BFAP
bureau for food and agricultural policy
www.bfap.co.za

Modelling the economic impact of climate change on the South African maize industry

BFAP report # 2007 - 02

April 2007

THE BUREAU FOR FOOD AND AGRICULTURAL POLICY (BFAP)

About us

BFAP is an independent research unit involving the University of Pretoria, University of Stellenbosch, the Department of Agriculture: Western Cape, the Food and Agricultural Policy Research Institute (FAPRI) and associate organisations. Our main objectives are:

1. To facilitate informed decision-making by South African policy makers, agri-businesses, trade negotiators and farmers through improved analytical capabilities;
2. To enhance the quality and quantity of applied disciplinary, multi-disciplinary and cross-institutional research related to applied trade and policy modelling and commodity market analysis;
3. To provide analyses of future policy and market scenarios and measure the impact of these on farm and firm profitability.

Contact us

The Bureau for Food and Agricultural Policy
Agricultural Annex
Department of Agricultural Economics, Extension and Rural Development
University of Pretoria
Pretoria
0002
Republic of South Africa

Email: bfap@up.ac.za
Web: www.bfap.co.za
Tel: +27 12 420 4583 / 4582
Fax: +27 12 420 4958

MODELLING THE ECONOMIC IMPACT OF CLIMATE CHANGE ON THE SOUTH AFRICAN MAIZE INDUSTRY

BY

THE BUREAU FOR FOOD AND AGRICULTURAL POLICY (BFAP)

APRIL, 2007

BFAP Report # 2007—02

RESEARCH TEAM

Ghian du Toit
Jeanette de Beer
Thomas Funke
Dr. Ferdinand Meyer
PG Strauss

ACKNOWLEDGEMENTS & DISCLAIMER

We would like to express our sincere appreciation towards the following institutions and individuals for their invaluable contribution in assisting this endeavour:

The Maize Trust
The Water Research Council

Dr. F. Engelbrecht	Department of Geography, Geoinformatics and Meteorology, University of Pretoria
Prof. Johann Kirsten	Department of Agricultural Economics, Extension and Rural Development, University of Pretoria
Prof. Rashid Hassan	Centre for Environmental Economics and Policy in Africa, University of Pretoria
Johan van den Berg	Agri Risk Specialists
Lozelle du Plessis	Department of Agriculture: Western Cape

Please take note that the views and interpretations expressed in this report can not be directed back to the University of Pretoria, nor to the Bureau for Food & Agricultural Policy. The authors have attempted presenting the data, models and findings as truthful and objectively possible, as obtained from the most credible sources at our disposal.

Executive summary

The aim of this report is to compile from the wealth of literature available, a comprehensive overview of the definitions and causes of climate change, incorporate the results of climate models into the BFAP sector model, and simulate the possible economic impacts of climate change on the South African maize industry. The BFAP sector model is already well know to the industry and has been used in various other studies, like modelling the impact of biofuels on the crops and livestock sector and the simulation of an alternative maize tariff dispensation. In this study, the application of the sector model is somewhat different in that it is applied in a futuristic scenario (2050), resulting in useful economic analyses that adds to the debate on climate change.

A comprehensive definition for climate change is given by the Intergovernmental Panel on Climate Change (IPCC, 2001) as "a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use."

The climate is a system of almost infinite complexity and fluctuates on multi-annual and multi-decadal time-scales. This, together with the general scarcity of meteorological observations across space and time, prohibit accurate long-range forecasting. Notable advances in computer technology and scientific knowledge have however greatly improved our understanding and interpretation of it.

Global Climate Models (GCMs), consisting of complex atmosphere and ocean models, are used to simulate future continental-scale climatic conditions. GCMs are based on physical laws which describe the dynamics of atmospheric chemistry and oceanic circulation, and are expressed as non-linear mathematical equations. Because of their coarse scale of spatial resolution, they need to be downscaled by Regional Climate Models (RCMs) which improve the resolution and takes into account regional specific climatic variables. Empirical downscaling gives a fairly accurate idea of the *pattern* and *direction* of change, but cannot report on *exact* changes with a high degree of certainty. RCMs utilize dissimilar methodologies and assumptions, leading to notable regional differences.

The latest report from the IPCC, an authoritative group of 2500 scientists from more than 130 nations working on climate change, concluded that the current high green house gas (GHG) levels are *very*

likely[1] humanly induced, and explains most of the warming that has occurred in the past 50 years. Their best estimate projects global temperatures to rise by between 1.8°C and 4.0°C in the 21st century, with a likely range of between 1.1°C and 6.4°C.

Greenhouse gas emissions directly impact the atmosphere's composition and radiative forcing, which leads to an altered climate. Hence, the ultimate aim of the concerned global community is to stabilize the atmospheric green house gas levels, currently at 430ppm of CO_2 equivalent, to between 450 and 550ppm CO_2e.

According to climate models HadCM2-no-sulphates and CSM, South Africa is expected to become warmer by between 1°C and 3°C, and receive approximately 5% to 10% less rainfall within the next 50 years (Hewitson, 1999). Common messages of consensus around precipitation are: a wetter escarpment in the east, a shorter winter season in the southwest, a slight increase in intensity of precipitation, and drying in the far west of southern Africa. For temperature, the country as a whole is projected to experience an increase in temperature, with the maximum increase in the interior.

Although the maize plant is quite hardy and adapted to harsh conditions, a drier and warmer climate can have detrimental effects on crop yields, and might make its cultivation unviable in marginal and exposed regions. However, improved crop cultivars, biotechnology, the fertilization effect from elevated CO_2 levels *inter alia* have the potential to assist agriculture in adapting to a changing environment, but the extent of these technologies, and their ability to alleviate unfavourable conditions are uncertain and poorly quantified.

Turpie *et al.* (2002) have estimated the economic impact of climate change on the South African maize industry at between R46 million and R681 million Rand per annum. The BFAP sector level model is further employed to highlight how the white and yellow maize industries would be affected in terms of commodity prices, quantities and stock levels, and it gives an indication of the sensitivity of the region's maize market.

Du Toit *et al.* (2000) have calculated the average percentage change in maize production for South African field conditions, with special reference to the influence of the *fertilization effect*. Two

---

[1] Assessed likelihood of an outcome or a result as used by IPCC(2001): *Virtually certain* > 99% probability of occurrence, *Extremely likely* > 95%, *Very likely* > 90%, *Likely* > 66%, *More likely than not* > 50%, *Unlikely* < 33%, *Very unlikely* < 10%, *Extremely unlikely* < 5%.

scenarios are developed from this, and are used as exogenous shocks to the BFAP baseline projection. Under the first scenario where the fertilization effect does not come into play, maize prices increase rapidly and South Africa becomes a net importer of white and yellow maize. In the second scenario, the fertilization effect marginalizes the impact of climate change and South Africa remains a net exporter of white maize, and trades at *autarky* in the case of yellow maize.

Climate change is a reality, and although its projections are over a long time horizon, there is more than enough reason to believe that its reality is likely to create an even harsher environment for us as a human race, and for agriculture in particular. We should therefore start converting our lifestyles, our practices and our attitudes to face up to the reality and proactively pursue more sustainable ways.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

AOGCM	Atmosphere-Ocean General Circulation Models
CO_2	Carbon dioxide
C-CAM	Conformal Cubic Atmospheric Model
GCM	Global Climate Model
GHG	Greenhouse gases
IPCC	Intergovernmental Panel on Climate Change
OGCM	Ocean General Circulation Models
ppm	parts per million
RCM	Regional Climate Model
SRES	Special Report on Emission Scenarios
UNFCCC	United Nations Framework Convention on Climate Change

1. Introduction

Today, the world is, figuratively speaking, much smaller than it was about 50 years ago. Rapid advances in information and telecommunication technologies, as well as frequent international discourses cause our economic, political and social spheres to be more integrated than ever before. In the process, we as the human race have come to realise that the actions, lifestyles and consumption levels of individuals not only influence the global community as a whole, but also bear an undeniable impact on our planets' ecological and climatological systems.

Our climatological system has received exceptional attention in this regard, as scientists started realising that factors such as population pressure and pollution can have a substantial negative influence on the correct functioning of biological and chemical cycles underpinning climatic systems. Climate, also commonly known as "weather", is variable in nature and involves both short- and long-term changes. Its complex nature and spatial spread make it difficult for scientists to make long-term projections and monitor alterations in its functioning. Many scientists have, however, started picking up signs of changes in temperatures and precipitation, but have always been unsuccessful in proving that these changes are more than just a natural phenomenon. For instance, mathematician and physicist Joseph Fourier, had already argued in 1824 that changing the composition of gases in the atmosphere can alter the earth's surface temperature, a phenomenon he termed "the greenhouse effect". Yet, it is only a century later that the majority of scientists, as well as sceptics, agree that our climate has been changed by our unsustainable activities and will continue to change unfavourably if we do not take serious heed to the warning signs.

The Intergovernmental Panel on Climate Change (IPCC), an authoritative group of 2500 scientists representing more than 130 nations, was established by the World Meteorological Organization (WMO) and United Nations Environment Program (UNEP) in 1988 to assess the scientific and technical aspects of climate change and to evaluate its risks and uncertainties. In their Fourth Assessment Report they conclude that,

> Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land-use change, while those of methane and nitrous oxide are primarily due to agriculture.

Apart from being confident that climate change has indeed taken place since the Industrial Revolution, the panel is now even more confident in their projections about future climates. Among a range of other predictions, they predict that it is "very likely" for hot extremes, heat waves and heavy precipitation events to either continue or to become more frequent, and deem it "likely" for future tropical cyclones (typhoons and hurricanes) to intensify (IPCC, 2007). These, as well as other predictions, are on a continental scale and are very general in nature and, therefore, need to be downscaled to show their relevance and application on a national level. However, after downscaling the predictions to a national level, one has to ask how one would interpret and analyse them to be of worth for decision-making and adaptation strategies.

1.2 Purpose of the study

In accordance to the aforesaid, the purpose of this study is to investigate the potential impact of a changing climatic environment on South Africa's agricultural sector, with special emphasis on dry land maize production. The main objectives are to:

- Collect information from the plethora of research on the most credible predictions on future climatic variables, in other words, carbon dioxide (CO_2) concentrations, temperature and precipitation, from both Global Climate Models (GCM) and Regional Climate Models (RCM), which may affect maize production;
- Make use of the BFAP sector level model to analyse how these changes might affect total maize production and to analyse the ripple effect caused in other agricultural sectors;
- Develop a climate scenario to investigate how maize and maize related industries might react to different climatic situations; and
- Elicit debate among stakeholders in an effort to be pro-active and build resilience.

It is the role of researchers and policy makers to support their farming community and agri-businesses to stay ahead of changing times. A changing environment brings new and different risks and uncertainties to the table, necessitating a constant flow of research and dissimilation.

1.3 Methodology and delineation

This report essentially consists of a desktop study which reviews the plethora of scientific research on the matter, with maize production in South Africa as the focal point. Maize is the main staple and main feed grain in South Africa. Maize has also been responsible for the largest, or second largest, contribution to the gross value of agricultural production. Maize meal is one of the key drivers in the food price inflation basket and, therefore, any shift in the maize price has an effect on inflation in the country. Thus, any impact or major shift in the maize industry has a great impact on the agricultural sector and the total economy.

Prior to 1997, the maize industry was, as the rest of the agricultural sector, regulated by a single channel marketing scheme. Producers were paid a fixed price determined by the Maize Board. In 1997, the industry was deregulated and white and yellow maize are now formally traded on the South African Futures Exchange (SAFEX) where prices are determined by underlying fundamental factors. Although the total area planted under maize decreased in the period after deregulation, South Africa still meets its annual maize requirements almost entirely from domestic production. This can be attributed to increased yields, which are largely due to better varieties and less marginal land on which maize is being planted. However, net maize exports have decreased over time and, the question unavoidably arises whether South Africa will become a net importer of maize in the future. The debate on the possible impact of climate change and global warming on rainfall and temperature in maize producing areas further underlines the concern whether South Africa will be able to meet its annual maize requirements from local production.

2. What is climate change?

2.1 Background and definitions

There are various definitions of climate change. Two of the most internationally recognised definitions are provided by the International Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC). According to the IPCC (2001),

> Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic[2] changes in the composition of the atmosphere or in land use.

The UNFCCC, however, differentiates between climate change and climate variability. The UNFCCC defines climate change as, “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods” (IPCC, 2001)

and climate variability as,

---

[2] Anthropogenic, meaning from or produced by humans (IPCC, 2001).

> variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability) (IPCC, 2001).

In order to clarify the above definitions, it is worthwhile to note what is meant by a climate system and radiative forcing. The climate system is defined as being "the highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the land surface and the biosphere, and the interactions between them". This system is seen to evolve over time under the influence of both of its own internal dynamics and external forcings, for example, volcanic eruptions, solar variations and human-induced forcings such as the changing composition of the atmosphere and land-use (IPCC, 2001). Radiative forcing, on the other hand, is a measure of the influence that a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is calculated as an index of the importance of the factor as a potential climate change mechanism (IPCC, 2007). Positive forcing tends to warm the surface, while negative forcing tends to cool it. Radiative forcing could occur due to an internal change or an external change in the climate system, such as, a change in the concentration of carbon dioxide or the output of the Sun (IPCC, 2001). This measure is thus used to compare how a range of human and natural factors could and do drive warming or cooling influences regarding global climate (IPCC, 2007). Since the IPCC's Third Assessment Report (TAR), new observations, as well as the related modelling of greenhouse gases, solar activity, land surface properties and some aspects of aerosols, have led to improvements in the quantitative estimates of radiative forcing.

Another important climatic phenomenon, known as global dimming, needs to be mentioned briefly because of its relevance to agricultural productivity (Stanhill and Cohen, 2001). Global dimming is the phenomenon where increased greenhouse gases make clouds more reflective and cause significantly less solar radiation to reach the earth. This could potentially lead to a reduction in yields as plants have less radiation available to photosynthesize. However, since decreases in solar radiation affects a range of other plant-climate interfaces, especially the crop water balance and evapotranspiration, the net effect of global dimming might not be that severe on crop production. Stanhill and Cohen (2001:273), for example, state that "a 10-20% decrease in solar radiation reaching the surface of the earth, if unaccompanied by other climatic changes, would probably have only a minor effect on crop yields and plant productivity."

2.2 General Circulation Models

The behaviour of the climate system, its components and its interactions, can be studied and simulated using tools known as climate models (IPCC, 2001). These models are designed mainly the for study of climate processes and natural climate variability, as well as for projecting the response of the climate to human-induced forcing. Each component, or coupled combination of components, of the climate system can be represented by models of varying complexity.

The core of the most complex atmosphere and ocean models, called General Circulation Models (Atmospheric General Circulation Models [AGCMs] and Ocean General Circulation Models [OGCMs]), are based upon physical laws describing the dynamics of the atmosphere and ocean, expressed by mathematical equations (IPCC, 2001). Coupled atmosphere-ocean models, including such parameterised physical processes, are called Atmosphere-Ocean General Circulation Models (AOGCMs). They are combined with mathematical representations of other components of the climate system and are sometimes based on empirical relations, such as the land surface and the cryosphere. The most recent models may include representations of aerosol processes and the carbon cycle, and in the near future, perhaps atmospheric chemistry[3]. In this way, AOGCMs attempt to represent the full three-dimensional ocean-atmosphere land-surface system by means of a set of partial differential equations and comprehensive physical parameterisation schemes, which are the ideal tools for creating comprehensive future climate change scenarios (Engelbrecht, 2005). The development of these very complex coupled models goes hand-in-hand with the availability of ever larger and faster computers to run the models (IPCC, 2001). Climate simulations require the largest, most capable computers available.

These equations are non-linear and, as a result, they need to be solved numerically by means of well-established mathematical techniques (IPCC, 2001). Atmosphere models are currently solved spatially on a three-dimensional grid of points on the globe, with a horizontal resolution of typically 250 km and some 10 to 30 levels in the vertical. A typical ocean model, on the other hand, has a horizontal resolution of 125 to 250 km and a resolution of 200 to 400 m in the vertical. Their time-dependent behaviour is typically computed by taking time steps of approximately 30 minutes.

---

[3] A realistic representation of the coupling between the various components of the climate system is essential. In particular the coupling between the atmosphere and the oceans is of central importance (IPCC, 2001). The oceans have a huge heat capacity and a decisive influence on the hydrological cycle of the climate system, and store and exchange large quantities of carbon dioxide. To a large degree the coupling between oceans and atmosphere determines the energy budget of the climate system.

A necessary condition for confidence in a model simulation of climate change is that the model should be able to adequately simulate the present-day climate (Engelbrecht, 2005). Factors which could be looked at when evaluating how well a model simulates present-day climate include: (1) how well the long-term mean circulation patterns and surface fields are simulated, (2) the variability of many time scales from diurnal through to seasonal and decadal time periods and beyond and (3) sometimes "by running them under different palaeoclimate" conditions, for example, an Ice Age (IPCC, 2001). A range of diagnostic tools has been developed to assist the scientists in carrying out the evaluation, but despite this model, validation could still be difficult due to the scarcity of meteorological observations in space and time, as is the case in southern and tropical Africa (Engelbrecht, 2005). Once the quality of the model is established, two different strategies have to be applied to make projections of future climate change (IPCC, 2001).

The first strategy, the so-called equilibrium method, involves changing (for example, doubling) the carbon dioxide concentration in the atmosphere and rerunning the model to reach a new equilibrium (IPCC, 2001). The differences between the climate statistics of the two simulations provide an estimate of the climate change corresponding to the doubling of carbon dioxide, as well as of the sensitivity of the climate to a change in the radiative forcing.

The second strategy is the transient method, which is commonly used today due to improved computer resources (IPCC, 2001). In the transient method, the model is forced by using a greenhouse gas and aerosol scenario. The difference between the resulting simulated values and the original baseline simulation provides a time-dependent projection of climate change.

The transient method requires a time-dependent profile of greenhouse gas and aerosol concentrations (IPCC, 2001). These scenarios may be derived from Emission scenarios or idealised scenarios[4]. Emission scenarios are plausible representations of future radiatively active emissions, which have been developed by the IPCC and others, on the basis of various internally coherent assumptions concerning future socio-economic and demographic developments. The most recently published IPCC emission scenarios are described in the IPCC Special Report on Emission Scenarios (Nakic´enovic´ *et al.*, 2000). These scenarios are referred to as the Special Report on Emission Scenarios (SRES) and are based on different assumptions concerning, for example, the growth of the world population, energy intensity and efficiency, as well as economic growth.

---

[4] Transient simulations, based on artificially constructed (idealised) scenarios for example, a scenario assuming a gradual increase of greenhouse gas concentrations followed by stabilisation at a particular level (IPCC, 2001), can be used to provide insight into the response of climate to potential policy measures, leading to the stabilisation of GHG concentrations. This stabilisation is the ultimate objective of the UNFCCC.

The SRES scenarios are comprised of four families of scenarios, namely A1, A2, B1 and B2, which reflect consistent variations of possible future storylines regarding demographic, societal, economic and technical-changes (IPCC, 2001). Each SRES family is then made up of groups. The A1 scenario family includes four groups, designated as A1T, A1C, A1G and A1B, which explore alternative structures of future energy systems. In the Summary for Policymakers by Nakic´enovic´ *et al.* (2000), the A1C and A1G groups have been combined into one "Fossil Intensive" A1FI scenario group. The other three scenario families consist of one group each. The SRES scenario set reflected in the Summary for Policymakers of Nakic´enovic´ *et al.* (2000), thus consist of six distinct scenario groups, all of which are equally sound and together capture the range of uncertainties associated with driving forces and emissions. From these emission scenarios, concentration scenarios can be derived and used as input in climate models in order to compute climate projections (IPCC, 2001).

Projections from present models show substantial agreement, but, at the same time, there is still a considerable degree of ambiguity and difference between the various models (IPCC, 2001). All models show an increase in the globally averaged equilibrium surface temperature and global mean precipitation. Model results are more ambiguous, however, about the spatial patterns of climate change than about the global response. Regional patterns depend significantly on the time dependence of the forcing, the spatial distribution of aerosol concentrations and details of the modelled climate processes.

Global or continental scale climate change and variability may be more predictable than regional or local scale change because the climate on very large spatial scales is less influenced by internal dynamics, whereas regional and local climate is much more variable under the influence of the internal chaotic dynamics of the system (IPCC, 2001). It is also notable that the climate system is a non-linear system which may exhibit rapid change as a response to internal processes or rapidly changing external forcing. As the probability of their occurrence may be small and their predictability limited, they are colloquially referred to as "unexpected events" or "surprises". The abrupt events that took place during the last glacial cycle are often cited as an example to demonstrate the possibility of such rapid climate change. Certain possible abrupt events, as a result of the rapidly increasing anthropogenic forcing, can be envisioned, while others may not as yet be envisioned and result in rapid and unexpected change. Examples of possible, envisioned events include a possible reduction of upper-level ocean cycling in the Southern Ocean, or a possible, but unlikely, rapid disintegration of part of the Antarctic ice sheet with dramatic consequences for the global sea level.

2.3 Downscaling

It is important to note that although the core tool for projecting future climate is the General Circulation Model (GCM), a tool which is used in simulating the large-scale dynamics of the atmosphere, GCMs are inappropriate for use at regional scales (Hewitson, Englebrecht, Tadross and Jack, 2005a)[5]. This is particularly important, as the generation of scenarios at spatial and temporal scales of regional impacts, as well as in terms of climate attributes of relevance, is essential if anything of value is to be undertaken in terms of policy development and resource management. The consequence of this inability of GCMs is that an intermediate step of downscaling, or scale translation, is imperative to derive products from the GCMs which are appropriate for regional analyses.

Downscaling tools provide some consistent messages across multiple GCM forcing (Hewitson *et al.*, 2005a). This consistency is a strong indication that the GCMs are in agreement with regard to the large scale circulation changes and, given that the downscaling tools are credible, the regional projections may then be taken at the appropriate scales as reasonable indicators of the direction in which the climate system is likely to change.

There appears to be significant skill involved in evaluating the downscaling tools which replicate the current climate (Hewitson *et al.*, 2005a). However, this does not necessarily translate into the skill of projecting future climate. Consequently, it is imperative to characterise the envelope of future possibilities and examine these in light of common messages, assuming that qualitative agreement between methods in their regional projections suggests high probability that the real signal is being captured.

Even with sources of uncertainty, the projections agree on the scale of larger regions (Hewitson *et al.*, 2005a). Furthermore, these projections are physically explainable and are consistent with the current understanding of climate processes, as well as with identified historical change. Confidence in projecting changes in climate patterns is seen to be of greater importance than the magnitude of the changes (Hewitson *et al.*, 2005b) as they are contingent on the global GHG emissions, which are, in

---

[5] According to Hewitson, Tadross and Jack (2005), “Southern Africa is one of the regions of the world most vulnerable to climate change, a region still under-resourced in regard to climate change research, and a region where the climate dynamics are often still poorly understood. In response, a critical need exists for development of regional scenarios from GCM climate change simulations, for analysis of uncertainty surrounding the regional scenarios, and for developing a better understanding of the physical processes and changes in the climate system that give rise to shifts in future climate. In conjunction with this, there exists the constraint of limited research capacity among southern African scientists in regard to this computationally intensive task.”

turn, dependent on societal behaviour. This means that the projection of the magnitude of changes is associated with far greater uncertainty than the pattern of change. The magnitude of change should, thus, be viewed as a scalable entity and should rather be used to provide perspective on spatially relative changes, as well as the pattern direction of change (Hewitson *et al.*, 2005a).

In the light of this, downscaling provides a valuable message, as, with regard to all the GCMs, there appears to be a commonality of response in the circulation fields which leads to a commonality in the downscaled regional climate change projections because the empirical downscaling is directly reflective of the circulation (Hewitson *et al.*, 2005b). This in turn lends confidence to the idea that the pattern and direction of change indicated by the empirical downscaling may be viewed with some degree of credibility.

Two main downscaling techniques are employed in regional climate modelling (Engelbrecht, 2005), namely empirical/statistical interpolation and dynamic regional modelling. Both techniques work well for the simulation of the regional characteristics of present-day climate. However, the dynamic modelling approach is more likely to produce reliable results for an atmosphere of enhanced greenhouse gas concentrations, as it is explicitly based on the physical laws and elements of the climate system. Statistical models are usually developed by using present-day climate and are, therefore, inherently dependent on the dynamics and physics of present-day conditions. They should be used with caution when extrapolating to a future climate with conditions outside the range of those observed today.

When employing the dynamic regional modelling approach to downscaling, there are two main approaches which could be followed (Engelbrecht, 2005). The first is "nested limited-area modelling", which is the traditional approach. In this approach, a full atmospheric model is integrated over a limited area of earth (called the domain of the limited-area model) and receives information on the initial state of the atmosphere. It also receives information at the lateral boundaries of the domain at regular time intervals from a GCM (or from an observed data set, in the case of present-day climate modelling). In this way, high-resolution simulations can be obtained over an area of interest in a computationally efficient way.

The second new approach is called "variable-resolution global modelling". In this approach, a GCM is integrated with high horizontal resolution over the area of interest, but the GCM resolution gradually decreases as one moves away from the area of interest. Compared to the nested limited-area modelling approach, variable resolution modelling provides great flexibility for dynamic downscaling from any global model as it essentially requires only sea-surface temperatures and far-field winds from the host model. It also avoids other problems which may occur with limited-area models, such as reflections at lateral boundaries.

According to Engelbrecht (2005), the ideal solution for the simulation of both present-day and future climate on the regional-scale is the application of a high-resolution dynamical model that employs a cumulus parameterisation scheme suitable for universal application. He argues that this is the most sound choice for modelling a future atmosphere with physical characteristics (mainly resulting from enhanced greenhouse gas concentrations) that differ from the present-day atmosphere. The emphasis when selecting a cumulus parameterisation for climate change applications should be to choose one which has been found to perform fairly satisfactorily over all regions of the globe and during all seasons. The modelling of the circulation patterns of the future climate at a regional scale, could also lead to better insights into the physical and dynamical mechanisms responsible for regional climate change. Statistical downscaling achieves these results to a lesser extent, as it is limited by its inherent dependency on the physics of present-day climatological conditions.

3. Climate change in South Africa

Low precipitation levels and relatively poor soils place heavy challenges on South Africa's ability to produce agricultural goods and services. Despite this, the sector produces high quality grains, meat, fruits, vegetables and wines; exporting commodities to both international and neighbouring countries. The sector also makes a contribution of 2.4%[6] (South African Reserve Bank, 2007) to South Africa's annual Gross Domestic Product and employs approximately 8.9% of the total population (Statistics South Africa, 1999).

Broadly speaking, agriculture applies the natural environmental resources such as soil, water and air, in such a manner as to convert energy (primarily sunlight) to nutritious and useful goods (Mannion, 1997). This is not only important for mere survival, but also for the assurrance of a nation's food security, the creation of economic wealth and provition for miscellaneous products and services. To maintain a productive agricultural sector is thus imperative for any nation's survival and development, especially in developing countries such as South Africa. Since a suitable environmental milieu (with

---

[6] GDP at current prices, by production approach (seasonally adjusted annualised rates), yearly for 2006.

associated apt climatic conditions) plays such a huge role in the success of agricultural production, devoting sufficient research into the dynamics of these disciplines is necessary. Agriculture is highly influenced by climate, temperature and atmospheric CO_2 levels. To follow is a brief discussion on how predicted climate change will alter these factors.

The Centre for Environmental Economics and Policy in Africa (2006) has identified five key drivers of climate change that may affect the agricultural sector, namely: temperature, precipitation, sea level rise, atmospheric CO_2 content and the incidence of extreme events. Each of these drivers will be discussed accordingly, with the exception of sea level rise, since the majority of South Africa's production occurs inland.

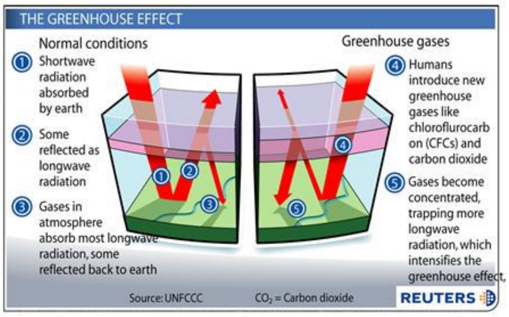


Figure 1. The Greenhouse effect.
Source: Reuters (2007).

3.1 Changes in carbon dioxide levels

The biophysical world primarily functions by way of specific cycles, which allow for a healthy balance between entities. This magnificent principle provides regeneration and sustainability. In this way, the earth and its biota have managed to survive and thrive for billions of years. The sun radiates life-giving sunlight down to earth, which is absorbed by the earth's surface. Atmospheric and oceanic circulations redistribute this energy, which is eventually radiated back into space. This creates an approximate balance between incoming solar radiation and outgoing terrestrial radiation (IPCC, 2001).

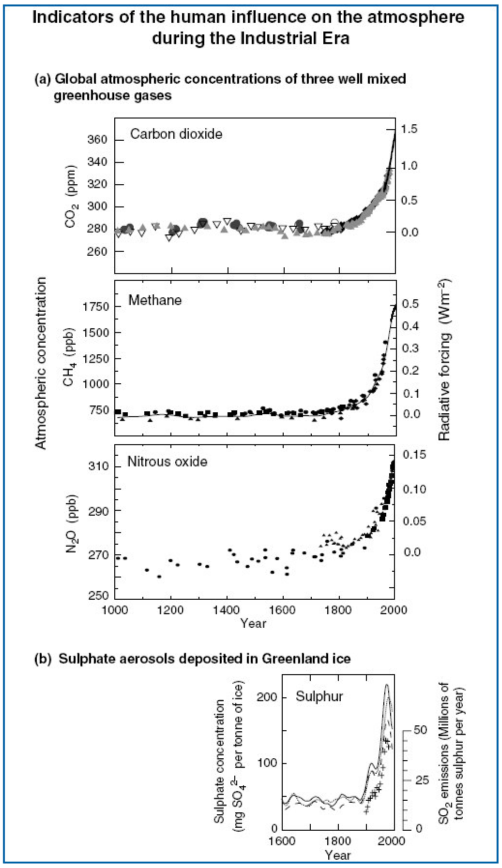


Figure 2. Indicators of the human influence on the atmosphere during the Industrial Era.
Source: IPCC (2001).

The earth's atmosphere contains natural gases such as ozone, water vapour, carbon dioxide, methane and nitrous oxides, but when the concentration of these gases is superficially increased, the balance is disturbed and affects our weather systems. The burning of fossil fuels such as oil, coal and natural gas emits additional particles into the atmosphere, which build up to cause a reflection of terrestrial radiation back to the earth's surface, with consequent warming effects (Figure 1). Changing the radiative balance of the earth alters the global hydrological cycle and atmospheric and oceanic circulation, thereby affecting weather patterns and changing regional temperatures and precipitation (IPCC, 2001).

Currently, 430 parts per million of CO_2 equivalent (ppm CO_2e) is present in our atmosphere. Predictions say that failure to reduce emissions will have greenhouse gases reach double their pre-industrial level by the year 2035. This will cause a global average temperature rise of 2ºC and there exists a confidence of 50% that temperatures might even rise by 5ºC. It was, therefore, advised that in order to avoid the calamities climate change can bring, the global community should endeavour to stabilise the atmospheric greenhouse gas levels to between 450 and 550ppm CO_2e. (United Kingdom Treasury, 2006). Figure 2 shows how greenhouse gas levels have been elevated as a result of human activities over the past 1000 years. Up until the 1800s, it can be seen that atmospheric concentrations of carbon dioxide, methane and nitrous oxide had been more or less stable, with very few sudden changes. However, the period following this saw a sudden and exponential increase in all three gas levels, which is most likely the consequence of increased pollution during the Industrial Era.

3.2 Changes in temperature

The majority of leading scientists agree that globally, temperature is on the rise. Figure 3 shows how the earth's surface temperature has increased over the past 140 years, as well as over the past 1000 years. The best estimate from the IPCC (2001) is that the global mean surface temperature has

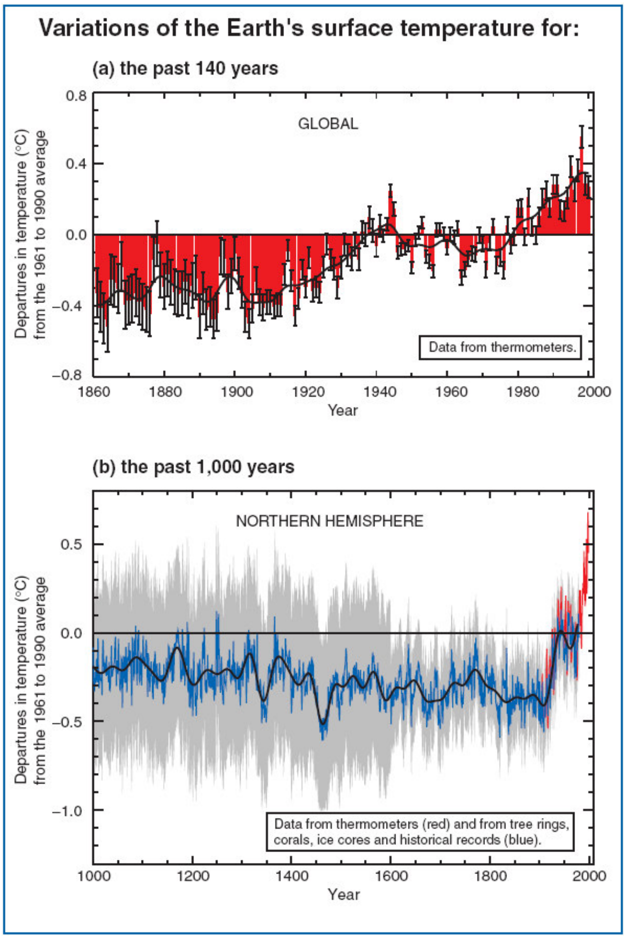


Figure 3. Variations of the earth's surface temperature.
Source: IPCC (2001).

increased by 0.6°C over the past 140 years, with a margin of error of about 0.2°C. They estimated the 1990s to have been the warmest decade and 1998 to have been the warmest year in the millennium. A strong correlation can be observed between the increased atmospheric gas levels (Figure 2 a) and global surface temperatures (Figure 3 a).

For South Africa in particular, an increase of 0.13°C per decade has been calculated for the period 1960 to 2003 (Benhin, 2006). Climate models, HadCM2-no-sulphates and CSM, have calculated a continental warming of between 1°C and 3°C over the next 50 years (Hewitson, 1999). Figure 4 illustrates the possible spatial distribution of such changes. Predominantly warmer conditions have been projected for regions of aridity and slightly warmer conditions for the coastal regions. Figure 5 further shows South Africa's main maize producing area devided into different agro-climatological sections.

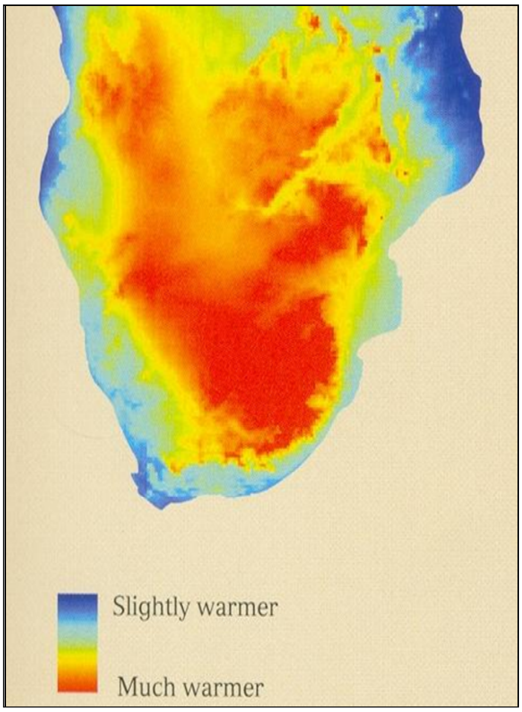


Figure 4. **HadCM3 climate model predictions of changes in temperature for 2050, relative to mean conditions over the 1961 to 1990 period, under the IPCC SRES A2 (high emissions) scenario.**
Source: Scholes & Biggs (2004), data interpolated by G. Hughes, National Botanical Institute, South Africa.

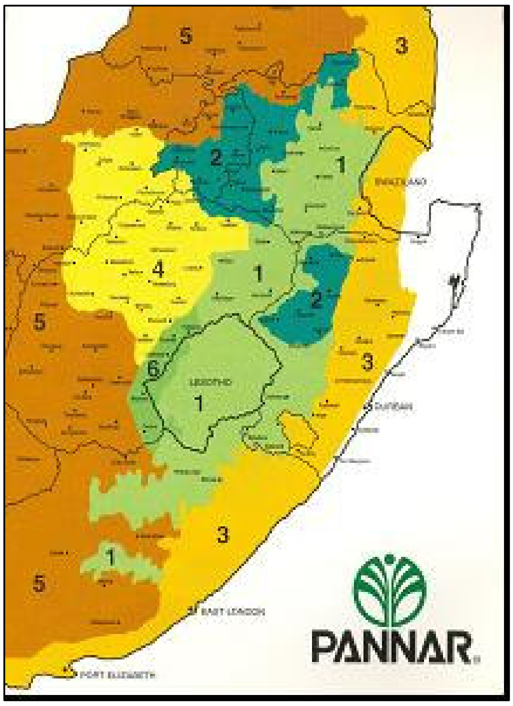


Figure 5. Maize producing areas in South Africa.
Source: Pannar, 2006.

1& 6. Cool Eastern Production Region
2. Moderate Eastern Production Region
3. Kwa-Zulu Natal Midlands
4. Western Production Region
5. Far Western and Northern Production Regions

According to Van den Berg (2006), the two periods since 1880 which showed the highest rise in temperature were 1920 to 1945 and 1980 to 2005, both rising by 0.4°C. The maize plant is a summer crop and grows only in areas where the mean daily temperature of the summer months is at least 23°C. Yields are negatively affected above the critical point of 32°C (Du Plessis, 2003). Increased temperatures have the potential to bring into production those areas which are constrained by insufficient heat units (Van den Berg, 2007). Conversely, increased temperatures can make already warm areas too hot for viable maize production. There is also strong evidence for increased incidences of diseases and pests when minimum (or winter) temperatures are increased (Van den Berg, 2007). The mean temperature of the production season is an important consideration, but even more important is the temperature at each of the different stages of the maize plant. If a mid-summer drought strikes during growth stage five (the silk appearance and pollen shedding stage shown in Figure 10), significant yield reductions may be suffered.

Seasonality and climatic cycles govern the scheduling and management of farming activities such as tillage, planting, spraying and harvesting. Therefore, adapting to embrace a changing environment is imperative for survival in the long-run.

The projected temperature changes are, at one level, very cohesive and clear. Both historically and from the projected change, the message is simply that it gets warm everywhere. Underlying this simple message are indications that:

- Surface air temperatures warm;
- Inland regions warm more than coastal regions; and
- Land surface feedbacks can be a very significant exacerbation or mitigation factor (Hewitson *et al.*, 2005a).

The spatial detail of temperature change is, in part, contingent on changes in radiative forcing. One component is a uniform increase in background infrared radiation due to the increase in "well mixed" GHGs. However, an additional component is due to atmospheric moisture. The increases in water vapour lead to a significant increase in downward radiative infrared fluxes. Conversely, increases in water vapour may lead to increased cloud formation (although not necessarily), which, in turn, reduces the received incoming solar radiation at the surface. These two effects work to counter one another in terms of forcing surface air temperature and, at present, the tools are not sophisticated or well developed enough in order to arrive at a definitive conclusion about the regional attributes of this aspect (Hewitson *et al*., 2005a).

Table 1 shows three commonly used international climate scenarios for 2050 and 2100, revealing a range of possible future changes in global temperature and precipitation. Therefore, with the anticipated increased temperatures, hot areas are likely to become even hotter. Together with lower precipitation levels and higher evaporation rates, the maize plant may, in future, be severely stressed.

Table 1: Impacts of selected climate scenarios on temperature and precipitation.

		2050			2100	
Climate scenario	**CGCM2**	**HadCM3**	**PCM**	**CGCM2**	**HadCM3**	**PCM**
Change in temperature (ºC)	3.6	3.9	2.3	9	9.6	5.6
Change in precipitation (%)	-4	-8	-2	-8	-15	-4

Source*:* Benhin (2006).

3.3 Changes in precipitation

South Africa has experienced its share of rainfall shortages, the worst being a set of serious droughts in the early '80s. The country is semi-arid by nature, having erratic and variable rainfall (DEAT, 2004). It lies within a drought belt and receives, on average, only 464 mm of rain annually; a comparative disadvantage to the world average of 857 mm (DEAT, 2004). It is estimated that even without climate change, South Africa will have fully utilised its total available surface water by the year 2030 (DEAT, 2004). Estimates by climate models HadCM2-no-sulphates and CSM indicate broad reductions of approximately 5% and 10% in South Africa's current rainfall within the next 50 years (Hewitson, 1999). Figure 6 illustrates the possible spatial distribution of such changes.

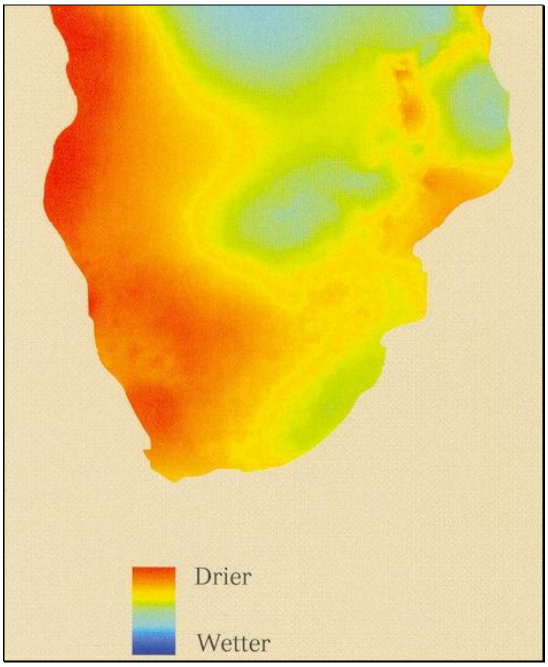


Figure 6. HadCM3 climate model predictions of changes in precipitation by 2050, relative to mean conditions over the 1961 to 1990 period, under the IPCC SRES A2 (high emissions) scenario.
Source: Scholes & Biggs (2004), data interpolated by G. Hughes, National Botanical Institute, South Africa.

Radiant energy and moisture are the two most important elements of weather with regard to crop production (Mallett & de Jager, 1974). Thus, receiving a sufficient amount of rain at appropriate times is crucial to ensure satisfactory yields and profits. Farmers plant different seed varieties according to the biological and physical nature of their immediate region, in the hope of aligning their production with the weather conditions prevalent. If the long standing "average" climatic conditions change, the impact thereof will be evident in the yield produced.

The dependency on rainfall can be partially eliminated by technologies such as irrigation practices and/or drought resistant cultivars (Kurukulasuriya, *et al.*, 2006). However, because of water scarcity, the majority of grain production in South Africa takes place on dry land conditions. High rates of evaporation, looming signs of desertification and alien vegetation unfortunately exert further pressure on this already scarce resource.

Precipitation is regarded as a "noisy" variable, exhibiting significant variability in space and time. Precipitation requires moisture availability in the atmosphere, as well as a mechanism and environmental conditions to induce cloud formation, specifically cloud systems that lead to precipitation. The downscaled projections of the change in precipitation agree with the physical process in this respect. It is apparent that the global atmosphere is increasing in moisture content due to increased temperatures and evaporation from water surfaces. Increased moisture content of the atmosphere suggests increased precipitation, assuming other mechanisms are in place. However, at the same time, there are clear indications that there are historical and projected increases in circulation modes that are conducive to subsidence over the continent – modes that suppress convective activity. For higher latitudes (relevant to the South-Western Cape), there are indications of a pole-ward move in the mid-latitude jet stream consistent with the aforementioned increase in continental high pressure systems - again conducive to the southern tip of the continent which recieves less precipitation (Hewitson *et al.*, 2005a).

Hewitson *et al.* (2005a) also feel confident in making the following general statements about regional climate change:

- On the east half of South Africa, especially on the escarpment and eastward, increased moisture availability supports the projected increase in precipitation, the increase in rain days and the increase in rainfall intensity. Seasonally, this conclusion varies in magnitude depending on the method used to arrive at the downscaled projection. For example, in the Conformal Cubic

Atmospheric Model (C-CAM) predictions, this result is limited to the early summer, and eastern South Africa is simulated to experience drier conditions in the late summer (February to April). The empirical downscaling, forced by three different GCMs, shows similar increased early summer precipitation, but extends throughout the summer and exceeds even the summer season. The empirical downscaling is inherently consistent with the GCM synoptic scale circulation and, thus, these three GCMs shows disagreement for the late summer, east of the escarpment;

- The interior regions to the west of the eastern escarpment show more ambiguous changes. Much of the region shows slight increases. The intensity of precipitation, although not clear from the projections, may be anticipated to increase;
- For coastal regions subject to significant orthographic precipitation, the seasonal totals may be expected to remain relatively stable or increase; and
- The winter rainfall over the Western Cape shows indications of drying. When seasonally averaged, the message is less consistent. However, in terms of monthly anomalies, most months indicate drying. From the empirical downscaling, there appears to be a short sub-seasonal period of increased precipitation within each model, although the timing of this period is not consistent within these models. More months of the winter season, however, show drying in each model. This is consistent with the suggestions that the region will intersect weaker frontal systems of which its core is further south than at present.

For the winter months, June to August, the empirical downscaled scenarios show a small general increase in precipitation over the central and eastern interior regions of South Africa, while the RCMs show a general decrease in rainfall over the interior. The RCM patterns are more consistent with the expected, generally stronger, subtropical high-pressure belt that is associated with the southward displacement of frontal systems and increased subsidence over the interior. However, given the sensitivity of the RCM to moisture process parameterisations, it may be sensitive to how it represents the increase in atmospheric moisture (Hewitson *et al*., 2005a).

The empirically downscaled scenarios and PRECIS RCM show a general increase in precipitation in autumn (March to May) over eastern South Africa, in contrast to drier conditions projected by the C-CAM and (to a lesser extent) MM5 RCMs. These regional discrepancies among downscaling solutions reflect, in accordance to the methods, issues of maturity in the methods, feedbacks and sensitivities to different sources of forcing. While the research in this area has matured significantly in recent years, there remains much to be investigated to reduce these sources of uncertainty (Hewitson *et al*., 2005a).

3.4 Climate extremes

It was only a few years ago that the world saw "one of the deadliest natural disasters in recorded history" (Wikipedia, 2007). The 2004 Indian Ocean earthquake triggered a tsunami on December 26, 2004, killing about 300 000 people and inundating coastal communities in many parts of Asia. Less than a year later, one of the costliest and deadliest hurricanes in America's history, hurricane Katrina, dissipated on August 31, 2005, leaving a trial of destruction along much of the north-central Gulf Coast of the United States. More recently and in closer proximity, a tropical cyclone called Favio (see Figure 7) formed off the coast of Madagascar on February 14, 2007 (Earth Observatory, 2007). This category four cyclone moved towards central Mozambique, which devastated signs of civilization in the province of Inhambane.

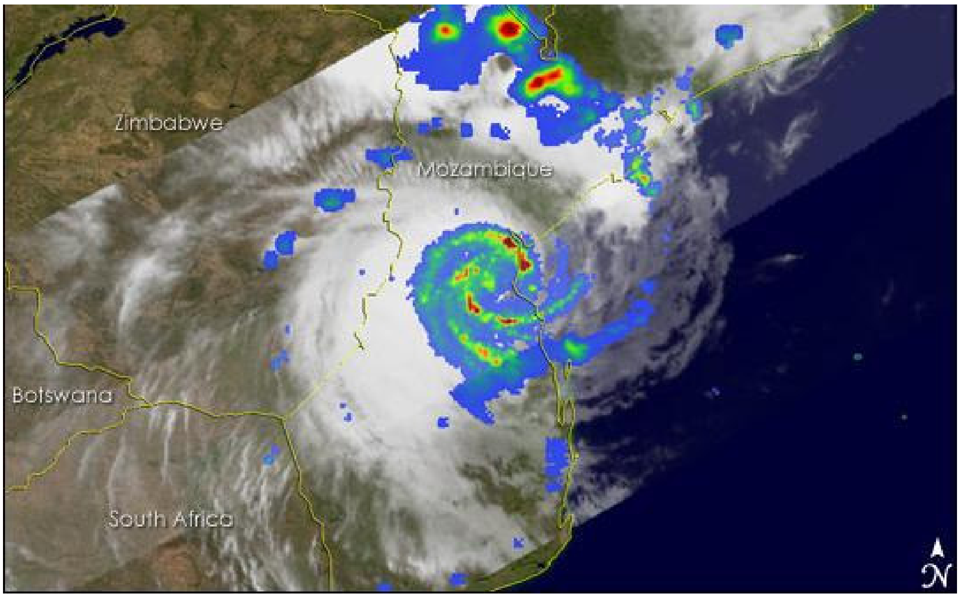


Figure 7. Tropical cyclone Favio over Mozambique.
Source: Earth Observatory, image acquired February 22, 2007.

Mozambique is actually still recovering from its last tropical cyclone, Eline, which had caused widespread torrential rain and flooding in 2000/2001 (Rae, Todd & Clark, 2007). South Africa had also been affected by cyclone Eline, with heavy rains and floods recorded in the Northern Province, Mpumulanga and Gauteng. Early estimates of the damages came to over R1 billion, not even mentioning the people who paid with their lives.

Occurrences such as these necessitate adaptation strategies on both the farmers' and the government's part (Du Toit, Prinsloo, Durand & Kiker, 2000). Researchers have an equal obligation in aiding this by developing appropriate new cultivars and projecting the impacts of climate change. Adapting to an altered environment will, however, not happen without economic and social costs. Figure shows the rapid increase in the number of extreme weather events and the total associated economic losses.

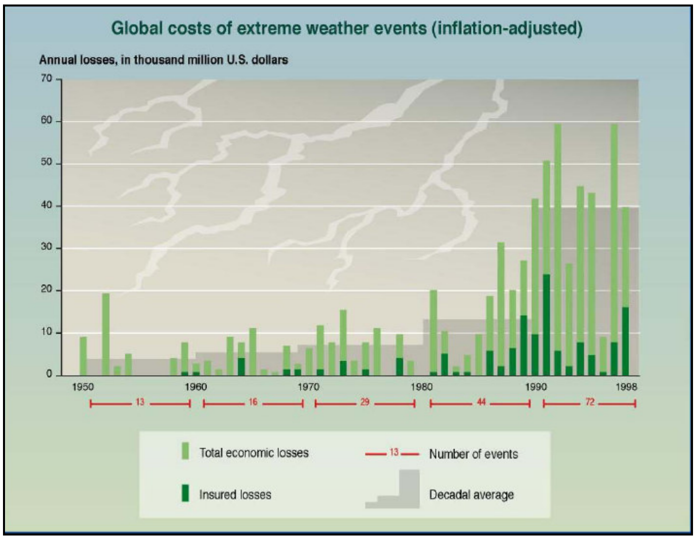


Figure 8. Global costs of extreme weather events (inflation adjusted).
Source: Lotsch (2006).

Drought is another major concern for South African crop producers and, according to Time Magazine (2006), "the amount of the earth's surface afflicted by drought has more than doubled since the 1970s". During December 2003, for example, an emergency water provision programme was issued by the Department of Water Affairs and Forestry (DWAF) after traditional rains remained elusive, causing most of the country's dams to be critically empty. The provinces of Limpopo, KwaZulu-Natal and Mpumalanga were hit the hardest, and irrigation activities were either suspended or limited (Southern Africa Flood and Drought Network, 2006).

The recent 2006/07 production season saw extremely dry conditions, especially in the late summer. The second estimate by the Crop Estimates Committee estimates the total maize crop at 6.90 million tons under the prevailing weather conditions (Crop Estimates Committee, 2007). According to Rautenbach (2007), this distressing dry spell is the direct consequence of cyclone Favio. It collected moisture from South Africa's interior, "milking" out the clouds that were supposed to bring much-needed summer rainfall. The western maize production areas were hit the hardest. Bothaville, Licthenburg and Schweizer-Reneke respectively received 27%, 56% and 60% less rainfall in the period November 2006-January 2007 when compared to the long-term average (Landbouweekblad, 2007). According to the newest estimates by the IPCC (2007), it is likely[7] that intense tropical cyclone activities will increase in the future.

3.5 Thresholds of the maize plant

According to the National Department of Agriculture, the maize plant (*Zea Maize*) requires on average between 450 and 600mm of rain per season. It is estimated that approximately 15kg of maize is produced for each millimetre of water consumed and that the average maize plant will have consumed around 250 litres of water once it has reached maturity (Du Plessis, 2003).

Maize requires a minimum daily temperature of 19°C or, alternatively, it requires that the mean temperature in summer months is less than 23°C. For germination to proceed normally, a minimum air temperature of between 10°C and 15°C is required for seven successive days. The ideal germination-temperature is between 16°C and 18°C. At 20°C, maize should emerge within 5-6 days, but if the temperature rises above 32°C it may affect maize production detrimentally. Frost is the main cause of damage to maize and a frost free period of at least 120 to 140 days is required in order to prevent permanent damage (Du Plessis, 2003).

In conjunction with these thresholds, it is worth noting what the long-standing temperature and precipitation levels are, and how they might be altered by a changing climate. Appendix A and B give a comprehensive summary of the long-term temperature and precipitation levels of South Africa's nine provinces, disaggregated by season. The maize plants' different growth stages are reflected in Figure 9.

---

[7] "Likely" is used by the IPCC to indicate a >66% likelihood for the event to occur.

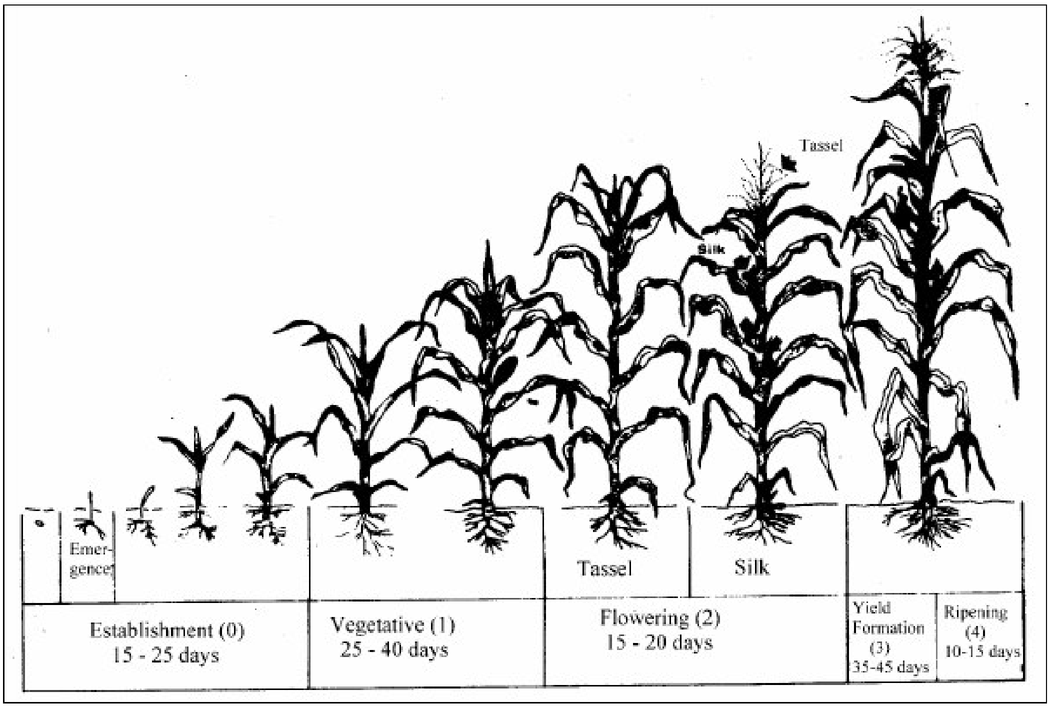


Figure 9. Growing periods of maize.
Source: Doorenbos and Kassam (1986).

It is also interesting to look at the trend in maize yields over time, as is indicated in Figure 10. It shows a positive upward trend in yields for the period 1981/82 – 2005/06. Average yields in the 1980s were around 2 tons/ha, but have improved over time to an average well above 3 tons/ha. Van den Berg (2007) remarks on several factors which could have contributed to this increasing trend:

- Increased area under irrigated maize;
- Reduction in total area planted (marginal areas excluded);
- Water harvesting methods implemented (in other words, fallow systems);
- Improved cultivation methods (in other words, conservation agriculture);
- Improved genetic characteristics of crop cultivars (in other words, ultra short growers);
- Better use of seasonal climate forecasts to make the best use of shorter growing seasons; and
- Rainfall distribution over time was very favourable since about 1996, despite very strongly developed El Nino events. The 2006/07 season was, however, very unfavourable, with very little or no rain in the crucial months of February and March (compare well with 1982/83 and 1991/92).

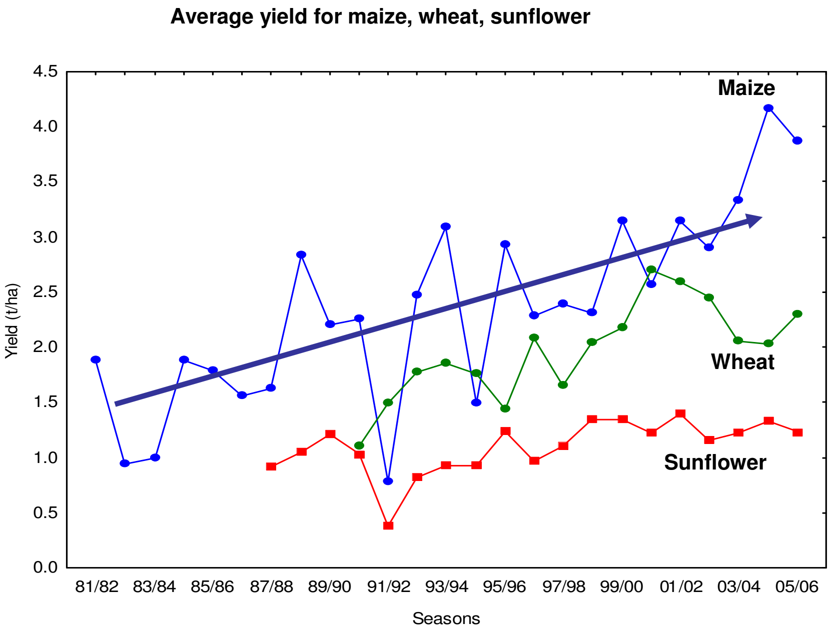


Figure 10. Average yields (t/ha) over time for South Africa for maize, wheat and sunflower.
Source: Van den Berg (2007).

Sustained efforts by researchers and producers to improve crop yields seem to have paid off, and could potentially curb many of the negative effects of anticipated climate change should such adaptation strategies be maintained or even enhanced.

4. Modelling the economic impact of climate change on the maize industry

4.1 The BFAP Sector Model

The Bureau for Food and Agricultural Policy (BFAP) has developed a sector model which simulates South African field crop, animal, and horticultural sectors. The output is in the form of projected commodity balance sheets and prices under a certain set of assumptions to facilitate decision-making and policy formulation. The sector model is an econometric, recursive, partial equilibrium model. For each commodity, the important components of supply and demand are identified and equilibrium is established in each market by means of balance sheet principles where demand equals supply. For example, in the case of a typical crop, these components include the area devoted to production, the yield per hectare, total production, direct human consumption, industrial use, exports, imports and ending stocks. All grain and livestock commodities are modelled in a closed system of equations. This implies that any shocks in the grain sector are transmitted to the livestock sector and vice versa.

Baseline projections on international commodity markets, as received from the Food and Agricultural Policy Research Institute (FAPRI) at the University of Missouri in the USA, are incorporated into the BFAP models. Scenario planning is also used extensively to stay ahead of times by asking the important question “What if?”. Inherent uncertainties in policy, weather and economic markets need to be taken into account and their effects regularly investigated.

The impact of weather is incorporated into the sector-level model by means of monthly precipitation. The South African Weather Services has delineated the country into 94 different regions (as can be seen in Figure 11), where the shaded areas approximate the main maize producing regions.

The sector-level model makes a distinction between the months which influence the production *area* and production *amount*. The average rainfall received between August and December influences the amount of maize *area* planted (in hectares). The average rainfall received between October and March (of the following year) influences the amount of maize *production* (in tons).

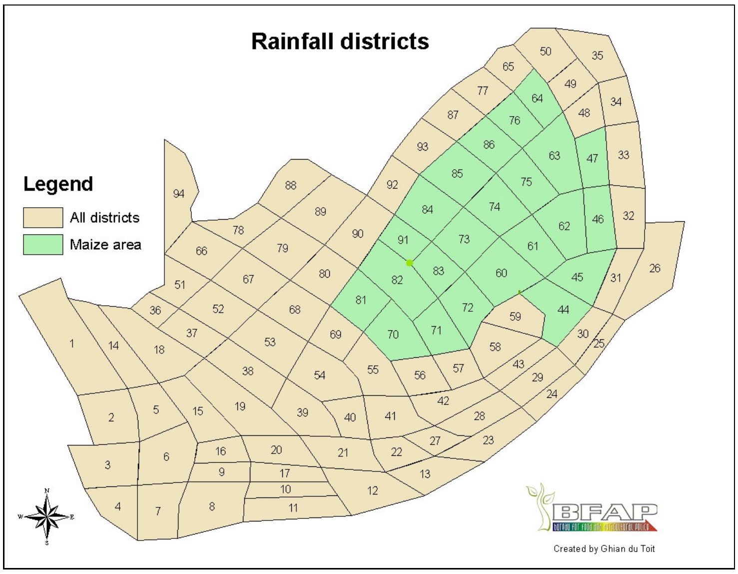


Figure 11. Maize producing areas in South Africa.
Additional source: South African Weather Services (2006).

In order to compare various scenarios, a “reference scenario” needs to be simulated that can serve as a benchmark to show the most likely outcome if no major shocks occur. This reference scenario is called a *baseline*. A baseline is a simulation of the sector model under agreed policy and certain assumptions with respect to macro-economics, the weather and technological change.

Macro-economic assumptions are based on forecasts prepared by a number of institutions, such as Global Insight, the Food and Agricultural Policy Research Institute (FAPRI) at the University of Missouri, ABSA bank and the Actuarial Society of South Africa (for projections on population). For this study, it is important to note that baseline projections are simulated under the assumption of "normal" weather conditions. Normal weather conditions are defined as the average rainfall over the past 30 years. Tables 2 and 3 present the baseline projections for white and yellow maize.

Table 2: White maize baseline, 2007 – 2015.

	2007	2008	2009	2010	2011	2012	2013	2014	2015
	thousand hectares								
Area harvested	1597.0	1910.5	1566.5	1690.5	1661.5	1645.1	1625.1	1617.7	1604.2
	t/ha								
Average yield	2.75	3.34	3.37	3.40	3.43	3.46	3.49	3.52	3.54
	thousand tons								
Production	4389.7	6383.2	5283.5	5753.0	5703.5	5694.1	5670.3	5687.9	5682.7
Feed consumption	609.1	649.6	629.4	638.9	665.2	678.0	699.0	722.2	745.8
Human consumption	3517.6	3722.2	3624.0	3627.4	3597.4	3566.2	3539.8	3514.3	3483.5
Domestic use	4451.7	4696.9	4578.4	4591.3	4587.6	4569.2	4563.8	4561.5	4554.3
Ending stocks	594.0	1126.7	965.6	1092.1	1159.9	1217.4	1256.0	1302.8	1344.1
Imports	100.8	0.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0
Exports	628.3	1153.7	891.2	1035.1	1048.2	1067.3	1067.9	1079.7	1087.0
	R/ton								
SAFEX price	1610.8	1134.7	1352.3	1283.8	1286.6	1283.6	1306.4	1321.4	1345.1

Table 3: Yellow maize baseline, 2007 – 2015.

	2007	2008	2009	2010	2011	2012	2013	2014	2015
	thousand hectares								
Area harvested	1086.3	1224.8	1003.3	1078.7	1037.7	1047.7	1041.8	1046.3	1048.9
	t/ha								
Average yield	2.71	3.56	3.60	3.65	3.69	3.73	3.77	3.80	3.84
	thousand tons								
Production	2948.8	4359.8	3615.3	3932.7	3825.6	3904.5	3922.5	3978.8	4027.1
Feed consumption	2992.9	3493.0	3383.9	3502.3	3502.7	3553.3	3596.1	3652.1	3709.8
Human consumption	217.9	243.8	233.1	236.5	233.3	232.1	229.5	227.3	224.4
Domestic use	3392.8	3918.7	3799.0	3920.8	3917.9	3967.3	4007.6	4061.4	4116.2
Ending stocks	197.3	733.8	665.3	777.4	788.8	828.9	850.4	877.4	901.5
Imports	204.8	222.5	219.3	221.7	221.2	221.3	220.7	220.2	219.6
Exports	407.1	318.0	334.4	322.0	324.8	324.3	327.3	329.8	332.7
SAFEX price	1528.6	1026.7	1221.9	1141.6	1188.8	1195.4	1244.4	1288.7	1344.4

Tables 2 and 3 show that white and yellow maize exports will grow marginally over time as yields increase. This implies that both white and yellow maize are projected to trade closer to export parity than import parity over time. The sector model estimates yield as a function of rainfall and a logarithmic trend. It is interesting to note that the domestic consumption of white maize is projected to decrease, whereas the domestic consumption of yellow maize is projected to increase over time. The decreasing trend in white maize consumption could be explained by a projected decrease in the consumption of maize meal, as consumers shift to eating more bread because per capita income increases and urbanization takes place. Yellow maize consumption increases are possibly due to the fast expansion of the livestock industry.

4.2 Scenario analyses

At this point in time, the sector level model is limited in its capacity to incorporate environmental and climatological variables, and is not coupled with any crop growth model. Because of this limitation, the estimates of Du Toit *et al*. (2000, as cited in Turpie *et al*., 2002) are resorted to. They have made projections on future percentage changes in maize yields for 19 individual sites, which represent most of the maize production regions of South Africa. They have done this by imposing the H2N (Hadley 2 model, with no sulphate forcing) scenario on a CERES-Maize crop simulation model (version 3, calibrated for South African conditions). Table 4 presents the result of their study, which further provides for the influence of the so-called “fertilization effect” from elevated CO_2 levels. The first scenario applies to a situation where the fertilization effect does not affect crop yields significantly, while the second scenario presents how the fertilization effect benefits crop growth. The baseline projections, as calculated by the sector level model, are used as a “reference scenario” to benchmark how the white and yellow maize industry will probably look under prevailing “normal” weather (without climate change).

Table 4: Projected impact of climate change on maize yields by 2050.

Maize yield change by 2050 H2n model			
Province	**Region**	**No fertilisation effect**	**With CO2 fertilisation effect**
Freestate	Betlehem	-28%	-10%
Freestate	Bultfontein	-46%	3%
Freestate	Koppies	-38%	-10%
Freestate	Kroonstad	-39%	-18%
Freestate	Petrusburg	-27%	1%
Freestate	Viljoenskroon	-38%	-15%
Freestate	Wesselsbron	-31%	9%
Freestate	Glen	-12%	22%
Gauteng	Petit	-34%	-13%
Gauteng	Bloekomspruit	-35%	-15%
Mpumalanga	Bethal	-24%	-14%
Mpumalanga	Ermelo	-7%	16%
KwaZulu Natal	Cedara	-36%	-20%
KwaZulu Natal	Greytown	-28%	-17%
North West	Lichtenburg	-36%	-13%
North West	Ottosdal	-30%	-10%
North West	Potchefstroom	-37%	-21%
North West	Setlagole	-25%	-2%
North West	Wolmaranstad	-36%	-11%

Source: Du Toit *et al*. (2000).

As literature and common knowledge suggests, climate change is primarily the result of an unnatural increase in atmospheric greenhouse gases, with CO_2 singled out as the main contributor. Despite the adversities caused by CO_2, a higher atmospheric concentration of this gas has the potential to increase plant growth rates and may, consequently, be to the benefit of crop production (Turpie *et al*., 2002), assuming, however, the absence of other limiting factors. This is because of CO_2s vital role in photosynthesis and plant growth. However, unfortunately, the net effect of the fertilization effect is still a contentious issue as it is affected by a range of plant and soil factors (Hartwell Allen, Baker & Boote, 1996). Turpie *et al*. (2002) remark that the beneficial effects of augmented CO_2 levels on maize grown under South African field conditions, have not yet been adequately quantified. While the fertilization effect might enhance plant productivity and, in the process, alleviate disadvantages associated with climate change, Bazzaz and Sombroek (1996) caution that the benefit of increased CO_2 concentrations is quickly saturated.

The BFAP sector model simulates average yields on a national level and, therefore, the projected impacts on yields (Table 4) for each region need to be aggregated to weighted national averages. Furthermore, a distinction needs to be made between white and yellow maize. Table 5 presents the calculation of the aggregate impacts of climate change on yields for white and yellow maize respectively by 2050. The first step is to aggregate the regions into provinces in order to calculate an average percentage change per province. Thereafter, the average production is calculated for white and yellow maize per province for the past six production seasons. Average production is then expressed as a share of total production and, finally, the weighted impact of climate change is calculated by multiplying the shares for each province by the percentage changes per province. Table 5 clearly shows that the impact on white maize is projected to be larger than the impact on yellow maize. The reason for this is that the dryer western regions, where more white maize is grown, is projected to become dryer than the eastern regions, where white maize production dominates. In other words, the impact on the Free State and North West provinces is projected to be larger than the impact on Mpumalanga.

Table 5: Weighed average impact on maize yields.

Average projected % change (2050)			**White**				**Yellow**			
	No fertilization (effect 1)	With CO_2 fertilization (effect 2)	Ave production (00/01-05/06) – tons	Weight	Weighted average (effect 1)	Weighted average (effect 2)	Ave production (00/01-05/06) - tons	Weight	Weighted average (effect 1)	Weighted average (effect 2)
Freestate	-32%	-2%	2029000	0.38	-12.25%	-0.85%	1067500	0.29	-9.42%	-0.65%
Gauteng	-35%	-14%	247850	0.05	-1.59%	-0.65%	156150	0.04	-1.47%	-0.60%
Mpumalanga	-16%	1%	949250	0.18	-2.74%	0.18%	1261600	0.34	-5.33%	0.34%
KwaZulu Natal	-32%	-19%	172500	0.03	-1.03%	-0.59%	182500	0.05	-1.59%	-0.92%
North West	-33%	-11%	1782500	0.33	-10.90%	-3.79%	493750	0.13	-4.41%	-1.53%
Western Cape	no results	no results	370	0.00	n/a	n/a	23500	0.01	n/a	n/a
Northern Cape	no results	no results	165000	0.03	n/a	n/a	278000	0.08	n/a	n/a
Eastern Cape	no results	no results	17200	0.00	n/a	n/a	61950	0.02	n/a	n/a
Limpopo	no results	no results	68000	0.01	n/a	n/a	20800	0.01	n/a	n/a
TOTAL			**5364050**	1.00	**-28.51%**	**-5.70%**	**3669950**	1.00	**-22.22%**	**-3.36%**

The BFAP sector model is not set up to generate projections up to the year 2050, but it is argued that if the possible impacts of climate change are already introduced in the model in 2008 and simulated through to 2015, it can at least indicate where the new equilibrium in the maize industry could lie when analysing the outlining years (2012 – 2015) in the sector model results. Tables 6 to 9 illustrate the possible impact of climate change on the white and yellow maize industries respectively.

Scenario 1

The first scenario assumes the fertilization effect to have no positive net effects on crop growth. The results of the simulation are shown in Table 6 and Table 7.

Table 6: White maize percentage change from baseline.

	2008	2009	2010	2011	2012	2013	2014	2015
	thousand hectares							
Area harvested	0.0%	1.7%	-2.5%	0.8%	2.1%	3.2%	3.9%	4.9%
	t/ha							
Average yield	-28.5%	-28.5%	-28.5%	-28.5%	-28.5%	-28.5%	-28.5%	-28.5%
	thousand tons							
Production	-29.0%	-27.8%	-30.8%	-28.4%	-27.5%	-26.7%	-26.2%	-25.5%
Feed consumption	-13.0%	-14.4%	-15.5%	-18.1%	-18.6%	-19.5%	-20.4%	-21.1%
Human consumption	-6.2%	-5.4%	-6.4%	-6.6%	-6.7%	-6.7%	-6.8%	-6.8%
Domestic use	-6.7%	-6.3%	-7.2%	-7.8%	-8.0%	-8.2%	-8.5%	-8.7%
Ending stocks	-68.2%	-79.3%	-81.7%	-82.8%	-83.6%	-84.1%	-84.6%	-85.1%
Imports	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Exports	-55.0%	-100.0%	-99.5%	-90.0%	-85.1%	-82.0%	-78.4%	-74.6%
	R/ton							
SAFEX price	48.5%	36.4%	47.4%	50.3%	53.1%	54.2%	56.3%	58.0%

In this scenario, white maize yields are expected to decrease by as much as 28% by 2015, resulting in fewer exports and more imports. Since the baseline projection for white maize imports is zero, it prohibits calculating how imports in the scenario are likely to deviate (%) from the baseline. Prices are projected to increase by approximately 58% in the long-run and it shows a market previously trading at export parity, shifting towards import parity. High prices and a decrease in production also drive ending stocks down, and stock levels are projected to decease by approximately 80%. It is interesting to note that the area planted under white maize increases over time due to increases in gross returns. The model shows an increase in gross returns per hectare in this scenario because the percentage increase in price is larger than the percentage decrease in yield. However, the area planted under white maize increases only marginally and, as a result, the production of white maize is projected to decrease by approximately 25%.

In the case of yellow maize (Table 7), the net impacts are somewhat smaller than that of white maize, but the general trends are similar in nature. Prices are projected to increase significantly over the baseline period and local production will probably shrink by approximately 20%. Imports increase strongly over time, starting at 12 in 2008 and rocketing to over 100 by the year 2015. Exports are shown to decrease between 3% and 35% over the period. Therefore, in this scenario, South Africa becomes a net importer of both yellow and white maize.

Table 7: **Yellow maize percentage change from baseline.**

	2008	2009	2010	2011	2012	2013	2014	2015
	Thousand hectares							
Area harvested	0.0%	8.1%	3.4%	7.8%	6.4%	6.4%	5.1%	3.8%
	t/ha							
Average yield	-22.2%	-22.2%	-22.2%	-22.2%	-22.2%	-22.2%	-22.2%	-22.2%
	thousand tons							
Production	-22.0%	-15.7%	-19.3%	-15.9%	-17.0%	-17.0%	-18.0%	-19.0%
Feed consumption	-12.0%	-9.6%	-11.9%	-10.5%	-10.2%	-9.2%	-8.2%	-7.3%
Human consumption	-10.3%	-8.8%	-11.2%	-10.9%	-11.2%	-11.1%	-11.1%	-11.1%
Domestic use	-11.4%	-9.1%	-11.3%	-10.1%	-9.8%	-8.9%	-8.0%	-7.2%
Ending stocks	-63.5%	-72.1%	-74.1%	-70.4%	-67.6%	-64.7%	-62.7%	-61.1%
Imports	12.4%	51.9%	57.4%	60.1%	69.2%	82.2%	99.2%	117.3%
Exports	-3.5%	-15.8%	-16.6%	-17.6%	-20.2%	-24.3%	-29.6%	-35.4%
	R/ton							
SAFEX price	47.2%	32.2%	44.7%	41.5%	42.5%	39.9%	38.2%	36.0%

Scenario 2

The second scenario is where the fertilization effect does in actual fact prove to have a net benefit in crop growth. In this case, the impact on both white and yellow maize industries is projected to be relatively small, as can be seen in Table 8 and Table 9. Prices increase by approximately 11% and 6% for white and yellow maize respectively, with little impact on exports and imports. Therefore, in this scenario, South Africa is projected to remain a net exporter of white maize. The yellow maize market is basically *in autarky*[8], with yellow maize being imported at coastal regions and exported to neighbouring land-locked countries.

Table 8: White maize percentage change from baseline (with the fertilization effect).

	2008	2009	2010	2011	2012	2013	2014	2015
	Thousand hectares							
Area harvested	0.0%	1.2%	1.2%	2.1%	2.0%	2.1%	2.1%	2.2%
	t/ha							
Average yield	-5.7%	-5.7%	-5.7%	-5.7%	-5.7%	-5.7%	-5.7%	-5.7%
	thousand tons							
Production	-6.0%	-4.9%	-4.8%	-4.0%	-4.1%	-4.0%	-4.0%	-4.0%
Feed consumption	-3.9%	-5.9%	-6.0%	-5.7%	-5.3%	-5.1%	-4.8%	-4.5%
Human consumption	-1.2%	-1.4%	-1.5%	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%
Domestic use	-1.5%	-1.9%	-2.0%	-2.0%	-1.9%	-1.9%	-1.8%	-1.8%
Ending stocks	-14.9%	-20.7%	-21.5%	-20.4%	-20.0%	-19.7%	-19.4%	-19.1%
Imports	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Exports	-12.7%	-11.9%	-12.5%	-11.7%	-12.1%	-12.0%	-12.2%	-12.3%
	R/ton							
SAFEX price	9.2%	9.3%	11.1%	10.9%	11.2%	11.2%	11.4%	11.4%

---

[8] Domestic yellow maize price trading between import parity and export parity.

Table 9: Yellow maize percentage change from baseline (with the fertilization effect).

	2008	2009	2010	2011	2012	2013	2014	2015
	Thousand hectares							
Area harvested	0.0%	1.7%	1.2%	1.8%	1.5%	1.7%	1.5%	1.6%
	t/ha							
Average yield	-3.4%	-3.4%	-3.4%	-3.4%	-3.4%	-3.4%	-3.4%	-3.4%
	thousand tons							
Production	-3.0%	-1.3%	-1.9%	-1.2%	-1.6%	-1.4%	-1.5%	-1.5%
Feed consumption	-1.4%	-1.1%	-1.4%	-1.2%	-1.3%	-1.2%	-1.2%	-1.2%
Human consumption	-1.5%	-1.5%	-1.8%	-1.7%	-1.8%	-1.8%	-1.9%	-2.0%
Domestic use	-1.4%	-1.0%	-1.3%	-1.1%	-1.2%	-1.2%	-1.2%	-1.2%
Ending stocks	-8.9%	-9.5%	-9.6%	-8.7%	-8.6%	-8.1%	-7.9%	-7.6%
Imports	-0.9%	-0.7%	-0.8%	-0.7%	-0.8%	-0.8%	-0.8%	-0.8%
Exports	3.3%	2.2%	2.8%	2.5%	2.7%	2.6%	2.7%	2.7%
	R/ton							
SAFEX price	6.8%	5.4%	7.1%	6.3%	6.8%	6.5%	6.6%	6.5%

5. Conclusion

This report provides an overview of the prevailing literature on climate change in general, making special reference to possible impacts on the production and economics of growing maize in South Africa. Sophisticated international climate models unequivocally show major changes in international weather systems in the form of increased global temperatures, floods and droughts, as well as heat waves and rising sea levels. Because agriculture is inherently exposed to climate, these events will have definite consequences on agricultural production and agro-industries. This sends out a clear message that proactive steps need to be taken to address the challenge of adapting to an altered climate.

Knowledge about climate systems and how they work has been greatly improved since the mid-1970s and is augmented with greater computer and scientific capacities. Unfortunately, because climate models employ different methodologies and take into account an array of different assumptions, the results of projected changes in climate are not clear-cut and absolute, but rather vague and generalised. Hence, it is difficult (if not yet impossible) to reach a conclusion concerning absolute changes in the two main climate variables affecting agriculture, viz. temperature and precipitation. At this point in time, confident estimates can only be made with respect to the direction of change for a broad spatial area and the magnitude of such changes reported as a range. According to Durand (2006), general consensus projects temperature increases of between 1ºC and 3ºC, and a reduction in rainfall by about 5 to 10%. Furthermore, maize production is expected to decrease by approximately 10 to 20% (Du

Toit *et al*., 2000). Other general consensuses from literature regarding climate change in South Africa are:

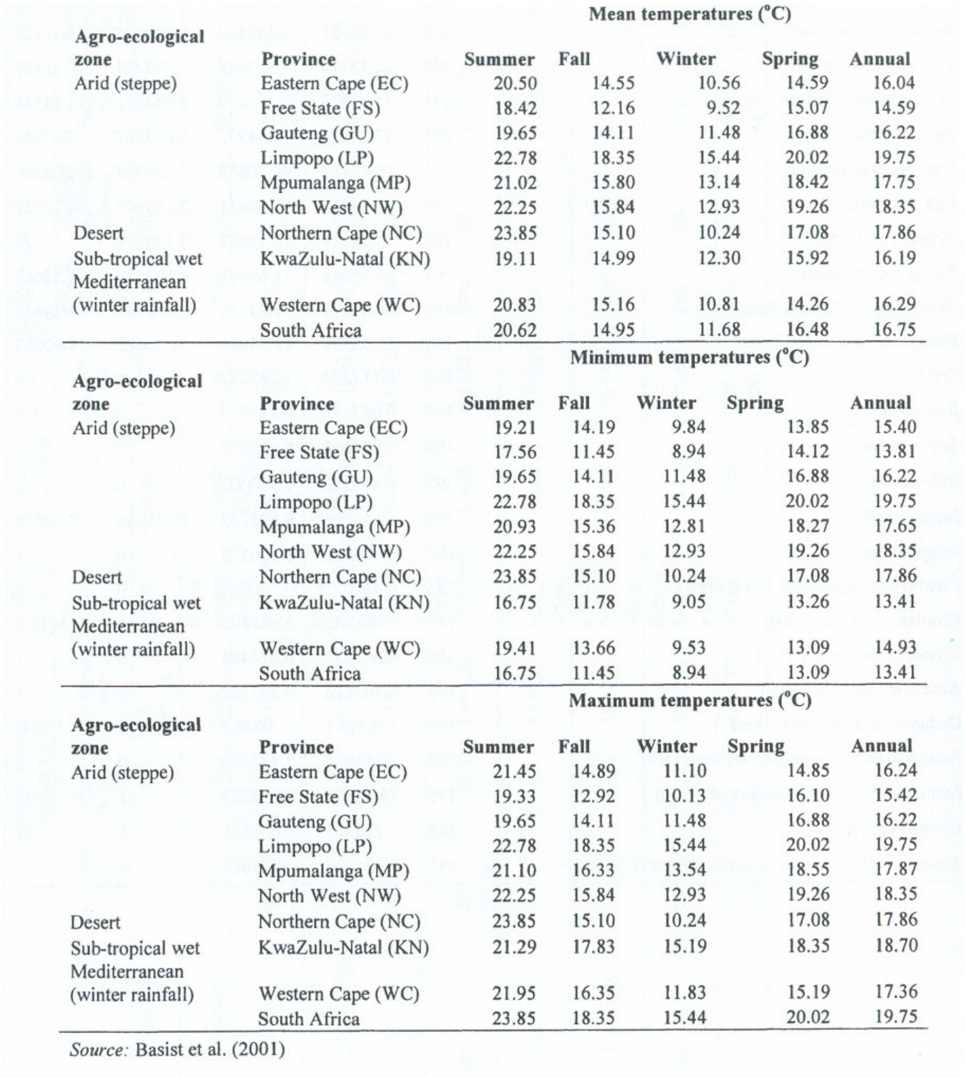
- A generally drier and hotter climate, with longer dry spells;
- Increased rainfall variability and a reduction in mean annual rainfall;
- Increases in the severity of flood events;
- An increase in the frequency of heavy (greater than 20 mm per day) rainfall events;
- Marginal western production areas likely to become unsustainable for maize production in the future;
- Depending on population growth and economic development, a potentially increased hydrological hazard is likely to occur in the future, in terms of both drought and flood frequency, as well as intensity; and
- Increased temperatures will possibly have negative effects on water quality.

Regarding the possible economic consequences of the above, Turpie *et al*. (2002) estimate the economic impact of climate change on the South African maize industry to be between R46 million and R681 million Rand per annum. Econometric modelling was further employed by BFAP to highlight how the white and yellow maize industries would be affected in terms of commodity prices, quantities and stock levels, and was then augmented by two climate scenarios. In the first scenario, maize prices increased rapidly and South Africa became a net importer of white and yellow maize, while in the second scenario, the fertilization effect marginalised the impact of climate change and South Africa remained a net exporter of white maize, trading yellow maize at *autarky*. This exercise gives a good indication of the sensitivity of the region's maize market and how it is likely to change in the event of climatic changes.

To summarize, it is worthwhile to quote Antle's (1995) comment: "Considering the time horizons and the uncertainties involved in climate change, the wise policy strategy is to pursue investments that are economically justified, whether or not climate change occurs."

APPENDIX

Appendix A: Long-term temperature in the nine provinces for four seasons



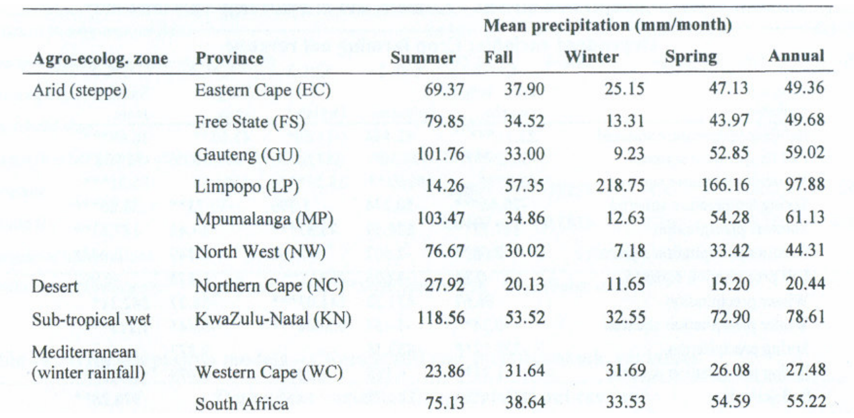
Agro-ecological zone	Province	Mean temperatures (°C) Summer	Fall	Winter	Spring	Annual
Arid (steppe)	Eastern Cape (EC)	20.50	14.55	10.56	14.59	16.04
	Free State (FS)	18.42	12.16	9.52	15.07	14.59
	Gauteng (GU)	19.65	14.11	11.48	16.88	16.22
	Limpopo (LP)	22.78	18.35	15.44	20.02	19.75
	Mpumalanga (MP)	21.02	15.80	13.14	18.42	17.75
	North West (NW)	22.25	15.84	12.93	19.26	18.35
Desert	Northern Cape (NC)	23.85	15.10	10.24	17.08	17.86
Sub-tropical wet	KwaZulu-Natal (KN)	19.11	14.99	12.30	15.92	16.19
Mediterranean (winter rainfall)	Western Cape (WC)	20.83	15.16	10.81	14.26	16.29
	South Africa	20.62	14.95	11.68	16.48	16.75

Agro-ecological zone	Province	Minimum temperatures (°C) Summer	Fall	Winter	Spring	Annual
Arid (steppe)	Eastern Cape (EC)	19.21	14.19	9.84	13.85	15.40
	Free State (FS)	17.56	11.45	8.94	14.12	13.81
	Gauteng (GU)	19.65	14.11	11.48	16.88	16.22
	Limpopo (LP)	22.78	18.35	15.44	20.02	19.75
	Mpumalanga (MP)	20.93	15.36	12.81	18.27	17.65
	North West (NW)	22.25	15.84	12.93	19.26	18.35
Desert	Northern Cape (NC)	23.85	15.10	10.24	17.08	17.86
Sub-tropical wet	KwaZulu-Natal (KN)	16.75	11.78	9.05	13.26	13.41
Mediterranean (winter rainfall)	Western Cape (WC)	19.41	13.66	9.53	13.09	14.93
	South Africa	16.75	11.45	8.94	13.09	13.41

Agro-ecological zone	Province	Maximum temperatures (°C) Summer	Fall	Winter	Spring	Annual
Arid (steppe)	Eastern Cape (EC)	21.45	14.89	11.10	14.85	16.24
	Free State (FS)	19.33	12.92	10.13	16.10	15.42
	Gauteng (GU)	19.65	14.11	11.48	16.88	16.22
	Limpopo (LP)	22.78	18.35	15.44	20.02	19.75
	Mpumalanga (MP)	21.10	16.33	13.54	18.55	17.87
	North West (NW)	22.25	15.84	12.93	19.26	18.35
Desert	Northern Cape (NC)	23.85	15.10	10.24	17.08	17.86
Sub-tropical wet	KwaZulu-Natal (KN)	21.29	17.83	15.19	18.35	18.70
Mediterranean (winter rainfall)	Western Cape (WC)	21.95	16.35	11.83	15.19	17.36
	South Africa	23.85	18.35	15.44	20.02	19.75

Source: Basist et al. (2001)

Appendix B: Long-term precipitation in the nine provinces for four seasons



		Mean precipitation (mm/month)				
Agro-ecolog. zone	**Province**	**Summer**	**Fall**	**Winter**	**Spring**	**Annual**
Arid (steppe)	Eastern Cape (EC)	69.37	37.90	25.15	47.13	49.36
	Free State (FS)	79.85	34.52	13.31	43.97	49.68
	Gauteng (GU)	101.76	33.00	9.23	52.85	59.02
	Limpopo (LP)	14.26	57.35	218.75	166.16	97.88
	Mpumalanga (MP)	103.47	34.86	12.63	54.28	61.13
	North West (NW)	76.67	30.02	7.18	33.42	44.31
Desert	Northern Cape (NC)	27.92	20.13	11.65	15.20	20.44
Sub-tropical wet	KwaZulu-Natal (KN)	118.56	53.52	32.55	72.90	78.61
Mediterranean (winter rainfall)	Western Cape (WC)	23.86	31.64	31.69	26.08	27.48
	South Africa	75.13	38.64	33.53	54.59	55.22

Source: World bank (2003)

References

Antle, J.M. 1995. Climate Change and Agriculture in Developing Countries. *American Journal of Agricultural Economics* 77: 741-746.

Basist, A. *et al*. 2001. Using the Special Sensor Microwave Imager to monitor surface wetness. *Journal of Hydrometeorology* 2: 297-308.

Bazzaz, F.A. & Sombroek, W.G. 1996. Global climatic change and agricultural production: An assessment of current knowledge and critical gaps. *In*: Bazzaz, F.A. & Sombroek W.G. (eds.) Global climate change and agricultural production. Direct and indirect effects of changing hydrological, pedological and plant physiological processes, FAO, Rome, Italy.

Benhin, J. K. A. 2006. Climate change and South African Agriculture: impacts and adaptation options. CEEPA Discussion Paper No. 21, July. Centre for Environmental Economics and Policy in Africa, University of Pretoria.

Centre for Environmental Economics and Policy in Africa (CEEPA), 2006. Climate change and agriculture in Africa. Available from http://www.ceepa.co.za/climate_change/index.html

Crop Estimates Committee, 2007. Second production forecast for summer crops as at 27 March 2007. Crop Estimates Committee, Pretoria.

Doorenbos, J. & Kassam, A.H. 1986. Yield Response to Water. Irrigation and Drainage Paper 33. Food and Agricultural Organization of the United Nations: Rome. *In*: Martin, R. *Seasonal maize forecasting for South Africa and Zimbabwe derived from an agro-climatological model*, unpublished MSc dissertation , Environmental change unit, University of Oxford.

Durand, W. 2006. *Assessing the impact of climate change on crop water use in South Africa*. CEEPA Discussion Paper No.28, Centre for Environmental Economics and Policy in Africa, University of Pretoria.

Du Plessis, J. 2003. *Maize production.* Directorate Agricultural Information Services, Department of Agriculture in cooperation with ARC-Grain Crops Institute, Potchefstroom.

Du Toit, A.S., Prinsloo, M.A., Durand, W. & Kiker, G.A. 2000. *Vulnerability of maize production to climate change and adaptation assessment in South Africa*. Contribution to the Vulnerability & Adaptation project of the South African Country Study on Climate Change. Department of Environmental Affairs & Tourism, Pretoria.

Department of Environmental Affairs and Tourism (DEAT). 2004. United Nations Framework Convention on Climate Change (UNFCCC) – South Africa's Initial National Communication, Pretoria.

Earth Observatory, 2007. Natural hazards - Tropical Cyclone Favio.
Available from http://earthobservatory.nasa.gov/NaturalHazards/

Engelbrecht, F. 2005. Simulations of Climate and Climate Change over Southern and Tropical Africa with the Conformal-Cubic Atmospheric Model. *In*: Schulze, R.E. (Ed) *Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation.* WRC Report 1430/1/05. Chapter 4, pp. 57-74. Water Research Commission, Pretoria.

Hartwell Allen, L., Baker, J.T. & Boote, K.J., 1996. The CO_2 fertilization effect: higher carbohydrate production and retention as biomass and seed yield. *In*: Bazzaz, F.A. & Sombroek W.G. (eds.) *Global climate change and agricultural production. Direct and indirect effects of changing hydrological, pedological and plant physiological processes*, FAO, Rome, Italy.

Hewitson, B. 1999. Regional Climate Change Scenarios. Prepared for the SA Country Studies Programme.

Hewitson, B., Engelbrecht, F., Tadross, M. & Jack, C. 2005a. General Conclusions on Development of Plausible Climate Change Scenarios for Southern Africa. *In*: Schulze, R.E. (Ed) *Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation.* WRC Report 1430/1/05. Chapter 5, pp. 75-79. Water Research Commission, Pretoria.

Hewitson, B., Tadross, M. & Jack, C. 2005b. Climate Change Scenarios: Conceptual Foundations, Large Scale Forcing, Uncertainty and the Climate Context. *In*: Schulze, R.E. (Ed) *Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation.* WRC Report 1430/1/05. Chapter 2, pp. 21-38. Water Research Commission, Pretoria.

IPCC, 2001: Climate Change 2001: *The Scientific Basis*. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, & C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881pp.

IPCC, 2007. Climate Change 2007: *The Scientific Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Climate change, February 2007, Paris.

Kurukulasuriya, P., Mendelsohn, R., Hassan, R., Benhin, J., Deressa, T., Diop, M., Eid, H.M., Fosu, K.Y., Gbetibouo, G., Jain, S., Mahamadou, A., Mano, R., Kabubo-Mariara, J., El-Marsafawy, S., Molua, E., Ouda, S., Ouedraogo, M., Sine, I., Maddison, D., Seo, S.N. & Dinar, A. 2006. *Will African Agriculture Survive Climate Change?* The World Bank Economic Review Advance Access. Oxford University Press.

Lotsch, A. 2006. Weather and climate risks in Africa. CRMG, The World Bank ITF Meeting, May 15-17, Pretoria.

Mannion, A.M. 1997. *Agriculture and Environmental Change – Temporal and spatial dimensions.* John Wiley & Sons Ltd.: West Sussex, England.

Mallett & de Jager, 1974. A mathematical model for determining maize yield probabilities on a Doveton Soil:I. Theory. Agroplantae 6:1-6. *In:* Fowler, R. *Conservation tillage research and development in South Africa*. Unpublished research document, Grain Crops Institute, Agricultural Research Council, Pietermaritzburg.

Nakic'enovic', N., Alcamo, J., Davis, G., De Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Grubler, A., Jung, T. Y., Kram, T., La Rovere, E. L., Michaelis, L., Mori, S., Morita, T., Pepper, W., Pitcher, H., Price, L., Raihi, K., Roehrl, A., Rogner, H.H., Sankovski, A., Schlesinger, M., Shukla, P., Smith, S., Swart, R., Van Rooijen, S., Victor, N., Dadi, Z., 2000. *IPCC Special Report on Emissions Scenarios*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 599 pp.

Rae, K., Todd, M. & Clark, L. 2007. Tropical Cyclone “FAVIO” heads towards Mozambique. National Forecast Centre (NFC), Pretoria. Available from http://www.weathersa.co.za/Pressroom/2007/2007Feb20TropicalCyclone.jsp

Rautenbach, H. 2007. *In*: Beeld, 2007. In die hitte van die werklikheid. 7 March, Pretoria.

Reuters, 2007. UN climate panel says global warming man-made. 5 February. Available from http://today.reuters.com/news/articlenews.aspx?type=topNews&storyid=2007-02-02T075512Z_01_ L019 23284_ RTRUKOC_0_US-GLOBALWARMING.xml

Scholes, R.J. & Biggs, R. (eds.) 2004. Ecosystem services in southern Africa: A regional assessment. Council for Scientific and Industrial Research, Pretoria.

South African Reserve Bank, 2007. Economic and Financial Data for South Africa, Available from http://www.reservebank.co.za/

South African Weather Services, 2006. Personal communication with Tracey Gill.

Southern Africa Flood & Drought Network. 2006. Alarming SA dam levels. Available from http://gisdata.usgs.net/sa_floods/categories.asp?catid=11

Stanhill, G. & Cohen, S., 2001. Global dimming: a review of the evidence for a widespread and significant reduction in global radiation with discussion of its probable causes and possible agricultural consequences, *Agricultural and Forest Meteorology*, 107, 255-278.

Statistics South Africa. 2000. Statistics in brief 2000. Statistics South Africa, Pretoria.

Statistics South Africa, 1999. *Annual commercial agricultural surveys*, Report No.11-01-01 (1996), Pretoria.

Time magazine, 2006. *Global warming – Be worried, very worried.* Vol.167. No.14. April, 3.

Turpie, H., Winkler, H., Spalding-Fecher, R. & Midgley, G. 2002. Economic impacts of climate change in South Africa: A preliminary analysis of unmitigated damage costs, Southern waters Ecological Research & Consulting & Energy & Development Research Centre, University of Cape Town, Cape Town.

United Kingdom Treasury. 2006. Stern Review: The Economics of Climate Change. Available from http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_ change/stern_review_report.cfm

Van den Berg, J. 2006. Weather patterns and Global warming. Proceedings of the 47th annual congress of the fertilizer society of South Africa, 28 April 2006.

Van den Berg, J. 2007. Peer review of this research document, in a letter dated 20 April 2007.

Van Zyl, J., Kirsten, J.F., Binswanger, H.P. 1996. *Agricultural land reform in South Africa: policies, markets and mechanisms*. Cape Town: Oxford University Press.

Wikipedia, 2006. The Free Encyclopedia. Climate change. Oct, 4. Available from http://en.wikipedia.org/w/index.php?title=Climate_change&oldid=79087154