observations on Environmental Change in South Africa provides pertinent scientific evidence to assist the people of our country in formulating intelligent and responsible policies and practices for the betterment of our society and to ensure the long-term sustainable futures of South Africans.

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