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**CLIMATE CHANGE EFFECTS ON LAND DEGRADATION  
AND AGRICULTURE IN THE SWARTLAND, SOUTH  
AFRICA**

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DOCTOR OF PHILOSOPHY  
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## **ABSTRACT**

**"Climate Change Effects on Land Degradation and Agriculture in the Swartland, South Africa"**

The Swartland is a region of sparse natural vegetation, consisting of primarily dry-land crop farming. The area is particularly sensitive to the changing Mediterranean-type climatic conditions and is characterised by undulating terrain and a history of land degradation and soil erosion. This thesis therefore considers how future climate change may impact on soil loss in such a climatically sensitive region of central economic significance for southern Africa.

In order to gain an understanding of future climate change, an in-depth analysis of the literature and other historical records revealed the sensitivities and value of the region with respect to agriculture, the primary land-use. Agricultural trends are identified with an examination of historical wheat yields, the dominant land-use, and past climate effects on these yields.

Potential climate impacts on the region are explored through an examination of projections of future temperature, precipitation and wind speed from Global Climate Models (GCM). Regionally downscaled precipitation projections are used in addition to GCM outputs, to gain a better regional perspective of future precipitation change. Future climate change projections from GCMs suggest increased temperatures for all seasons, increased wind speeds over winter and possibly decreased wind speeds over summer. Regionally downscaled precipitation scenarios indicate changes in the 90<sup>th</sup> percentile range along with clear indications of a shortened winter rainfall season with increased dry spell duration.

In order to assess the direct impacts of future climate change on soils in the Swartland, a soil loss estimator for southern Africa (SLEMSA) was applied. This soil loss model proved successful after some simple modifications to calculate the effects impending future climate changes may have on the region. SLEMSA suggests that future climate change would lead to increased soil erosion in the Swartland, under current farming practices and methods. Thus farmers are advised to take careful consideration of the projected climate changes when planning for the future, particularly concerning type of cultivar planted and management practices relating to soil erosion.

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***CHAPTER ONE:  
INTRODUCTION &  
BACKGROUND***

University of Cape Town

## **1.1 Introduction**

The primary aims of this thesis are to examine future climate change impacts on land degradation, specifically soil erosion, and its potential effects on agriculture. The study is based in the Western Cape Province of South Africa, in an area vulnerable to climate change. It is an area of little remaining natural vegetation, largely having been cultivated for grain and grape farming, with a few pastures for grazing sheep. The area under investigation has a long history of soil erosion (Meadows, 2003a), with the geological make-up of the area being prone to land degradation. It is from this perspective that this study examines what future climate change impacts might be on an area already vulnerable to environmental change.

Before advancing further, it is necessary to explore a few terms, their meaning and various other related studies. Terms include: *climate change* –on a global as well as regional scale; the *climate-soils link*; *land degradation* and *climate induced soil erosion*; and areas of distinct *vulnerability*. The rest of this chapter introduces these terms with appropriate case studies, ending with a summary of the objectives of the present study.

## **1.2 Global climate change issues**

Solar energy is absorbed by the earth and then emitted in the form of long-wave radiation into the atmosphere. This long-wave radiation is partially absorbed by the atmosphere and re-radiated in all directions, some of which returns to the earth's surface. The rate of absorption and hence re-radiation back to the surface, is dependent on the chemical composition of the atmosphere. Carbon dioxide is a strong absorber of long-wave radiation and any increases in its concentration result in more long-wave radiation at the surface. This is the greenhouse effect in a nutshell, and without this process, there would be no life on Earth.

Human activities since the beginning of the Industrial Revolution, around two hundred years ago, particularly the burning of fossil fuels (coal, natural gas, oil)

and the clearing of forests, have increased the concentration of greenhouse gases in the atmosphere. This increase is causing more solar radiation to be trapped in the atmosphere, thus warming the Earth's surface and enhancing the greenhouse effect. Carbon dioxide is one of the main greenhouse gases, and it has been increasing rapidly since the beginning of the Industrial Revolution (Figure 1.1), and most dramatically towards the end of the last century with the dramatic increase in the use of fossil fuels and the deforestation of the tropics (O'Brien, 1998; Laurance, 1999).

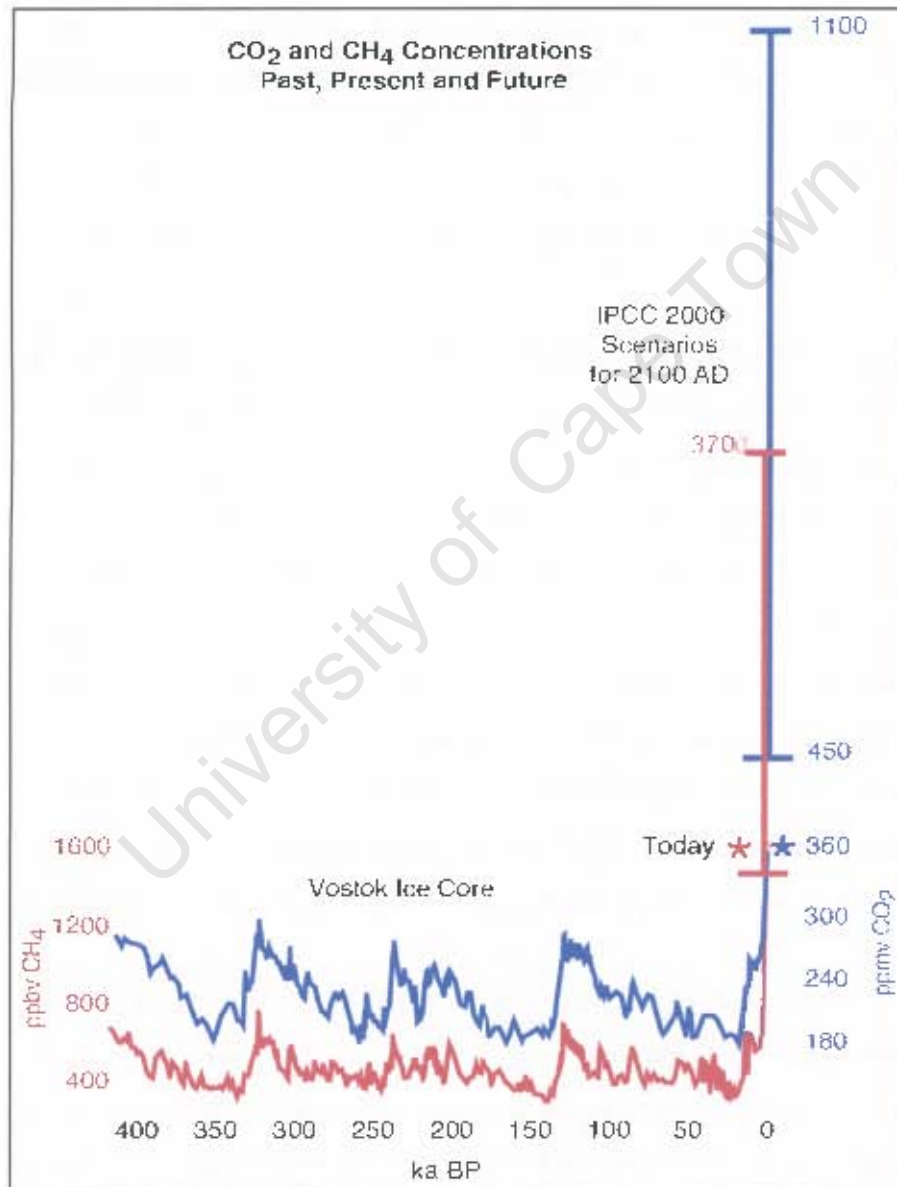


Figure 1.1: Changes in greenhouse gases CO<sub>2</sub> and CH<sub>4</sub> as recorded in the Vostok ice core; extrapolated to present day values and compared with the range of IPCC scenarios for the year 2100 (Aiverson *et al.*, 2001)

Fossil fuel combustion in the late 1980s was estimated at emitting 5.4 billion tonnes of carbon into the atmosphere annually (Huntley *et al.*, 1989). Since the pre-industrial era, the atmospheric concentrations of greenhouse gases have increased due to human activities, reaching their highest levels on record in the 1990's (Gitay *et al.*, 2002), and most are predicted to continue increasing.

Climate is an important component of the Earth's environment and climatic fluctuations have a strong impact on many aspects of the earth system including, for example, sea level, water supplies, soil, vegetation, agriculture and energy use (Houghton *et al.*, 2001). Periods of fluctuating warm and cold, drought and flood, famine and plenty have occurred repeatedly in the past and it is certain that these natural cycles will continue to occur in the future.

Global climate change is a critical issue for the future of society, as it poses an unprecedented threat to all human beings (Downing *et al.*, 2003). Climate change is becoming more and more a concern of the present as we move closer to experiencing the climate change scenarios projected by the Intergovernmental Panel on Climate Change (Houghton *et al.*, 1996). Already the rate of global warming is greater than at any other time in the last few thousand years (WMO, 2004). This general warming is expected to continue and thus have an impact on all areas of society (CCSP, 2003). It is predicted that as this forecasted warming increases regionally in intensity and persistence, it will be accompanied by fewer regional precipitation events, which are likely to be of greater magnitude (Desanker, 2002; Williams, 2001).

In 2003 the World Meteorological Organisation (WMO) noted that there was a marked increase in extreme events around the world; from record temperatures in Europe, to abnormally high numbers of tornadoes in the USA, and especially heavy rains from tropical cyclones in Sri Lanka. These extreme events occurred across the world (Showstack, 2003a) and scientists hinted at these weather events possibly being precursors of climate changes to come.

The predicted Intergovernmental Panel on Climate Change (IPCC) changes in climate indicate an increase in precipitation intensity in many areas, suggesting a greater frequency of extreme rainfall events (Houghton *et al.*, 2001; 1996). The current trends in climate are expected to continue in the future due to continuing increases in greenhouse gas and aerosol emissions, thus altering the chemical composition of the atmosphere.

Bowes and Crosson (1993) examined the consequences of climate change on the economy of the central United States, focusing on impacts and responses. They concluded that the impacts of climate change on the agricultural, energy, forestry and water sectors would reverberate negatively throughout the regional economy (Bowes and Crosson, 1993). They found the largest economy-wide impacts to be via the agricultural and water sectors, implying a direct effect on natural resources.

The worst effects of global warming could be a problem future generations will have to contend with, however the current position gives no room for complacency. The African climate is warmer than it was 100 years ago. According to Hulme *et al.* (2001), the African climate has been warming at an average rate of 0.5°C through the 20<sup>th</sup> century (Figure 1.2). The six warmest years in Africa from the last century have all occurred since 1987, with the warmest being 1998 (Hulme *et al.*, 2001). This rate of warming is concurrent with that experienced globally, and the periods of most rapid warming -1910s to 1930s, and the post 1970s – occur simultaneously in Africa as they do in the rest of the world (Figure 1.2).

While the warming of the atmosphere might be the first and most tangible consequence of the greenhouse effect, many secondary impacts are suggested. These could reach significant levels by 2050, some of which include:

- Major changes in global and regional climates (Giorgi *et al.*, 2001a; Kerr, 2001; Hulme and Turnpenny, 2004).

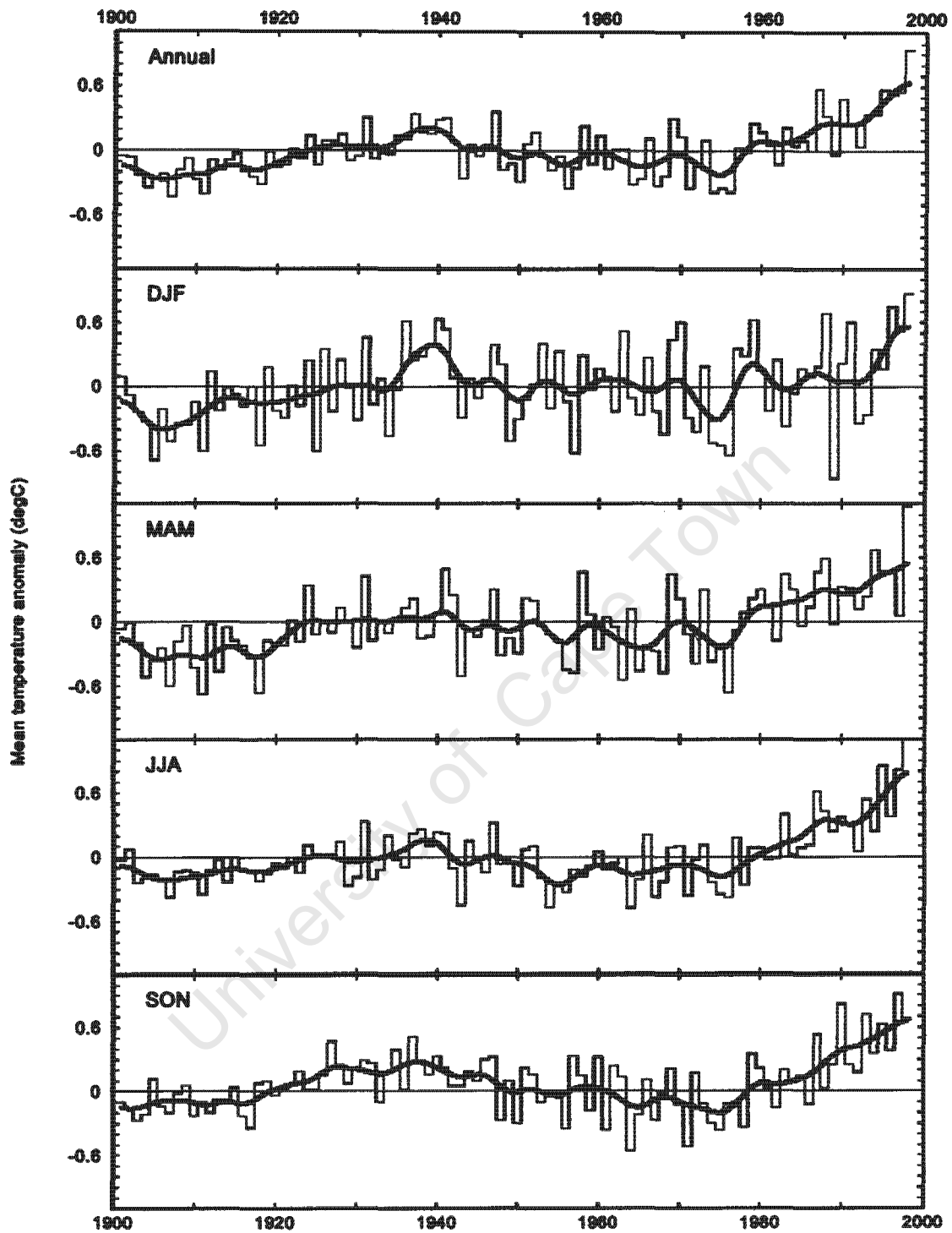


Figure 1.2: Mean air surface temperature anomalies for the African continent, 1901-1998, expressed with respect to the 1961-90 average; annual and four seasons. The smooth curves result from applying a Gaussian filter (Hulme *et al.*, 2001).

- Crop and economic losses necessitating changes in agricultural patterns (Sanchez, 2000; McMichael, 2001; Darwin, 2004).
- Increased frequency and amplitude of extreme weather events (Francis and Hengeveld, 1998; Rosenzweig *et al.*, 2002; Huntingford *et al.*, 2003).
- Rising sea levels (Brochier and Ramieri, 2001; McInnes *et al.*, 2003; Wild *et al.*, 2003).
- Spread of diseases and pests (Sutherst, 2001; Tanser *et al.*, 2003; Hales and Woodward, 2003).
- Rapid losses of species (Porter *et al.*, 2000; Laurance, 2001; Sax, 2001; Hannah *et al.*, 2002; Parmesan and Yohe, 2003).
- Desertification (Desanker and Justice, 2001; Karl and Trenberth, 2003; Meadows and Hoffman, 2003).

A warmer world, richer in carbon dioxide should generally be able to grow more food, benefiting some nations while being detrimental to others (Darwin, 2004; Schulze and Kunz, 1995). This would introduce the potential for profound changes in economic rankings, e.g.: much of the North American grain belt could suffer permanent drought (Wilhelmi *et al.*, 2002; Rosenzweig and Hillel, 1998). Climate change studies in the late 1980s showed that a 1°C increase in temperature plus a 10% decrease in rainfall could reduce the North American wheat crop by one-fifth – with adverse consequences not only for North Americans, but also for more than 100 countries that benefit from the USA's grain surplus (Huntley *et al.*, 1989). In other parts of the world the optimum climate for wheat might shift onto unsuitable soils, like in Australia with its unpredictable climate causing often devastating problems of drought and flood (White, 2001), changing the country from an exporter to an importer of wheat (Reyenga, *et al.*, 2001). In contrast, the area suited to maize or other crop production might increase, thereby decreasing the amounts previous importers of grain might require from exporting nations.

The loss of crops through a changed climate is one of many components of potential crises in the future of food production. The loss of genetic diversity is also of concern (Hannah *et al.*, 2002; Parmesan and Yohe, 2003), as fewer

than 20 species of plants produce 90% of the world's food (Huntley *et al.*, 1989). The genetic makeup of these plants, that allows them to adapt to a changing climate, is limited. Also the potential of breeding new strains and varieties, capable of adapting to a changed environment, would be severely restricted by the rapid pace of the predicted climate changes.

Research into the effects of climate change shows an increased frequency and magnitude of extreme events such as droughts, floods, hailstorms and hurricanes (Rosenzweig *et al.*, 2002; Huntingford *et al.*, 2003). These extreme events are likely to occur as the global climate moves through a series of temporal states to a new equilibrium (Szuromi, 2001), having a severe impact on infrastructure (Trenberth, 2002), agriculture (Barson and Wright, 1999; McMichael, 2001) and reinsurance (Wigley and Raper, 2001). Not all developing and most developed countries would be able to prevent or cover the costs of the natural disasters that might follow in the wake of the changing global climate (Houghton, 2004).

Polar ice caps are expected to melt under an enhanced greenhouse effect, and accompanied by the expansion of water of warmer oceans, this could cause sea levels to rise by as much as 1.5m by 2050 (Wild *et al.*, 2003; McInnes *et al.*, 2003). One impact of such a change in sea level to existing infrastructure and natural processes, would be to accelerate coastal subsidence. Without undertaking extremely expensive precautionary measures, much of the Netherlands would be flooded, together with half of Florida and huge sections of other low-lying areas, such as New York, London and New Orleans. Venice and Bangkok, who currently experience frequent flooding, would become permanently submerged. The combined effects of sea-level rise and coastal subsidence imply a scenario in which more than 30% of the arable land of Egypt and Bangladesh could be inundated –countries already prone to frequent flooding on an annual basis.

Global climate change is happening and it is necessary to take precautions towards what a changing future may hold. The next section analyses climate

change in a southern African context, then focuses in on what the future holds for South Africa.

### **1.3 Regional climate change: southern Africa**

While some regions of southern Africa might become wetter and others drier than at present, all regions are expected to experience increased temperatures (Hulme *et al.*, 2001; Stott and Kettleborough, 2002). Future climate change projections for the majority of southern Africa indicate a generally warmer, drier situation.

The impact of climate change on hydrology in southern Africa is also a critical concern (Schulze *et al.*, 2001), where the predictions for southern Africa seem to be drier than present conditions, taking into account future increases in water demand (New, 2002). Countries within the region are in the process of making important economic and social decisions on long-term projects for the next 50 years and beyond. These include issues of water resources management, such as planning large and small dams and their associated hydraulic designs, irrigation and hydro-power projects, drought relief schemes and ecologically orientated stream-flow regulation (Schulze, 2000a; 1997; 1990). Where historically observed climate and stream-flow data were reliable guides in predicting future changes, global warming and its feedbacks with other environmental systems are expected to update these earlier findings (Pittock, 1988).

Schulze (1990) identified the following possible temperature change-induced rainfall scenarios for southern Africa:

- (i) The reduction of thermal gradients latitudinally may decrease the inter-annual variability of precipitation, with the timing and distribution of rainfall being likely to change;
- (ii) Rain belts are generally expected to shift polewards, i.e. the summer rainfall regimes extending further south;

- (iii) Summer rains might start earlier in spring and/or last longer into autumn;
- (iv) The present winter rainfall regimes being replaced by summer rainfall distributions.

Current studies show that these predictions may not be far from the truth (Hewitson and Crane, in press; Hewitson, 2001a; Turpie *et al.*, 2002; van Jaarsveld and Chown, 2001). A closer examination of future climate changes on a more regional scale in southern Africa is needed to judge the impacts that are likely to occur, should these drastic scenarios happen over the short time scale that is being predicted.

Most of Africa's, and particularly South Africa's, industrial, domestic and agricultural users are highly dependent on a reliable supply of rainfall. As a result, the region as a whole is highly vulnerable to changes in climate variability, seasonal shifts and precipitation patterns (Desanker, 2002), with any negative changes in rainfall immediately being perceived as problematic. It is postulated that a reduction in rainfall amount, increased variability, or increased evaporation due to increased temperatures, would put further strain on the limited available hydrological resources. It is thought that global warming could bring an increase in rainfall, linked to higher concentrations of atmospheric carbon dioxide in southern Africa, and result in a possible reduction of plant water use and thus ease the problems of drought in some areas, but this is yet to be proven.

Global warming has become an important consideration of conservation in southern Africa, where the continued existence of many organisms is in serious jeopardy, unless steps are taken to alleviate the effects of climate change (Alverson *et al.*, 2003; Midgley *et al.*, 2001; Meadows *et al.*, 1993). Many organisms, such as those endemic to the Cape Floral Kingdom in the southwestern Cape, are more seriously under threat as their existence is already limited to refugia, hemmed in by agriculture, industrialisation, urbanisation and alien plant infestation. These species would have trouble

adapting to a changing climate as the isolation of plant species in habitat islands creates a serious constraint to potential future survival of many plant species (Peters, 1988 and Bridgwater, 1991).

Increased temperatures caused by a changing climate can also negatively affect water quality. Schulze (1990) suggests this could occur in some of the following ways: by increasing the mobility of toxic metals from soils into water; warmer temperatures influencing the spread of water-borne diseases such as malaria, typhoid, cholera and diarrhoea; and the probable effects of increases in algal blooms and other eutrophication-related problems. The regions identified as sensitive to climate change induced hydrological impacts, include humid areas, arid regions, and all regions where "shifts in climate could result in important changes in vegetation type" (Schulze, 1990, p379).

Even more significant may be the shift in seasonality. The southwestern Cape, presently a winter rainfall region, could become more of a summer rainfall region, with unfavourable consequences for its wine and wheat industries (Huntley *et al.*, 1989).

Future climate changes are also expected show impacts on natural vegetation. The southwestern Cape's remnant patches of lowland fynbos, among the richest of plant communities in the world, would be the hardest hit of all. Most of these patches occur in a sea of agricultural and urban development, thus limiting their chances of individual species dispersing as habitat conditions change.

Many if not most species of proteas and ericas and their associated biota will be at risk of extinction under projected climate change (Midgley *et al.*, 2001). South Africa's floral wealth is one of its richest natural assets and tourist attractions, yet many species are under threat of extinction due to climate change (Midgley *et al.*, 2001).

The flora of the Cape Floristic Kingdom in the southwestern Cape is the most severely threatened flora in southern Africa, with around 2373 species at risk of extinction (Huntley *et al.*, 1989). One of six major sub-divisions of the world's flora, it is by far the smallest area, with most threatened species surviving in remnant patches of fynbos between urban and agricultural areas. Even narrow corridors provided by roadside verges, stream banks, and hedgerows, have been diminished by ploughing, burning or other disturbances. A changing global environment could move the majority of the Cape's threatened species from the category of "endangered" to "extinct".

South Africa, with its current passion for the development of marinas and expensive coastal housing, would not remain unscathed (Huntley *et al.*, 1989). Much of the real estate and infrastructure development along our coastline could be at risk of rising sea levels and more severe storms by the year 2050. South Africa's position at the tip of Africa, exposed to the full brunt of the storms generated over the Southern Ocean, makes the coastline extremely vulnerable to the physical impacts of a rising sea level.

The "South African Country Study on Climate Change", hosted by the South African National Research Foundation (NRF) in 2000, commissioned an overview of the likely effects of forecast climate change on sectors representative of the South African economy (van Jaarsveld and Chown, 2001). Three main predictions came out of the study, as outlined in van Jaarsveld and Chown (2001), having serious commercial consequences:

- 1-3°C significant sub-continental warming, with greatest warming in the northern regions of the sub-continent;
- extended summer season characteristics;
- a probable reduction of 5-10% in mean annual precipitation.

A 10% decrease in water runoff is also predicted by the year 2015, particularly in the western part of South Africa. Water resources are already strained in southern Africa, particularly the southwestern parts (see *Appendix A*), and this,

with predicted population increases are likely to increase, not decrease water demand.

It is extremely difficult to separate the influence of people and climate on the environment. It is argued however, that current climate change scenarios indicate that we can expect less rain in the future and increased variability in rainfall amounts for southern Africa (Joubert and Hewitson, 1997), along with rising temperatures (van Jaarsveld and Chown, 2001). This can well have an impact on soil erosion and general land degradation when coupled to current land use patterns in some areas. Therefore given these projected impacts, land degradation in the arid southwestern parts of South Africa warrants closer examination.

#### **1.4 Background and history of land degradation**

Land degradation has been defined as the “substantial decrease in either or both of an area’s biological productivity or usefulness due to human interference” (Johnson and Lewis, 1995, p2). Soil erosion and related land cover changes have generally been considered the more obvious indicators of land degradation and desertification (Hoffman *et al.*, 1999). This study will concentrate on these aspects.

Soil is the medium for all plant growth. Without productive soils, there can be no food for humans or animals who are dependant on plant life for existence. There is a delicate balance between humans and their activities on the one hand and the environment on the other, especially in arid and semi-arid lands (Stamp, 1961). Soil resources are under increased pressure, as growing populations require increasing agricultural production from limited soils. Thus, there is a need to generate awareness of the erosion potential of soils, particularly as they form the buffer between the land and the atmosphere, absorbing and releasing nutrients and gases to the atmosphere and to plants (Paul and Clark, 1989).

Humankind began cultivating the soil as far back as 10 000BP, with wheat, barley, fruit and cattle being the chief agricultural products (Stamp, 1961). These products were initially used as primitive currency (Mattessich, 2000) and were grown in ancient Mesopotamia's northern valleys, in present day Iran (Wild, 1993). In this way plants and trees were spread from Iran to Egypt and Europe; millet from India was found in Italy and European oats and poppy appeared in Asia and China (Whyte, 1961).

The demise of the old Mesopotamian culture resulted from soil erosion and degradation of the land, where salinisation and gullies destroyed the upland areas and caused soil loss that, over the years, reduced food production (Whyte, 1961). This could be cited as the first human-induced accelerated erosion affecting an entire watershed (Wild, 1993). There are many examples throughout history where mass migrations of people and animals occurred due to famine, resulting from one or more years of deficient rainfall (Stamp, 1961) accompanied by already eroded soils. In Australia, desertification tends to be associated with land degradation, which has resulted from unsustainable land use and the impact of European settlement, rather than a changing climate (Pickup, 1998).

Since ancient Mesopotamian times around 5000B.C., accelerated soil erosion has become more common place, resulting from, for example, deforestation and clearing of vegetation for fields and building purposes, over-grazing and increased pressure on crop production. These all dramatically influence the water regime and runoff of the area concerned. The ultimate loss of soil is the most serious form of soil erosion. (Morgan and Rickson, 1995). Acidification, nutrient loss and accumulation of salts in a soil can to a certain degree be reversed (Paul and Clark, 1989). However, effectively the physical loss of soil cannot be reversed. Soil erosion is one of the key environmental problems facing the developing world, which, if not correctly managed, can lead to large-scale famine and hunger (Larson and Pierce, 1994).

Generally it takes 30 to 300 years to produce 25mm of soil by natural processes (Liu *et al.*, 2003; Lal, 2001). In the late 1980s South Africa was estimated to be losing soil at a rate more than 30 times higher than its natural rate of soil formation (Huntley *et al.*, 1989). This would equate to an average of 400 million tons of arable soil per year. This includes a rough estimate of 3300 tons of nitrogen, 26 400 tons of phosphorus and 363 000 tons of potassium per year, all valuable plant nutrients. These soil loss figures are surely rising with changing land use and increased food demands as the population increases (Yang, 2003), and to replace this loss of valuable plant nutrients by commercial fertilizers would come to well over R1 billion per annum (Morel, 1998).

In 1995, Arbuthnot (p1) reported that:

“South Africa's resources are in a critically poor state. Land degradation is an extremely serious problem that threatens the future of South Africa. Apart from its insidious long term effects, it can severely frustrate the implementation of the Reconstruction and Development Programme with serious socio-economic consequences. Poorly planned land redistribution will seriously aggravate and accelerate the land degradation problem, creating poverty traps that will drain limited resources that must be more effectively used to enhance the quality of life and eradicate the persistent poverty among rural communities.”

Arbuthnot's (1995) comments on soil erosion and land degradation affecting land redistribution has recently been seen as apt in Zimbabwe, where indigenous people have taken back their land, and then used unsustainable farming methods, causing increased soil erosion (Mail and Guardian, 2004a). Many of the originally profitable farmlands have become “poverty traps” where rural communities have joined together to make money off the newly acquired land and have ended up with a wasteland (Buckle, 2001; Mail and Guardian, 2004b). It is therefore critical that South Africa address soil erosion and land degradation issues (as Boardman *et al.* (2003) have done in the Great Karoo) so as to prevent such instances occurring in this country. This is especially important when people who are not aware of how to run a commercial farming business make land claims on profitable commercial farms.

## 1.5 Land degradation and agriculture

From the early 1970's, following the first UNCOD (United Nations Conference on Desertification) in Nairobi, desertification began being noted as a major environmental problem, which needed closer research to understand its implications, particularly under global change (Sevink and Imeson, 1998). Key areas of environmental concern when addressing desertification, but particularly land degradation are the following: Agricultural land and production; soil fertility; acidification of soils; loss of biodiversity (Arbuthnot, 1995). Other areas of concern globally are the loss of soil to support food production, loss of grasslands and forests; silting up of dams; deposition of erosion causing rivers to change course; variable flow of rivers and flooding; and water pollution (soil nutrients dumped into rivers) (Morel, 1998; White, 2001).

Nutrients, pesticides, pathogens, salts, and eroded soils are leading causes of water quality problems in many parts of the United States. A draft document of the US Global Change Research Program showed that in many parts of the western U.S.A., agriculture is a major user of scarce irrigation water<sup>1</sup>. The concern in southern Africa's agricultural areas is based on the encroaching problem of food production to meet food demand, as populations increase, with resultant increased pressure on water resources. This problem is compounded by a loss of valuable agricultural land due to the leaching of nutrients from the soil, thereby rendering soils less fertile (Beckendahl *et al.*, 1988; Arbuthnot, 1995).

Research on soil conservation first started in South Africa in the 1930's with the establishment of The Soil Erosion Advisory Council (Hoffman and Ashwell, 2001), continuing with the work of Bill Talbot, Hugh Bennett and others. This concern soon materialised in terms of legislation and policy, so that by the mid-

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<sup>1</sup> Draft document of the US National Assessment of the Potential Consequences of Climate Variability and Change - *Changing Climate and Changing Agriculture: Draft Report of the Agriculture Sector Assessment* (Accessed August 2004) <http://www.usgcrp.gov/usgcrp/nacc/agriculture/draft-report/chapter5.html>

1940s a Soil Conservation Act was in place (Verster *et al.*, 1992). Dr Hugh Bennet, the then Chief of the Soil Conservation Service of the US Department of Agriculture, toured South Africa in the early 1940s to promote soil conservation among commercial farmers (Meadows, 2003a).

Hudson (1971) found that up to two thirds and more of the southern African region is particularly susceptible to erosion from wind and water, with his view being based on a consideration of prevailing climatic conditions for the sub-continent. This view has been confirmed more recently by Middleton and Thomas (1997) where a large majority of the subcontinent of southern Africa is affected by soil degradation and erosion.

Soil erosion remains a serious problem over much of South Africa. Meadows and Hoffman (2003) found that land degradation resulting from soil erosion is clearly underpinned by poverty in South Africa, and these areas are likely to become even more susceptible to erosion under climate change. In the late 1980's annual soil losses were estimated at 300-400 million tonnes, nearly three tonnes per hectare (Huntley *et al.*, 1989), and this figure includes valuable plant nutrients such as nitrogen, potassium and phosphorus which are carried out to sea. Where crops are renewable, and to a certain degree genetically modifiable, soil to all intents and purposes is not and so needs to be conserved.

Soil properties are determined by a diverse range of soil processes, which can be physical, chemical or biologically mediated, all occurring at different rates (Rounsevell *et al.*, 1999). These physical characteristics of soils, along with topography and microclimate, all affect agricultural productivity (Antle *et al.*, 2004).

Soil erosion is not purely a farmer's problem but must be seen as a major environmental problem that affects every sector of society either directly or indirectly (Hoffman and Ashwell, 2001). The late winter rains of 2004 in the wheat farming areas of South Africa have caused huge increases of prices

throughout the economy, not only on the wheat market where farmers are forced to conserve water due to higher water prices (Dinar and Mody, 2004). Wheat shortages have robbed farmers financially, rendering them unable to prepare for the next season, and this has caused price hikes to ricochet throughout the economy (Gosling, 2005).

Puigdefabregas (1998) reported that almost all cases of dryland degradation show that transition trigger events that increase degradation are the result of some combination of anthropogenic and climatic factors, which reinforce each other to induce degradation. Thus, the importance of prevention is necessary, as well as a need to carefully consider where to apply rehabilitation and restoration to the landscape. This can only really be carried out when an understanding of the links between land degradation and climate change are defined, as in the next section.



## 1.6 *Land degradation and climate change: the climate-soils link*

Major environmental challenges for the future include deforestation, soil degradation and desertification, declining biodiversity and marine resources, water scarcity, and deteriorating water and air quality (Sola, 2001). All of these are likely to be affected by impending climate change. There is too much complexity here to meaningfully research every aspect of climate change on all these environmental challenges in one thesis. However, soil degradation, which is often the “key” feature of land degradation assessments, stands out as being immediately important in the context of looming food and water shortages (*Appendix A*) and the direct link to climate change already evident.

Conservationists should be seriously concerned about the implications of climate change, particularly when expressed by changes in precipitation patterns, for the conservation of soil and water resources (SWCS, 2003). Global warming is expected to lead to a more vigorous hydrological cycle, including more total rainfall and more frequent high intensity rainfall events

(Nearing *et al.*, 2004). These rainfall changes will have significant impacts on soil erosion rates.

The fragile nature of soils and their supporting vegetation make them good benchmarks for climate change research. Soils influence species distribution, productivity, water and biogeochemical cycling, and underpin the ability of land to grow crops and to support grazing (Rounsevell *et al.*, 1999). The importance of good quality soils for agriculture also makes them important indicators of future impending climate change.

Soil processes are influenced directly by temperature, precipitation, and atmospheric CO<sub>2</sub> changes; and indirectly by climate-induced changes in land use and management (Rounsevell *et al.*, 1999). Changes in soils will in turn affect the composition and structure of vegetation and feedback to the climate system (Antle *et al.*, 2004), thus making it important to examine how soil erosion will be impacted in the future.

If there is to be a future water erosion problem, then two main conditions must be met: firstly there must be sufficient future rainfall; and secondly that this rainfall must occur when the soil surface is insufficiently protected (Favis-Mortlock and Guerra, 1999). Predictions of future soil erosion can help in the management of valuable agricultural lands and suggest ways in which soil conservation strategies need to be adapted under a changing climate (O'Neal *et al.*, 2005). For example increasing air temperatures affect soil erosion in a number of ways: warmer temperatures can increase biomass production rates; impact microbial activity levels which directly impact on decomposition rates; as well as limit crop production in extreme heat (Pruski and Nearing, 2002).

Increased CO<sub>2</sub> can also lead to a moister soil, conducive to greater runoff-induced erosion. This happens through enhanced stomatal resistance and a suppression of transpiration (Schulze, 2000b). Evapo-transpiration rates are also influenced by temperature changes, thus impacting soil moisture and

directly influencing infiltration and runoff amounts and rates (Pruski and Nearing, 2002).

Precipitation changes are more complex and need to be examined on a regional basis for a clearer understanding of what future climate change has in store. For example, Schulze (2000b) found, using the CERES-Maize and ACRU models that a 10% increase in precipitation in parts of South Africa would lead to a 20-40% increase in run-off. Future climate change impact modelling conducted in the U.S. has shown that in every case where precipitation was predicted to increase significantly, soil erosion also increased significantly (Favis-Mortlock and Savabi, 1996; Flanagan and Nearing, 1995; Nearing *et al.*, 1989).

In quantifying the impacts of future climate change it is necessary to consider a complex array of factors, viz. changes on soil properties, changes in the timing of precipitation, and changes in planting date. Interactions between these variables may lessen or even reverse the general pattern of changes in soil loss and runoff (O'Neal *et al.*, 2005). Since the early 1990s, there have been various studies of the agricultural impacts of climate change (see IPCC, 2001a, section 5.3.4 for an overview). Perhaps the greatest impact of climate change on soils will arise from the climate-induced changes in land use and management (Rounsevell *et al.*, 1999). O'Neal *et al.* (2005) concluded that a change of management practice could have a significant effect on the accuracy of predicted soil loss under climate change. A changing climate will affect soil and water resources on agricultural land in many ways, however if the future climate change impacts are known, then the impacts on soil erosion can be lessened through adapting management practices (Williams *et al.*, 2001).

Different landscapes vary greatly in their vulnerability to soil erosion and runoff (SWCS, 2003). Timing of agricultural production and practices creates an even greater vulnerability to soil erosion and runoff during certain seasons. Changes in climate may also induce changes in aggregate production and prices in the farming community (Antle *et al.*, 2004). Jetten *et al.* (1999) showed that if more

data is available about the agricultural activity and the interaction between climate and the soil surface, then modelling results also improve.

### 1.7 "Why the Swartland?"

South Africa enjoys one of the most pleasantly temperate and healthy climates in the world –attractive to humans, but not necessarily to crops. The average annual rainfall of about 497mm for South Africa as a whole is well below the world average of 860mm. A comparatively narrow region along the eastern and southern coastlines receives a moderate amount of rainfall, but the greater part of the interior and the west of the country is arid or semi-arid (Schulze *et al.*, 2001). 65% of the country has an annual rainfall of less than 500mm, which is usually regarded as the minimum rainfall needed for crop farming without irrigation. 21% of the country receives less than 200mm. Over most of the country the annual potential evaporation, which ranges from about 1100mm to more than 3000mm, is well in excess of the annual rainfall. South Africa is by any standard an arid country (Huntley *et al.*, 1989).

A feature of South Africa's rainfall is the apparent existence of cycles of wet and dry spells. 18-year cycles of approximately 9 dry and 9 wet years occur in the summer rainfall area (Tyson and Preston-Whyte, 2000), and this variability has been present for at least 600 years as identified by tree ring data (Tyson *et al.*, 2002). The winter rainfall region of the Western Cape Province often displays the opposite trend to the wet and dry cycles of the summer rainfall area (Meadows, 1998; Preston-Whyte and Tyson, 1993). Thus the interior and eastern half of South Africa might experience an extended drought while the southwestern Cape enjoys above-average rains (Huntley *et al.*, 1989).

In more recent times the winter rainfall region of the Western Cape has undergone serious drought conditions, whereby some farmers have had to sell prize agricultural land for alternative land uses in order to survive. Appendix A contains a collection of recent news clippings where the drought has become a more urgent issue for farmers in the Western Cape. Some farmers have had to

lay off farm labourers in order to maintain the bare minimum of turnover, while others have uprooted the weakest fruit trees so as to conserve soil nutrients for the stronger trees more able to sustain the drought conditions.

The International Panel on Climate Change (IPCC) defines 'vulnerability' as "the extent to which a natural or social system is susceptible to sustaining damage from climate change; it is a function of the sensitivity of a system to changes in climate, adaptive capacity, and the degree of exposure of the system to climatic hazards" (McCarthy *et al.*, 2001, p89). This definition, combined with the factors mentioned above, has made the Swartland distinctly vulnerable to climate change.

The Swartland is a principal agricultural area in the Western Cape Province of South Africa, primarily known for its winter wheat, barley, and more recently vines (Dietrich *et al.*, 2004). Located in the winter rainfall region of South Africa, it exhibits a unique appearance, being an area of relatively uniform geology experiencing a semi-arid climate. There is very little natural vegetation remaining in the Swartland (~2.5%), being identified as prime agricultural land in the 1800's. With the already evident vulnerability of the region to drought, and a largely uniform geology, it makes the Swartland an important area to conduct such a climate change study. From this view, the study region of the Swartland is examined in more detail in *Chapter Three*.

### **1.8 Research aims and objectives**

As it has already been established that soil degradation is of paramount importance for the Swartland, this aspect will be the focus of the study. In response to the critical need to better understand our changing climate, the aim of this project is then to investigate how potential future climatic changes may affect geomorphic processes in this winter rainfall region of South Africa, particularly concentrating on soil erosion and processes related to the degradation of agricultural land that results.

Table 1.1: Objectives, methods and where the results are found for this regional study.

OBJECTIVES	ANALYTICAL TECHNIQUES	RESULTS CHAPTER
<ul style="list-style-type: none"> <li>• Introduce &amp; gain understanding of the study area.</li> <li>• Examine concerns of climate change impacts on the region.</li> <li>• Compile a historical account of wheat yields in the Swartland.</li> </ul>	<ul style="list-style-type: none"> <li>• Literature review of historical records, field surveys and consultation with experts in the field of agriculture, soils, climate and land use history of the Swartland.</li> <li>• Review of government records of wheat yields.</li> </ul>	<i>three</i>
<ul style="list-style-type: none"> <li>• Chose GCMs relevant to study.</li> <li>• Explore the present and future climate change projections from GCMs.</li> <li>• The relevance of GCMs on a regional study.</li> <li>• Constraints &amp; caveats of GCMs for regional climate change.</li> </ul>	<ul style="list-style-type: none"> <li>• Literature review of GCMs and applicability for southern Africa.</li> <li>• Examine present &amp; future simulations for the Swartland, particularly temperature, wind speed and precipitation.</li> <li>• Validate present day GCM output in the Swartland against observed data.</li> </ul>	<i>four</i>
<ul style="list-style-type: none"> <li>• Gain a more accurate regional understanding of future climate impacts in the Swartland.</li> <li>• Examine regional downscaling application to this particular study.</li> </ul>	<ul style="list-style-type: none"> <li>• Examination of downscaling techniques.</li> <li>• Identify present-day and future simulations of precipitation using regional downscaling methods.</li> <li>• Examine the efficiency of regional downscaling on a region such as the Swartland.</li> </ul>	<i>five</i>
<ul style="list-style-type: none"> <li>• Consider how future climate change may impact on soil erosion in the Swartland.</li> <li>• Evaluate what these impacts would be on agricultural trends, particularly for the Swartland.</li> <li>• Validation of Soil Loss EstiMator for Southern Africa (SLEMSA) for the Swartland.</li> </ul>	<ul style="list-style-type: none"> <li>• Literature review of present agricultural trends in the Swartland and what future climate change may hold for the region.</li> <li>• Application of SLEMSA, using present-day observed as well as downscaled future precipitation.</li> <li>• Modification of SLEMSA for specific use in the Swartland.</li> </ul>	<i>six</i>
<ul style="list-style-type: none"> <li>• Overview of findings.</li> <li>• Main constraints and caveats dealt with.</li> <li>• Recommendations for future research.</li> </ul>	<ul style="list-style-type: none"> <li>• Summary of results and objectives achieved.</li> <li>• Suggest recommendations for future research and possible considerations to be made by end users in the future.</li> </ul>	<i>seven</i>

Table 1.1 shows a summary of the objectives for this study, the analytical techniques required to meet these objectives, and where the results are found in the thesis. A detailed description of all the analytical techniques conducted is found in *Chapter Two*.

To analyse the effect of future climate change on soil erosion and land degradation, an analysis of past and present climate-soil erosion linkages needs to be made. Using a conceptual model, the key sensitivities of natural landforms need to be identified with respect to land degradation and then projected into the future to analyse the response to climate change. The overall aim is then to establish the relationship between the geomorphology of the area and its climatic sensitivity, where climate sensitivity is expressed as the "increase of global-mean equilibrium surface temperature for a doubling of pre-industrial atmospheric CO<sub>2</sub> concentration" (Knutti *et al.*, 2002, p719). Thus an examination of how a change in climate will affect the region.

The project deals with identifying the past, present and future climatic changes for the Swartland. An examination of regional scale historical climate change is made, using observed station data for the region. For examining the envelope of projected future change, a combination of six Global Climate Models (GCMs) is used, as well as regional downscaling techniques using three GCMs.

The six models used to simulate climate changes include: HADCM3; CSIRO-Mk2; ECHAM4/OPCY3; CCCMA; NCAR-CSM; and NCAR-PCM. These six models were chosen based on available data from the Intergovernmental Panel on Climate Change's Data Distribution Center (IPCC-DDC). Specifically, HADCM3, CSIRO-Mk2 and ECHAM4/OPCT3 have been used by CSAG (Climate System Analysis Group<sup>2</sup>) extensively and their results over southern Africa have proven appropriate thus far. All six models are current generation climate models and commonly reported on in the literature, thus making them familiar to researchers.

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<sup>2</sup> <http://www.csag.uct.ac.za>

The model simulations of present day conditions are first examined to assess the veracity of the model for the region. Precipitation, temperature and wind speed are the variables examined to establish the projected future climatic impacts over the Swartland. The SRES A2 and B2 emission scenarios will be used to force the GCMs to establish future climate change. These two emission scenarios are only two of many available scenarios, but chosen as the most appropriate for this regional study to gain an idea of the “worst case” and the “best case” scenario when considering future changes in climate.

The basic difference between the SRES A2 and B2 emission scenarios is that the A2 scenario envisions a rather slow economic and technological development with a steady population growth rate until 2100. The B2 scenario depicts a much slower population growth rate, with a more rapidly evolving economy linked with an emphasis on environmental protection. Thus the B2 scenario is thought to produce lower emissions and less future warming than the A2 scenario. These emission scenarios are discussed in more detail in *Chapter Two*.

The output for both the present conditions and a simulated CO<sub>2</sub> doubling around 2100 are used to examine present and future changes in climate. Following the analysis with respect to their effects on the study area, the models are examined in conjunction with a soil erosion model to examine their direct influences on the study area and their effects on the undulating geomorphology of the Swartland. This is achieved through the application of a soil erosion model (Soil Loss EstiMator for Southern Africa –SLEMSA (Stocking *et al.*, 1988)). The results from SLEMSA are computed from the present-day and future climate model simulations, knowing that SLEMSA has been proven in the southern African region. Conclusions are then drawn from the results of the soil erosion model, and these are examined regarding their effects on agriculture.

Since wheat is historically and currently the primary agricultural product of the Swartland, this is targeted in order to understand its natural response to climate

change. The projected climate changes examined with respect to soil erosion are closely scrutinised with wheat in mind.

By examining some main links in detail, the ultimate aim is to examine how climate change will affect the geomorphology and accordingly, the agriculture of the area. With the expected future warming of the climate system, its potential consequences increase the need for climate projections with clearly defined uncertainties and likelihood estimates (Schneider, 2001). The climate change effects are then examined with regard to soil erosion and land degradation, and how present vulnerable areas for growing winter wheat will be affected under these future climate change projections.

Previous studies have recommended that a more practical approach to erosion studies needs to be made by using models suited to the area (Stocking, 1995). Initially there is a tendency to overreact to the soil erosion question, and Stocking (1995) concludes that the problem is probably less severe than we have been led to believe. This has been proven for the Swartland where Talbot (1947) showed extensive gully erosion, which has in recent times been remarkably reversed (Meadows, 2003a; Muller, 1999; Morel, 1998). Thus a more interdisciplinary approach is considered appropriate for dealing with soil erosion issues in southern Africa.

**Chapter two** assesses the materials and methods used in the study to achieve the objectives mentioned in Table 1.1. **Chapter three** explores the study area in more detail, investigating the historical aspects of temperature, precipitation and wheat yield for the Swartland, thus setting the scene for the following chapters. **Chapter four** examines the climate modelling aspect of the study from a GCM point of view and their applicability for a regional study. **Chapter five** continues from **Chapter four** looking at climate modelling on a regional scale, with some downscaling results of present and future climate simulations for the Swartland. **Chapter six** examines the expected future climate change in relation to agriculture and the soil erosion issue using a soil loss estimator, and the study then concludes in **Chapter seven** with a summary and synthesis

of the results, constraints and caveats of the study, and finally how this research can move forward with possible recommendations to farmers and decision makers.

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***CHAPTER TWO:  
ANALYTICAL  
TECHNIQUES***

## **2.1 Introduction**

This chapter aims at summarising the methods applied throughout the study, and gives details of any additional materials used. The main sections are identified by the relevant chapter headings for easier cross-referencing:

## **2.2 The study area: The Swartland**

The physical details of the Swartland are gained mainly through a review of available literature. This includes government publications on the crops grown in the region, which date back to the very early 1900s. An understanding of the current climate of the Swartland is gained from reviews of climatological statistics from the South African Weather Service including historical station data, as well as past government publications.

Geological and geomorphological descriptions of the Swartland are obtained through a review of the literature in this regard, as well as two field trips to the region. Stratigraphy and soil maps, as well as consultations with soil scientists at the University of Stellenbosch also aided in a more complete understanding of the physical characteristics of the geological components of the region.

Identifying the vegetation composition of the Swartland was largely verified by the field trips to the Swartland. It is an area of gently undulating hills and therefore easy to identify the components of the vegetation, which are presently mostly cultivated lands. A review of the literature and government agricultural records revealed a long history of cultivation and the reasons behind the excessive removal of natural vegetation for cultivated crops in the early part of the 20<sup>th</sup> century. Fire has always been a natural component in this marked seasonal climatic region, that the indigenous population of the area quite likely utilised, however these hunter-gatherers and early pastoralists were seasonal migrators (Humphreys, 1998), so the main impacts on the landscape really only started with the settlement of the Dutch colony in the 1600s (Wesson, 1998).

A literature review reveals that current land use trends in the Swartland are still mostly as cultivated lands, however recent research has identified a move from crop farming towards more areas planted with grapes. This has also been identified from government records where political influences have caused farmers to plant one particular crop over another. This makes for an interesting future of farming in the Swartland, especially in the context of future climate change.

### **2.3        *Climate Modelling***

Climate modelling is divided into two main sections: climate modelling on a global scale; and regional scale climate modelling. Climate modelling from Global Climate Models (GCMs) is dealt with in this first section:

#### **2.3.1        *Constraints and caveats of GCMs***

Climate is simulated using mathematical models, which link the various equations that describe the key relationships and processes within a system to simulate its behaviour. By changing the values of certain variables, scientists can study how the system responds to both external and internal changes. Models tend to simplify reality, which is unavoidable because the system processes can never be understood perfectly (Hengeveld, 2000). For example, GCMs capture large scale features like deserts and the tropics very well, but have difficulty capturing smaller features like cyclones and thunderstorms because they occur at scales much smaller than the spatial resolution of the grid from the GCMs (Hennessy, 1998).

Models in many areas have, however, achieved a degree of skill that they are used routinely for operational purposes as well as for research, but for this study the model results would need to be used with caution as this is the first such study of these particular models for this research area. This section

examines constraints and caveats of the models in this study thus far, and how to progress further for more refined results within this study region.

The models do not (and cannot) take into account all processes (natural and anthropogenic) which affect climate variability and change. Some processes are not well understood and others must be represented in a simplified way in order to ensure computational efficiency. While continental-scale climatic features are well simulated for present conditions, regional features are captured with less accuracy (Hennessy, 1998).

The modelling team for the CSIRO GCM makes the statement that their model does not include the regional cooling effect of sulphate aerosol (Hennessy, 1998), which was identified early on by the Intergovernmental Panel for Climate Change (IPCC) as the important element of anthropogenic climate change (Houghton *et al.*, 1996). Although the largest aerosol emitters are countries in the northern hemisphere, these aerosols can impact on the southern hemisphere through long-distance teleconnection patterns (Markgraf, 2001), thus making them an important component of future climate change.

Many GCMs over-simplify the representation of ocean processes. This would be more likely to be important in determining patterns of climate change when examining a country like South Africa which is surrounded by oceans. These simplified ocean processes can include changes in the vertical profile of ocean temperature and/or salinity, and El Nino cycles (Hennessy, 1998). Small-scale influences of climatic features such as tropical cyclones, thunderstorms and cut off lows can also not be resolved at the GCM resolution.

Another constraint of GCMs is their inability to simulate plant physiology. The CSIRO GCM particularly excludes plant physiology (Hennessy, 1998), thus resulting in a lack of response from simulated vegetation to climate change and any changes in CO<sub>2</sub> levels. Another factor which is difficult to simulate and include in GCMs is that significant biospheric responses to climate change can occur in the real world, some of which resulting in land-use changes, which

would in turn result in complex climatic feedbacks (Hennessy, 1998). These feedbacks are difficult to simulate in a GCM as there could be any number of factors involved in the complex responses. Recent GCM research is, however, addressing this task.

One of the main issues of understanding *regional* climate change using a *Global* Climate Model is that of resolution. It so happens that the entire study area falls into one GCM grid box, thus making any small-scale regional changes impossible to simulate at a GCM level. With these constraints and caveats in mind, the next section explains the methods for GCM application to the Swartland.

### 2.3.2 GCM data and models' description

The present climate of the Swartland was simulated using six GCMs from the Intergovernmental Panel for Climate Change's Data Distribution Centre (IPCC-DDC). This output was then compared to historical station data and NCEP reanalysis data as observed.

NCEP (National Centers for Environmental Prediction) reanalysis data are from a GCM constructed using global analyses of atmospheric fields from observations. These observations include data from the land surface, ships, rawinsonde, pibal, aircraft, satellite, and other data (Kistler *et al.*, 2001). Reanalysis data are fine resolution gridded data, which combine observations with simulated data from numerical models. The observed data are then quality controlled and assimilated with a data assimilation system to eliminate perceived climate jumps associated with changes in the real time operational data assimilation system, but still being affected by changes in the observing systems (Kistler *et al.*, 2001). Table 2.1 shows the details of the six models, where they come from and how they compare to NCEP in terms of resolution.

**Table 2.1: Details of the six models to be compared to NCEP reanalysis data.**

MODEL	OWNER	RESOLUTION
NCEP	National Centers for Environmental Prediction –NOAA	2.5° x 2.5° (roughly 295 x 295km at the equator)
HADCM3	Coupled atmosphere-ocean from Hadley Centre, UK.	2.5° x 3.75° (295 x 278km)
CSIRO-Mk2	Climate Change Research Program – Australia	R21 at 5.625° x 3.25° (625 x 350km)
ECHAM4/OPYC3	ECMWF – Hamburg DKRZ – Max Planck Institute, Germany	T42 at 2.5° x 3.75° (295 x 278km)
CCCMA	Canadian Center for Climate Modelling and Analysis, Canada.	3.7 x 3.7
NCAR-CSM	National Center for Atmospheric Research, USA – Coupled System Model.	T42 at approx. 2.8° x 2.8°
NCAR-PCM	National Center for Atmospheric Research, USA – Parallel Climate Model.	384 x 288 x 32 grid with ave 2/3° lat. & long.

As mentioned in *Chapter One*, the choice of models was made based on the availability of model data and their common usage for other applications. Specifically, HADCM3, CSIRO-Mk2 and ECHAM4/OPYC3 have been used by CSAG (Climate System Analysis Group<sup>1</sup>) extensively and their results over southern Africa have proven appropriate thus far. CCCMA, and the two NCAR models are leading models in the field of future climate change, and are therefore important to the study (IPCC, 2001b). All the six models are current generation climate models and well reported on in the literature, thus making them familiar to researchers.

The NCEP reanalysis data results in a comprehensive and dynamically consistent three-dimensional gridded data set (the “analysis”) which represents the best estimate of the state of the atmosphere at that time (IPCC-TGCI, 1999). The NCEP reanalysis data are freely available from National Center for Atmospheric Research (NCAR), National Centers for Environmental Prediction (NCEP) and from the National Oceanic and Atmospheric Administration/

<sup>1</sup> <http://www.csag.uct.ac.za>

Climate Diagnostics Center (NOAA/CDC). Further details on the NCEP reanalysis data assimilation system can be found in Kalnay *et al.* (1996).

The atmospheric horizontal resolution of HADCM3 is 2.5° by 3.75°, with 19 levels in the atmosphere and 20 levels in the ocean (Braganza *et al.*, 2004). The ocean component uses a slightly higher resolution (1.25° by 1.25°) than the atmospheric component, thus giving improved representations of the physical processes in the atmosphere and the ocean (this is further described by Gordon *et al.*, 2000).

CSIRO Mark 2 is a coupled global climatic model with atmospheric, oceanic, biospheric and sea-ice components (Gordon and O'Farrell, 1997; Hennessy, 1998). The atmospheric component contains nine vertical levels with an R21 horizontal resolution, being roughly 5.625° longitude and 3.25° latitude (Braganza *et al.*, 2004). This is then coupled to a gridpoint ocean model of the same resolution with 21 vertical levels (Hirst *et al.*, 2000). CSIRO includes diurnal and seasonal variability within the model (Hennessy, 1998). Aerosol values for the SRES A2 and B2 emission scenarios being supplied by NCAR, with observed greenhouse gas concentrations for 1870 to 1990 are being used. The initial CO<sub>2</sub> concentration was set to 330ppm, as used in the model control calculations. The equivalent CO<sub>2</sub> was scaled relative to this, so that the evolution of the radiative forcing is correct (Dix *et al.*, 2001).

ECHAM4/OPYC3 is an atmospheric T42 spectral model with 19 vertical layers (Braganza *et al.*, 2004). The ocean part of the model (OPYC3) uses isopycnals as the vertical coordinate system described by Oberhuber (1993). A range of greenhouse gases are explicitly represented including that of aerosol radiative effects, described further in Roeckner *et al.* (1996).

The Canadian Center for Climate Modelling and Analysis (CCCMA) have included their CGCM2 model with the IPCC-DDC dataset which is being used in this study. This is a T32 spectral model, thus yielding a surface grid resolution of roughly 3.7° by 3.7°, and 10 vertical levels (Flato *et al.*, 2000).

The model uses heat and water flux adjustments obtained from uncoupled ocean and atmosphere model runs, followed by an 'adaptation' procedure in which the flux adjustment fields are modified by a 14 year integration of the coupled model.

Two models from the National Center for Atmospheric Research (NCAR) in the USA are examined in this study. Firstly NCARCSM, NCAR's community climate system model, version 2.0.1 which is a coupled climate model composed of four separate model components simultaneously simulating the earth's atmosphere, ocean, land surface and sea-ice, and one central coupler component (Buja and Craig, 2002). The high-resolution version is used here for future climate change studies and is at T42 in the land/atmosphere component and gx1v3 in the ocean/sea ice component. The grid cell resolution varies from a 2.8° by 2.8° grid over land to 1° by 1° grid over oceans and ice, with 26 levels in the vertical.

NCAR's Parallel Climate Model (NCARPCM) uses the parallel version of the NCAR Community Climate Model version 3.2 (CCM3), which includes the latest versions of radiation, boundary physics and precipitation physics (Kiehl and Gent, 2004) contributing to a modern, high-tech atmospheric component. The CCM3 also includes a land surface model with takes into account soil physics and vegetation. The ocean component of the NCARPCM includes a moderate resolution global ocean model with a parallel ocean program (POP) model. The horizontal grid has 384 by 320 grid points, with an average resolution of 0.7° latitude and longitude over the oceans, and 40 levels in the vertical. NCARPCM also includes a sea ice model and a river transport model, tying the components together and allowing for the exchange of fluxes and variables with a fully implemented flux coupler. Most of these details have been taken from the Climate and Global Dynamics Division (CGD) of NCAR webpages<sup>2</sup>, however more detailed information on this model can be found at Kiehl and Gent (2004).

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<sup>2</sup> <http://www.cgd.ucar.edu/pcm/> accessed 7<sup>th</sup> May 2005.

The above GCM simulations include emission scenarios from the Special Report on Emissions Scenarios (SRES) A2 and B2 scenarios. The A2 scenario describes a heterogeneous world where the underlying theme is self-reliance and preservation of local identities (Houghton *et al.*, 2001). This scenario uses a continuously increasing population structure, where economic development is primarily regionally oriented and *per capita* economic growth and technological change are fragmented and slower than the B2 scenario (Houghton *et al.*, 2001).

The SRES B2 emission scenario is on the opposite scale from the A2 emission scenario, where there is an emphasis on local solutions to economic, social and environmental sustainability. It reflects an increasing global population, however at a lower rate than A2, with intermediate levels of economic development (Houghton *et al.*, 2001). B2 scenarios are based on having less rapid and more diverse technological change, while also leaning towards environmental protection and social equity, focussed at a regional level. While many other differing scenarios of climate change exist, the A2 and B2 scenarios were chosen for the study as the best “extreme” cases for a regional study. Thus they are the most appropriate model output to consider for an envelope of future climate change to be established for the Swartland.

### 2.3.3 GCMs validation for the Swartland

The variables examined for the models' validation included temperature (average, maximum and minimum where available), precipitation, and wind speed from the IPCC-DDC GCM archive of simulations forced by the SRES A2 scenarios, for the first 30 years as a simulated climatology of the region. The GCM values were only available in “grib format” from the IPCC\_DDC, and so were converted into GrADS (Grid Analysis Display System) format using a “grib2ctl” script then running “gribmap” on the new “ctl” file.

Table 2.1 shows that all the models have a differing resolution. To enable accurate comparison between the models and NCEP, they were regridded

using the box averaging method, to a 4° by 4° degree grid. With the box averaging method, the inner region solutions are fixed by normalisation in such a way as to guarantee conservation of the probability within the box radius (Box and Jenkins, 1976; Hamilton, 2003). An advantage to using this method is that one is closely involved with the data and is therefore better able to judge the goodness-of-fit of the model and the influence that idiosyncrasies in the data have on the fit (von Storch and Zwiers, 2000). This method was conducted using GrADS for ease of verification and analysis in the study region.

The GCM values were taken over a study region of 32°S to 34°S and 18°E to 19.5°E to represent the Swartland, where the geological makeup of the Swartland falls within these latitude and longitude dimensions (the Swartland is explained in more detail in *Chapter Three*). As the Swartland is a relatively small area when examining GCM grid cell resolutions and it was found that the entire region fell into one grid box. Thus the GCM values for that one 4° by 4° degree grid box were taken as representative of the entire Swartland region and compared to NCEP as observed.

In order to validate the models for the Swartland region, the long-term average monthly mean for each variable over 30 years was determined for each model. This included NCEP as observed for comparison's sake. The difference between the models' long-term average monthly mean and NCEP was examined in order to establish the model bias. This value was then used to adjust the model output so that it is more representative of the study region and taken into account for all model output, i.e. both present and future. Monthly standard deviation and variance were then calculated, and the seasonal cycles examined to check if the models could correctly simulate seasonality for the region. The monthly average, maxima and minima were compared to NCEP.

The raw GCMs are too coarse to compare directly to NCEP (as observed) for the study without taking into account model sensitivity and model bias analyses (as mentioned above). Once these were examined with respect to how they represent present climatology, the model results of present and future climate

averages were statistically clustered with a “*Statistica*” package, using Single Linkage and Ward’s Method with Euclidean distance measures.

The Single Linkage clustering is performed to identify outliers, as in this method the distance between two clusters is determined by the distance of the two closest objects in the different clusters (StatSoft, Inc., 2004). Ward’s Method however, helps to identify cohesive groups by analysing the variance to evaluate the distances between clusters, thus making it insensitive to outliers (StatSoft, Inc., 2004). Ward’s Method is the most frequently used hierarchical clustering technique for climatic classification (Kalkstein *et al.*, 1987). Table 4.2 shows the outliers and cohesive groups resulting from the clustering techniques, while all the joining tree-clustering graphs examined can be found in *Appendix B*.

#### **2.3.4 Present and future GCM simulations**

Once the model simulations of present day conditions were adjusted for model bias, the output was used to examine present climate in the Swartland. The long-term average model temperature, precipitation and wind speed variables were plotted on a monthly basis and compared to NCEP. The results (*Chapter Four*) showed that the two NCAR models (that of CSM and PCM) did not adequately simulate present climate in the Swartland, and are therefore excluded from the study from this point forward.

Future climate change is then examined with respect to the raw GCM output of CSIRO, ECHAM4 and HadCM3 for both the A2 and B2 SRES scenarios, also adjusted for model bias as calculated earlier. These changes are then briefly analysed with respect to their effects on the Swartland in *Chapter Four*.

#### **2.4 Regional climate modelling: downscaling**

Downscaling climate data is a statistical technique based on the view that the large-scale climatic state and local physiographic features condition the

regional climate. Taking this perspective, regional climate information is derived by first determining a statistical model which relates large-scale climate variables to regional and local variables. In this case the three GCMs of CSIRO, ECHAM and HadCM3. The large-scale GCM output is then fed into this statistical model to estimate corresponding local and regional climate characteristics.

Some of the primary advantages of using such a technique are that it is computationally inexpensive, and also easily applied to output from many different GCM experiments. Site-specific information can also be derived, being especially beneficial to climate change impact studies (Wilby *et al.*, 2004). Downscaling is a widely recognised methodological approach for dealing with GCM inadequacies in developing regional scale scenarios, and is considered the most viable for the South African context (Hewitson, 1999).

Until recently, statistically downscaled climate modelling experiments were largely practised by climatologists, and not used by impact analysts at all (Wilby *et al.*, 2004). This is largely because the output has been regarded as unreliable, or too difficult to interpret. Generally, downscaled scenarios are mostly based on a single GCM, which can give a misleading impression of increased resolution equating to increased confidence in the projections. Thus, comprehensive impact studies must be founded on multiple GCM outputs, and not rely on the findings of only one simulation, for one scenario.

#### 2.4.1 Key downscaling assumptions

Several key assumptions are made when downscaling climate model output, both for current and projected future climates. It is imperative that these assumptions be considered before examining the downscaled output (Wilby *et al.*, 2004; Giorgi *et al.*, 2001b; Hewitson and Crane, 1996):

- Large-scale climate variables must be chosen on the balance of their relevance to the target regional/local variables, and their accurate

representation by the climate models used. Thus a verification of the GCM for the study area, at least for the large-scale climate variables of interest, is necessary before considering downscaled output. This was conducted in section 3.3 for this study.

- The assumption that the relationship between the large-scale climate variables and the regional/local variables remains valid for periods outside the fitting period. This is important to check for future climate projections, as there are no observed data to compare to, thus making verification of future climate output impossible. A possible solution is to validate the downscaling model with observational data stemming from periods well separated from the fitting period, i.e.: representing a "different" climate regime (Charles *et al.*, 2004). Here the caveat is the limited ability of climate models to simulate the local variable, however this has been checked for the three downscaled scenarios for the southern African region (Hewitson and Crane, in press).
- The large-scale climate variable set needs to sufficiently incorporate the future climate change 'signal' for the region. This assumption increases the confidence in the choice of large-scale climate variables for the study and shows that relationships derived during fitting remain legitimate for the future changed climate.
- The large-scale climate variables used for determining the future local climate should not lie outside the range of the downscaled model. If this does occur, then technically the downscaled model is invalid. Preliminary explorations of the output of ECHAM4 suggest that the assumption of 'stationarity' is robust for geopotential heights across most of the Southern Hemisphere, but less so for atmospheric moisture in the tropics (Hewitson, 2004). Using this assumption, the ECHAM4 model can be safely used for this study, keeping in mind that it tends to slightly over simulate precipitation over the southern African subcontinent (Hewitson and Crane, in press).

### 2.4.2 Data and models' description

Hewitson and Crane (in press) have developed the downscaled GCM scenarios that are being used in this study. The methods they apply are briefly summarised here (see Box 2.1), but for a full review, see Hewitson and Crane (submitted).

**Box 2.1:** Downscaled data and models description, as per Hewitson and Crane (submitted).

Daily mean atmospheric fields were constructed from 6-hourly NCEP reanalysis data for 1979 to 2002. The NCEP and GCM data were then regridded to a common 3° by 3° grid for comparisons sake. The variables used included u and v wind vectors, temperature, specific humidity and relative humidity, representing a common set that reflects the primary circulation and water vapour attributes. 'Surface' and '700hPa' levels were examined, so as to establish a correlation between variables and levels in the atmosphere. 'Surface' is particularly examined as it plays a significant role in characterising the atmospheric state in a region where orographic forcing is dominant. The precipitation data used came from a high resolution 0.25° gridded dataset for South Africa, originally derived from source station observations of around 3000 stations (described by Hewitson and Crane, 2005).

Self Organising Maps (SCMs) were then produced for each 3° by 3° grid cell and a unique set of possible synoptic states derived. A synoptically controlled precipitation probability density function (PDF) is then created for each precipitation grid point, from the 0.25° grid

The downscaling then standardises the GCM data using the same procedure as for NCEP, mentioned above. For future climate, this standardisation process uses means and standard deviations of the simulation data for present day climate, thus preserving any changes in the future from the present day means and standard deviations. These data are then mapped to the SOM, so that there is a SOM to describe the synoptic states associated with the domain, and thus the daily atmospheric states of the GCM control and future climate simulation data map onto the same set of observed synoptic states.

*Cont...*

**Box 2.1 cont...** Downscaled data and models description, as per Hewitson and Crane (submitted):

Downscaling the precipitation data then resulted in a generation of rainfall events of the correct magnitude for South Africa. Once the rainfall value was extracted, the daily data for the length of the record being used was generated and repeated 100 times. This created a monthly time series that reflected the median and mean responses within a stochastic envelope. Further details are available in Hewitson and Crane (in press).

Two main facts are notable immediately from the downscaled results for South Africa: firstly that the downscaling provides regional detail that is consistent with the actual spatial gradients over the region; and secondly that the pattern of agreement of positive and negative changes are remarkably consistent across the three GCMs (Hewitson and Crane, in press). This endorsed the confidence to use the downscaling for the regional study of the Swartland.

The downscaled output from these same three GCMs are analysed with respect to the Swartland, i.e.: that from CSIRO Mk2, ECHAM4.5 and HadAM3. Four variables of precipitation were analysed, as GCM temperature simulations are accurate for this particular regional study and no other downscaling data were available. It is necessary to note here that HadAM3 was used instead of HadCM3 as it is a higher resolution atmospheric model, however still driven by sea surface temperatures from HadCM3.

The variables examined from the downscaled output included monthly values of median total precipitation (mm); median rain days greater than 20.00mm; median dry spell duration; and median 90<sup>th</sup> percentile. The median values were taken as they are stochastically calculated from the means, being the median value for one specific month, and are therefore better representative of future climate for the region than the means generated directly from the downscaled data (Hewitson pers comm.). The anomalies of these variables are then examined with respect to present vs. future climate change.

### 2.4.3 *Analytical techniques of regional downscaling*

Monthly anomaly maps from the downscaled data for the variables mentioned above were created using GrADS by taking the future simulations and

subtracting the control for each model. The months were grouped in seasons for ease of comparison, i.e.: DJF (summer), MAM (autumn), JJA (winter) and SON (spring). A three-element moving time average was then applied to the anomalies to gain a better understanding of the seasonal change. The binomial center weighted smoother was the moving average technique used. This basically includes taking the anomaly of one month and adding half the anomaly for the months either side, then dividing this total by two. Applying this technique helps to reduce the extreme peaks in the data, thereby decreasing the chance of artificial results being presented.

The SRES A2 scenarios were examined for ECHAM4, HadAM3, and CSIRO, and then the SRES B2 scenario was also examined for CSIRO. The downscaling of GCMs in southern Africa is an ongoing project and it is planned that more precipitation scenarios and possibly even temperature will be examined in the future. This would include examining different scenarios to gain a possible "envelope of climate change". It is necessary to note here that with these future downscaled regional climate change output, the pattern or direction of change is what is examined, not the magnitude. This is because the magnitude is partly dependent on global CO<sub>2</sub> emissions and future global actions in this regard, which cannot be accurately predicted. These results are presented in *Chapter Five*.

## **2.5 Swartland climate and soils**

Land degradation is widely recognised as a global problem and is often referred to as desertification in arid, semi-arid and dry sub-humid zones (Gisladottir and Stocking, 2005) of which the Swartland is classified as semi-arid (*Chapter Three*). It is primarily through changes in rainfall patterns and in biomass production that climate change may effect land degradation (Gisladottir and Stocking, 2005). A survey of the potential impact of future climate change in South Africa concludes that the currently most severely degraded parts of the country are likely to become even more susceptible to land degradation and soil erosion (Meadows and Hoffman, 2003). It is explicitly

important to consider the soil as well as climatic variability when examining climate change impacts on crops and natural vegetation (Wassenaar *et al.*, 1999), and this is achieved through modelling likely patterns of future soil erosion.

### 2.5.1 Soil erosion modelling

Many soil erosion models have been used at different localities around the world. Researchers favour different models for their final output; amount of data and local knowledge required; level of expert information needed; scales of time and space; different processes examined; continuous or event based models depending on the final requirements; land-use considerations; socio-economic aspects; erosion links; etc... (Boardman and Lorentz, 2000). Models perform at different levels producing results at different time scales; relative versus absolute results; and results for runoff and soil loss. Thus it is important to choose a model based on the input necessary as well as the output required in the study.

Many different erosion models exist and have been used successfully in different parts of the world. Some of these include: GLEAMS, EUROSEM, GUEST, EPIC, WEPP, SLEMSA, MEDRUSH, CSEP, ACRU, USLE, AGNPS, EROSION3D, APSIM, among others. Boardman and Lorentz (2000) concluded their study of evaluating various soil erosion models with some valid points for choosing the model appropriate for the study concerned. These include the following:

- Modellers need to have some knowledge about the data and the locality being modelled.
- Hydrological processes are generally simulated more accurately than the erosion or sediment yield processes.
- Extreme events are generally poorly simulated in current models, particularly if they are empirically based.

- Model performance can be improved upon by incorporating spatial heterogeneities at the appropriate scale.

Models cannot be limited to special cases, but must be applicable to 'real world' situations if they are to be effective tools for conservation planning and erosion control (Morgan, 1981). Several erosion models were considered for this study and have been compared in detail in *Appendix C* for their validity to the Swartland. Some of the main points are summarised here, starting with ACRU (Agricultural Catchment Research Unit), which was indeed found to be appropriate for studying climate change impacts and CO<sub>2</sub> conditions on crop yields at the catchment scale (UNFCCC Secretariat, 2005). However ACRU is in essence a hydrological model, with its key outputs being crop yield and water balances for different climate change scenarios (Kiker and Clark, 2001). It does not simulate soil erosion at any scale, making it inappropriate for this study.

APSIM (Agricultural Production Systems simulator) has the unique quality of being able to integrate models being derived from different research domains, thus enabling a combination of research from different disciplines to be compared within one model (UNFCCC Secretariat, 2005; Asseng *et al.*, 2004). The APSIM output includes changes in crop and pasture yields, yield components, soil erosion losses, all for different climate change scenarios (McCown *et al.*, 1996), which are potentially helpful for this study. However, APSIM is aimed at trained agronomists, with an advanced knowledge of plant growth and more complex soil processes (McCown *et al.*, 1996), thus it does not appear to be viable for this study.

EPIC (Erosion Productivity Impact Calculator) is a generalised crop model, being physically based and therefore capable of simultaneously and realistically simulating the various physical and chemical processes of erosion (Huszar *et al.*, 1999). It is freely available for use via the Blackland Research and Extension Center<sup>3</sup> of Texas A&M University, USA. The primary aim of the

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<sup>3</sup> <http://www.brc.tamus.edu/epic>

EPIC model is to connect the rate of soil erosion to agricultural productivity (Sharpley and Williams, 1990). Its key outputs include the response of crop yields; yield components; and irrigation requirements to climate change, making it a desirable choice to use in this study. However, closer examination of the workings of the model reveal that EPIC is highly data intensive and difficult to use without sufficient qualifications in crop system science and moderate programming skills (UNFCCC Secretariat, 2005). Thus, being technically complex and data intensive, it was decided to reject EPIC in favour of an alternative.

SLEMSA (Soil Loss EstiMator for Southern Africa) has proved itself in other regions of southern Africa (Igwe *et al.*, 1999; Mughogho, 1998; Hudson, 1987), and so is a logical consideration. The key outputs produced by SLEMSA are estimated soil loss, given as the 'field rate of soil loss' or 'gross erosion' (Abel and Stocking, 1987) and these are derived from plot sized farming areas. It has a reasonable accuracy with the ability to extrapolate to unmeasured conditions and more complex farming systems practised in developing countries (Clark, 1996). No professional training is required to run SLEMSA and it is cheap to apply (Abel and Stocking, 1987) therefore making it a favourable option for this analysis.

A classic method for determining soil loss from an area is the USLE (Universal Soil Loss Equation) developed in the USA. It is an index-based, empirically derived model (Favis-Mortlock and Guerra, 1999) that allows one to estimate the average annual soil loss for a given region under natural and anthropogenic conditions. Although developed specifically for croplands east of the Rocky Mountains (Foster *et al.*, 2003), it has been widely used as it can be extrapolated for any region, with relatively little available data. However, the USLE has shown problems when applied to environments for which it was not originally designed and thus results need independent verification when used elsewhere, particularly for estimating and interpreting vegetation cover (Abel and Stocking, 1987) and dealing with deposition of sediments (Foster *et al.*, 2003; Clark, 1996). Including this necessary model validation and calibration

for use in “new” regions (Jetten *et al.*, 1999), this makes the USLE data-intensive and therefore not an option for this study.

The Water Erosion Prediction Project (WEPP) has developed a continuous simulation model, which is physically process-based (Favis-Mortlock and Guerra, 1999) and therefore able to predict soil loss and deposition reasonably accurately. WEPP takes into account climate, hydrology, water balance, plant growth, soil composition and consolidation (Laflen *et al.*, 1997) and models the effects global climate change is expected to have (Williams, *et al.*, 2001). Considering all these factors, WEPP is very data demanding when compared to simple response functions of many other erosion models, such as the USLE and SLEMSA. Although these large quantities of data can be simplified using GIS technology (Evans and Brazier, 2005; Amore *et al.*, 2004), this only adds to the data requirements necessary to use the model. This is an important factor when modelling in developing countries and thus a negative point when considering utilising this model.

Although the Universal Soil Loss Equation (USLE) has been the dominant method of soil loss prediction in many parts of the world, other methods have been tried and proven more satisfactory for the sub-tropical African continent (Maali, 2003; Igwe *et al.*, 1999; Stocking, 1995; McKyes, 1989; Stocking *et al.*, 1988; Stocking, 1981).

One of the successful approaches to soil erosion modelling in the southern African region in particular, is that of SLEMSA (Soil Loss EstiMator for Southern Africa). It was initially developed in Zimbabwe in the late 1960s to provide advice towards curbing an ever increasing soil loss problem on arable lands, and its framework is well documented in Stocking (1981). Since its inception, it has been successfully modified and used repeatedly in various studies in the southern African region (Igwe *et al.*, 1999; Mughogho, 1998; Hudson, 1987). After considering the six models mentioned above, SLEMSA seemed to be the most appropriate for this study in the Swartland and the details as to its usage follow.

The SLEMSA framework is simplified in Figure 2.1 and starts with the identification of the major physical processes that affect soil erosion, namely crop, climate, soil and topography. The control variables are the dominant factors influencing soil loss within the system, while at the same time being easily measurable and rational (Stocking, 1981). The fact that these control variables are logical and easily measurable is one of the main strengths of SLEMSA.

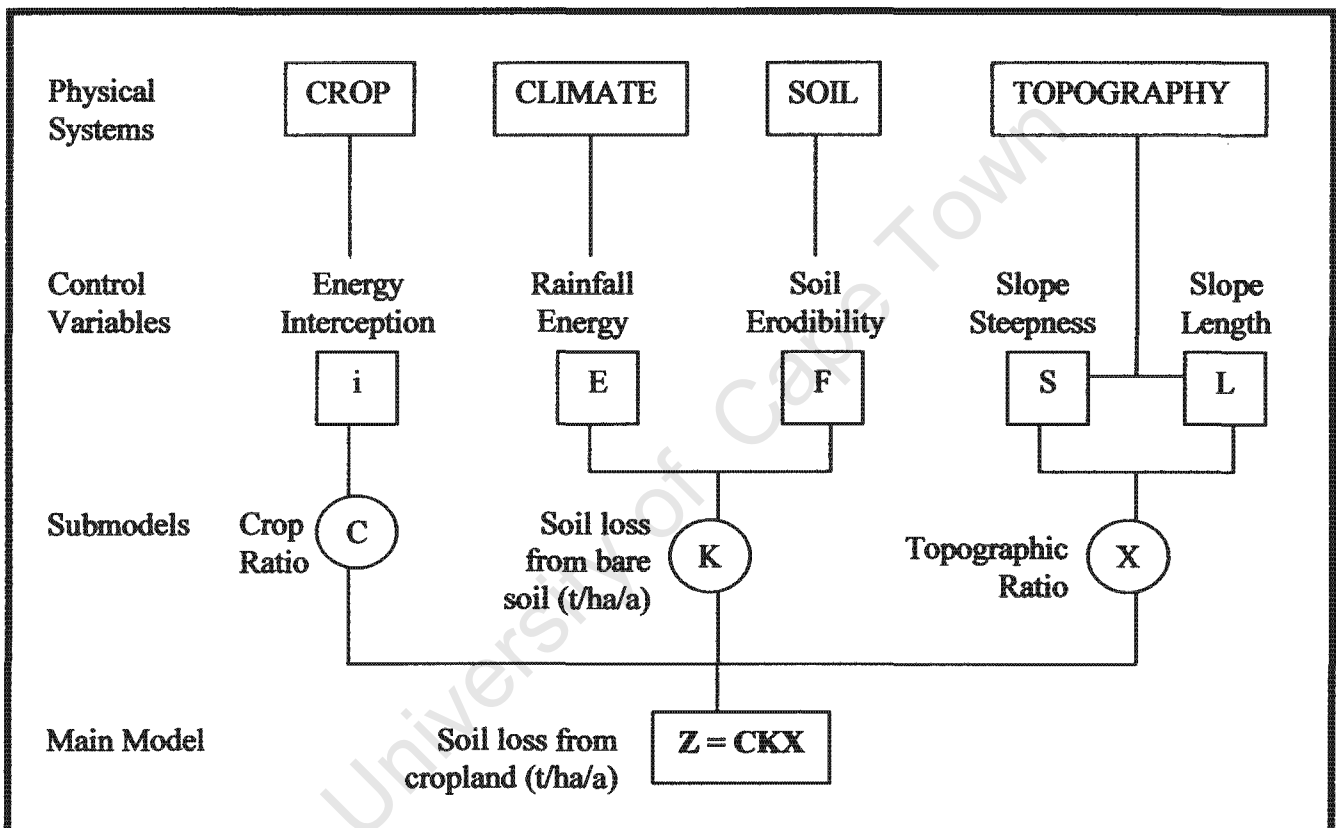


Figure 2.1: The SLEMSA framework, reproduced from Stocking (1981).

The control variables used in the model are explained as follows: Rainfall energy intercepted by the crop (i) is measured as a percentage. The seasonal rainfall energy (E) is the total kinetic energy of all rainfall events within the rainfall season, i.e.: 1<sup>st</sup> April to 30<sup>th</sup> September, and is measured in joules/m<sup>2</sup>. F is the soil erodibility and is calculated off an index (Stocking, 1981). The

slope steepness (S) is measured as a percentage, and the slope length (L) is measured in meters.

The sub-models of C; K; and X represent the crop ratio or crop canopy; the bare soil condition or soil loss from bare soil, measured in tonnes per hectare per annum; and the topography or topographic ratio respectively. These produce the output of Z, being the mean annual soil loss in tonnes per hectare, which is calculated by the multiplication of C, K and X.

### 2.5.2 Constraints and weaknesses of SLEMSA

SLEMSA was built to have a predictive capability on the Zimbabwe highveld. This is a region of relatively high elevation, inland and experiencing summer rainfall. The Swartland is an area experiencing winter rainfall, but although on the coastal plain, it is far enough inland to afford the opportunity of using SLEMSA with some small degree of accountability. The winter rainfall feature of the area is noted and will be discussed with the forthcoming results in *Chapter Six*.

It was noted that because of the simplistic nature of the soil loss estimator, it cannot take into account all the complex interactions involved in the soil erosion processes (Elwell, 1981), but merely serve as a guide and indicator towards possible future soil erosion scenarios. At this stage, this is all that is being required of using SLEMSA in this study. The thought is to gain an idea of what future climate change impacts would have on the study region. As these future climate changes are reliable only to a "direction of change" point of view (see *Chapter Four*), SLEMSA will provide an indication as to whether or not erosion will be intensified in the future, combined with climate change.

SLEMSA is used here as it utilises data that can be obtained at a relatively low cost, in less time than for conventional methods of soil data collection. As it is simple to utilise, a variety of models can be formulated to suit different localities and field conditions, hence the cautious use of SLEMSA in the Swartland. With

these thoughts in mind, the next section considers SLEMSA's output for the Swartland with downscaled future climate model output.

### 2.5.3 Applying SLEMSA to the Swartland

In order to examine climate change effects on erosion in the Swartland, SLEMSA was calculated using both present-day observed precipitation as well as using the downscaled future precipitation. The procedure followed when calculating SLEMSA factors, as mentioned above, were as follows:

- Firstly, mean annual precipitation in mm/year is needed. This was calculated from historical station data and the regionally downscaled climate model data. Table 2.3 shows the annual rainfall by which SLEMSA will be modelled, where the historical data was subjectively chosen as best to represent the Swartland region, i.e.: all stations with more than 1000mm/yr were disregarded as being orographically influenced and therefore not representative of the Swartland region (see *Chapter Three* for study area details).

Table 2.3: Mean annual precipitation as calculated from historical station data, and regionally downscaled data for the Swartland (latitude 32°-34°S and longitude 18°-19.5°E).

	Present day (mm/yr)	Future (mm/yr)
<b>Historical station data</b>	461.5033	
<b>ECHAM4</b>	333.886	314.367
<b>HADAM</b>	332.499	300.589
<b>CSIRO-A2</b>	319.185	270.081
<b>CSIRO-B2</b>	319.197	277.633

- E (rainfall energy) was then estimated from the annual mean precipitation, as the Swartland was identified as a "non-guti" area. Stocking (1981) explains "guti" as referring to those stations receiving significant amounts of orographic rainfall which tends to depress the proportion of high intensity rainfall received in the season. Thus "guti" stations generally have lower energy per millimetre of rainfall than "non-

guti". In the original study, "guti" stations were estimated at receiving more than twenty days of early morning drizzle annually (Stocking, 1981) which is not experienced in the Swartland, hence the classification of "non-guti" for this study.

An empirical relationship is assumed here between rainfall energy and total rainfall. In order to assume this empirical relationship, stationarity of the climate system is understood, given that there is a relationship between the larger-scale and the local climate. When considering the future climate state, the assumption is made where the observational data from which the relationship is developed, encompasses the required information for future cross-scale relationships (Hewitson and Crane, submitted). Essentially then the same synoptic states are present in the future as the present, and that climate change will manifest itself as a change in timing, persistence and frequency of these larger-scale events.

Thus E is estimated by plotting the mean annual precipitation (Table 2.3) against the graph in Figure 2.2. Table 2.4 shows the calculations for E from the graph in Figure 2.2.

Table 2.4: Average annual incident rainfall energy, E, calculated from historical station data, and regionally downscaled data for the Swartland (latitude 32°-34°S and longitude 18°-19.5°E).

	Present day E (kJ/m <sup>2</sup> )	Future E (kJ/m <sup>2</sup> )
<b>Historical station data</b>	8.5	
<b>ECHAM4</b>	6.5	6.1
<b>HADAM</b>	6.5	6
<b>CSIRO-A2</b>	6.2	4.8
<b>CSIRO-B2</b>	6.2	4.9

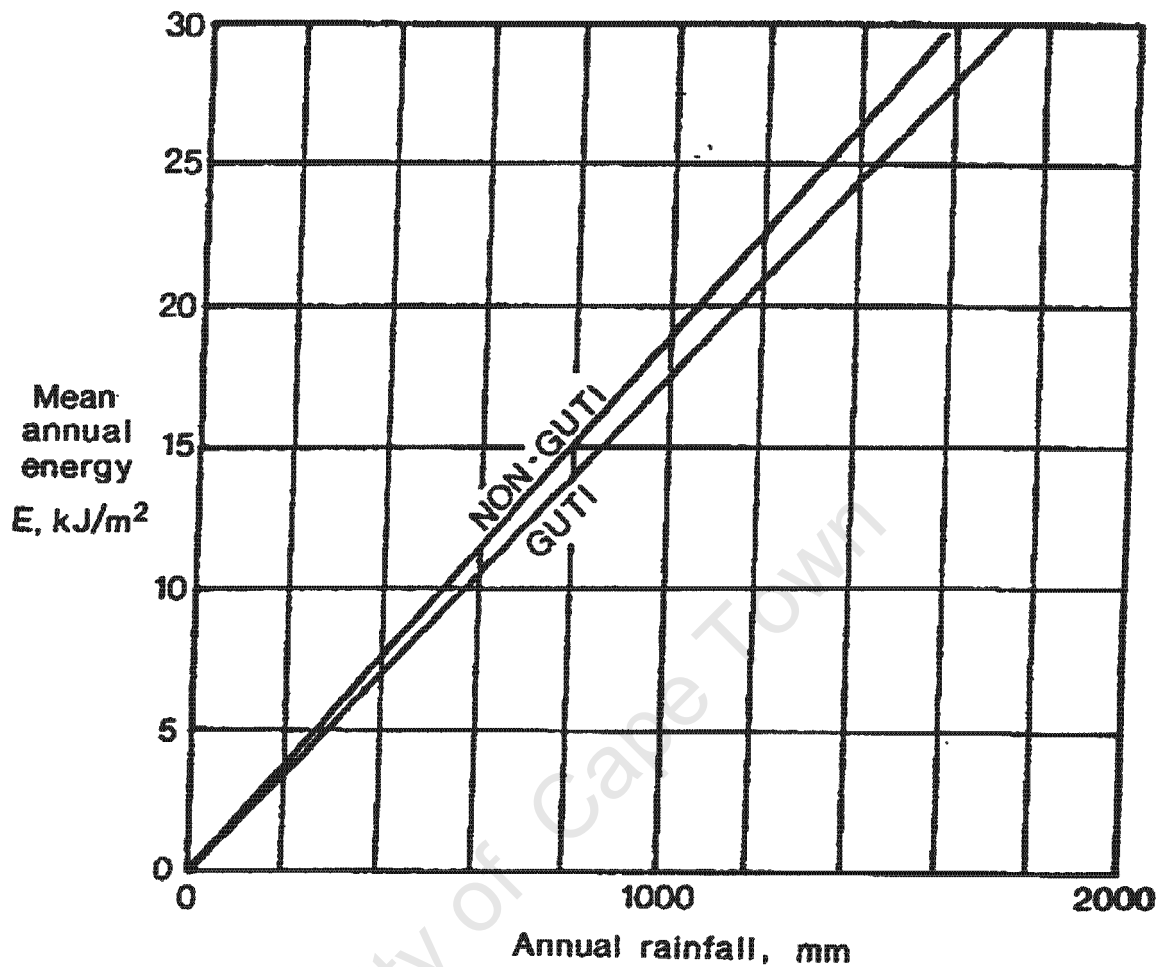


Figure 2.2: Mean annual rainfall energy versus annual rainfall for guti and non-guti regions (originally from Elwell, 1980).

- Soil erodibility ( $F$ ) was derived from SLEMSAs original tables which take into account soil group, soil family, soil texture, and land management factors and crop management, e.g.: crop rotation. The basic equation is as follows:

$F_m = F_b + \text{correction factors}$ , where the correction factor is determined by the crop practice and soil management techniques (see table in *Appendix D*).

$F_b$  is calculated from the basic soil erodibility factors for the different soil types (*Appendix D*). The Swartland generally has a combination of both lithosols and fersiallitic soil groups. The lithosols are mainly clayey and thus would have an  $F_b$  factor of 4.0. Granites and Malmesbury shales are also present, and these tend to produce more sandy soils, where little original topsoil remains. Soils in the Swartland tend to be duplex in nature, reflecting their ability to move downslope, thus making them more susceptible to soil erosion (Talbot, 1947)(see *Chapter Three*). These characteristics also provide an  $F_b$  of 4.0, which is what will be used in the calculation of soil erodibility.

The correction factor for the Swartland was determined by the following assumptions:

- Average soil losses occurred in the pervious year, assumed by the stringent conservation practices employed by farmers in the region. Factor: -0.5
- Ridging practices employed include normal tith. Factor: 0
- Crops are generally on small ridges (<200mm) and slope of >2% due to the topography of the region. Factor: -1.0
- Annual crops are planted on the contours and ploughed and rolled. Factor: 0.5
- Fallows and leys have been generally well vegetated for more than three years. Factor: 2.0
- Crops are mechanically cultivated dry land crops, i.e: they are not irrigated. Factor: -0.5

Thus the total correction factor estimated for the Swartland equals 0.5. Concluding that  $F_m = 4.0 + 0.5 = 4.5$

- Specific soil loss,  $K$ , is then shown in Table 2.6, as calculated from Figure 2.3.

Table 2.6: Specific soil loss,  $K$  (t/ha/yr), as calculated from Figure 2.2 for historical station data, and regionally downscaled data for the Swartland (latitude 32°-34°S and longitude 18°-19.5°E).

	Present day $K$ (t/ha/yr)	Future $K$ (t/ha/yr)
Historical station data	9	-
ECHAM4	4	2
HADAM	4	1
CSIRO-A2	3	0.5
CSIRO-B2	3	0.5

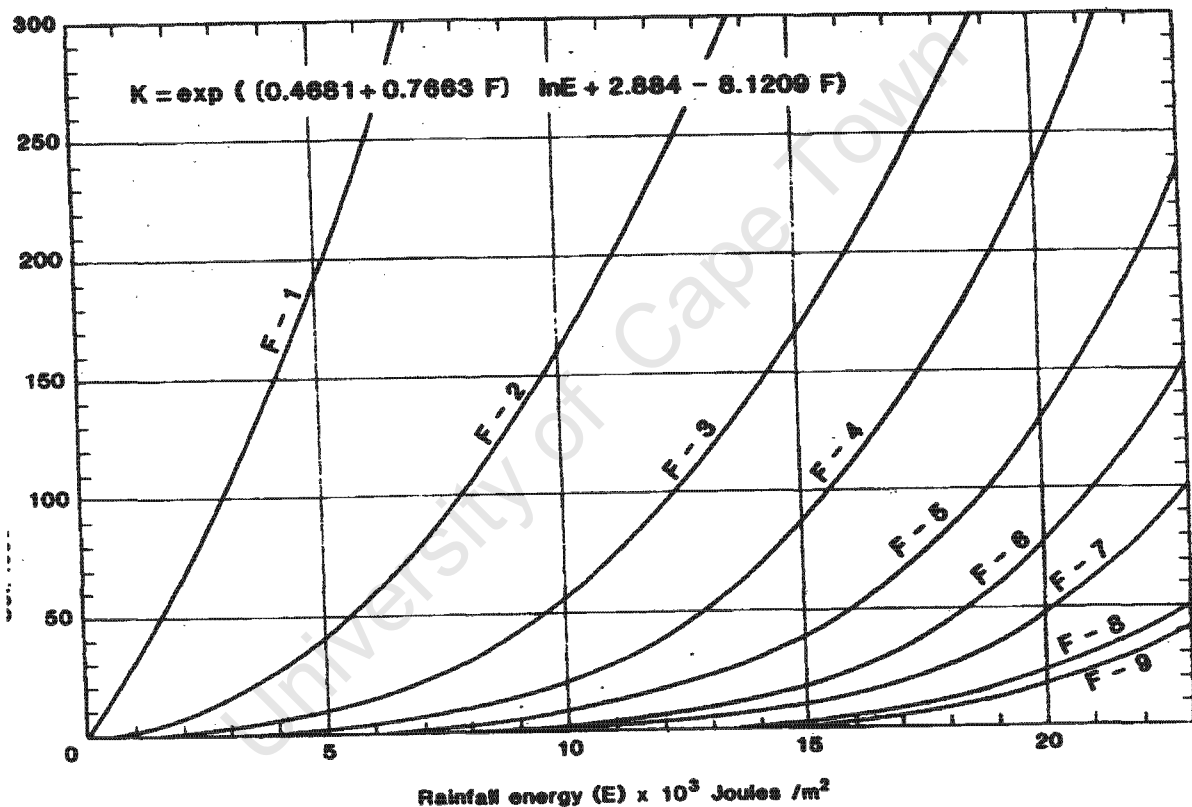


Figure 2.3: Specific soil loss rate,  $K$ , versus rainfall energy,  $E$ , for different degrees of soil erodibility,  $F$  (originally from Etwell, 1980).

- The proportion of rainfall energy intercepted by various crops ( $i$ ) is expressed as a percentage. This is calculated from the values of rainfall energy interception proportion for various crops, and emergence times

before and after the start of the rainy season (*Appendix D*). Thus a number of different scenarios exist, which are displayed in Table 2.7.

Table 2.7: Values of rainfall energy interception,  $i$  (%) proportion for wheat, with emergence times being before (-) or after (+) the start of the rainy season (originally from Elwell, 1980).

Yield (t/ha)	Emergence time after start of rainy season				
	-1 month	0	+1 month	+2 months	+3 months
1.0	39	40	35	25	12
2.0	47	49	43	30	15
6.0	81	84	73	52	26

- The next step in estimating soil loss is to evaluate the crop cover effect. Thus the crop soil loss ratio, or cropping factor (C), is read from Figure 2.4 and shown in Table 2.8 for the various scenarios.

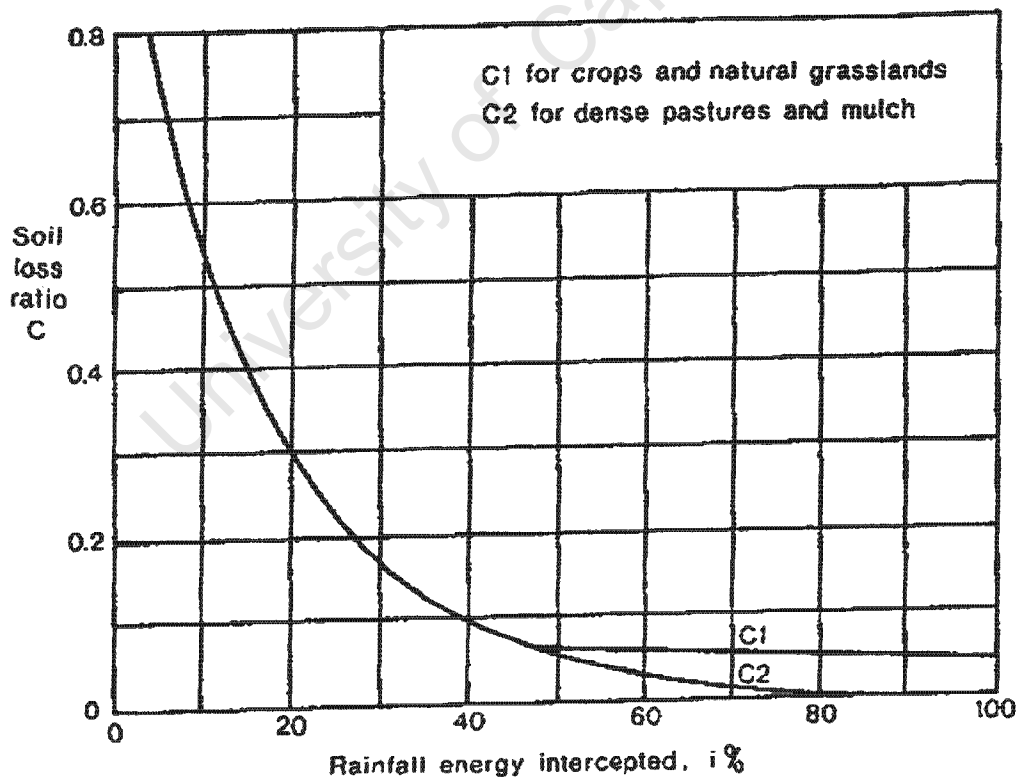


Figure 2.4: Soil loss ratio (C) versus the proportion of rainfall energy intercepted by various crops ( $i$ ) (originally from Elwell, 1980).

Table 2.8: Cropping factor, C, for the various scenarios of rainfall energy intercepted by wheat.

Yield (t/ha)	Emergence time after start of rainy season				
	-1 month	0	+1 month	+2 months	+3 months
1.0	0.1	0.1	0.14	0.24	0.5
2.0	0.07	0.07	0.08	0.17	0.4
6.0	0.06	0.06	0.05	0.07	0.23

- The estimation of topography factor (X) combines the field length (L) and the slope (S). The equations below give the appropriate topography factors for slopes less than or greater than 1%, where L is in meters and S is in percent:

$$\text{For } S < 1\% \quad X = S\sqrt{L} / (10.74S + 8.04)$$

$$\text{For } S > 1\% \quad X = \sqrt{L} (0.76 + 0.53S + 0.076S^2) / 25.65$$

This calculation for the Swartland used a standard field length and slope of 30m and 4.5% respectively. Thus:

$$\begin{aligned} X &= \sqrt{30} (0.76 + 0.53 \times 4.5 + 0.076 \times 4.5^2) / 25.65 \\ &= 1.0002 \end{aligned}$$

- Once the variables K, C and X have been calculated, they are simply multiplied together to estimate the mean annual soil loss from a field, in the following manner:

$$Z = K C X$$

The results for the mean estimate soil loss from a field, calculated for both the present and future climate change scenarios, are presented in *Chapter Six*.

#### 2.5.4 Modifying SLEMSA for the Swartland

The results shown in *Chapter Six* were rather simplified and when scrutinised more closely with the predicted regional downscaling of future climate, posed a significant problem. Estimates of soil loss are most sensitive to changes in the

E factor, as Hudson (1987) found in her use of SLEMSA in the Drakensberg. By reducing the amount of annual rainfall expected, one would tend to reduce the theoretical soil loss in SLEMSA. Future climate change predicts that the annual rainfall of the Swartland is likely to decrease or possibly remain the same, but this rainfall is more than likely going to occur over a shorter time with significantly longer dry spell events during this shortened winter rainfall season (*Chapter Five*). Thus increased dry spell duration, linked to increased temperatures (*Chapter Four*) would logically lead to decreased available soil moisture and therefore be cause for possible increased soil erosion.

SLEMSA does not make provision for the change in intra-annual rainfall patterns with the calculation of E. Therefore in order to apply SLEMSA to the Swartland, the downscaled precipitation variables examined in *Chapter Five* need to be re-considered. These include not only total annual precipitation, as addressed by SLEMSA, but also mean number of rain days greater than 20mm and mean dry spell duration. The long-term 30 year average of the mean of these two variables was examined for the Swartland as a region (between 32°S and 34°S and 18°E and 19.5°E). It was noted that for the average number of rain days greater than 20mm there was little significant future change predicted over the entire region. There was however a significant difference in dry spell duration for the region as a whole when examining future climate change (see Table 2.9).

Table 2.9: Long-term 30 year time average mean of dry spell duration taken from the regionally downscaled climate data.

Model	Present	Future	Ratio of change
ECHAM4	4.18187	6.23249	1.49
HADAM	3.51649	5.31189	1.51
CSIRO-A2	3.34007	4.34561	1.30
CSIRO-B2	3.34806	3.13675	0.94

Thus a crude adjustment needs to be made to correctly consider the future climate change scenarios for the Swartland. By taking the regionally

downscaled output of dry spell duration, and examining the anomaly, one can gain a percentage change between future and present (Table 2.9) by which to adjust the annual precipitation value in SLEMSA to make it more representative of the Swartland region for future climate change. This crude adjustment was called factor "A".

To create factor "A", the ratio of change between the future and present results of mean annual dry spell duration (Table 2.9) were then multiplied by the annual future precipitation as was the original input to run the model (see Table 2.3). These results (Table 2.10) were then used to determine the rainfall energy ( $E_A$ ) from SLEMSA once again (*section 2.5.2*), being more representative of the possible future climatic conditions.

Table 2.10: Mean annual precipitation as calculated from historical station data, and regionally downscaled data for the Swartland (latitude 32°-34°S and longitude 18°-19.5°E), with future precipitation adjusted for dry spell duration (A).

	Present day (mm/yr)	A (mm/yr)
Historical station data	461.5033	
ECHAM4	333.886	468.407
HADAM	332.499	454.190
CSIRO-A2	319.185	351.375
CSIRO-B2	319.197	260.142

After the adjustments were made for rainfall energy, E, using factor "A" rather than the simplified method of only considering annual precipitation (Table 2.11), SLEMSA was then recalculated using the methods explained in section 2.5.2. The results using the adjusted annual incident rainfall energy ( $E_A$ ) are presented and discussed in *Chapter Six*.

Table 2.11: Average annual incident rainfall energy,  $E_A$ , calculated from historical station data, and regionally downscaled data for the Swartland (latitude 32°-34°S and longitude 18°-19.5°E), with future precipitation adjusted for dry spell duration (A).

	Present day E (kJ/m <sup>2</sup> )	Future $E_A$ (kJ/m <sup>2</sup> )
<b>Historical station data</b>	8.5	
<b>ECHAM4</b>	6.5	9
<b>HADAM</b>	6.5	8.75
<b>CSIRO-A2</b>	6.2	7
<b>CSIRO-B2</b>	6.2	5

This concludes the analytical techniques applied in the study. The results are displayed in the relevant chapters as tabulated in section 1.8. *Chapter Three* now goes on to describe the study area.

***CHAPTER THREE:  
STUDY AREA: THE  
SWARTLAND***

### 3.1 Introduction to the study area

The Swartland forms part of the western lowlands of the Western Cape Province of South Africa (Figure 3.1). It is a region of gently undulating hills on Malmesbury Group shales, bordered by the Sandveld, an area characterised by sandy soils, to the west; the Picketberg Mountains and more karroid vegetation to the north; the Hottentot Mountains to the east; and the more densely populated Tygerberg region to the south (Dietrich *et al.*, 2004). The 'regions' shown in Figure 3.1 are identified on the basis of consistency of their physical environmental features, more particularly their geological make-up; their natural vegetation; their climate; and by the human activities conducted there (Meadows, 2003a).

The southwestern Cape represents a significant southern hemisphere example of a Mediterranean-type climate. Conacher and Conacher (1998) attempted to define the Mediterranean regions of the world (Fig. 3.2), above all agreeing that *summer drought* was the main distinguishing characteristic, they also deduced the following:

- Areas with >275mm mean annual precipitation for cool, coastal stations and >350mm mean annual precipitation for warm interior stations;
- Areas where mean monthly temperature is >0°C;
- Areas which receive >65% of their rainfall in winter;
- Generally falling between the latitudes 30° and 40°, between temperate and tropical arid zones;
- Areas occur on the west coasts of continents washed by cold ocean currents.

Large parts of the southwestern Cape of South Africa fall into the category of having a Mediterranean-type climate. The region experiences marked contrasts between hot, desiccating summers and cool, wet winters. Strong winds are a prominent feature in all seasons, with frontal rains from the northerly movement of the 'roaring forties', which, together with winter fogs,

bring moisture to the region. The climatic variability of these intense drought periods followed by intense wet periods, which can occur on a monthly to yearly basis, is what characterises Mediterranean-type regions around the world (Conacher and Sala, 1998).

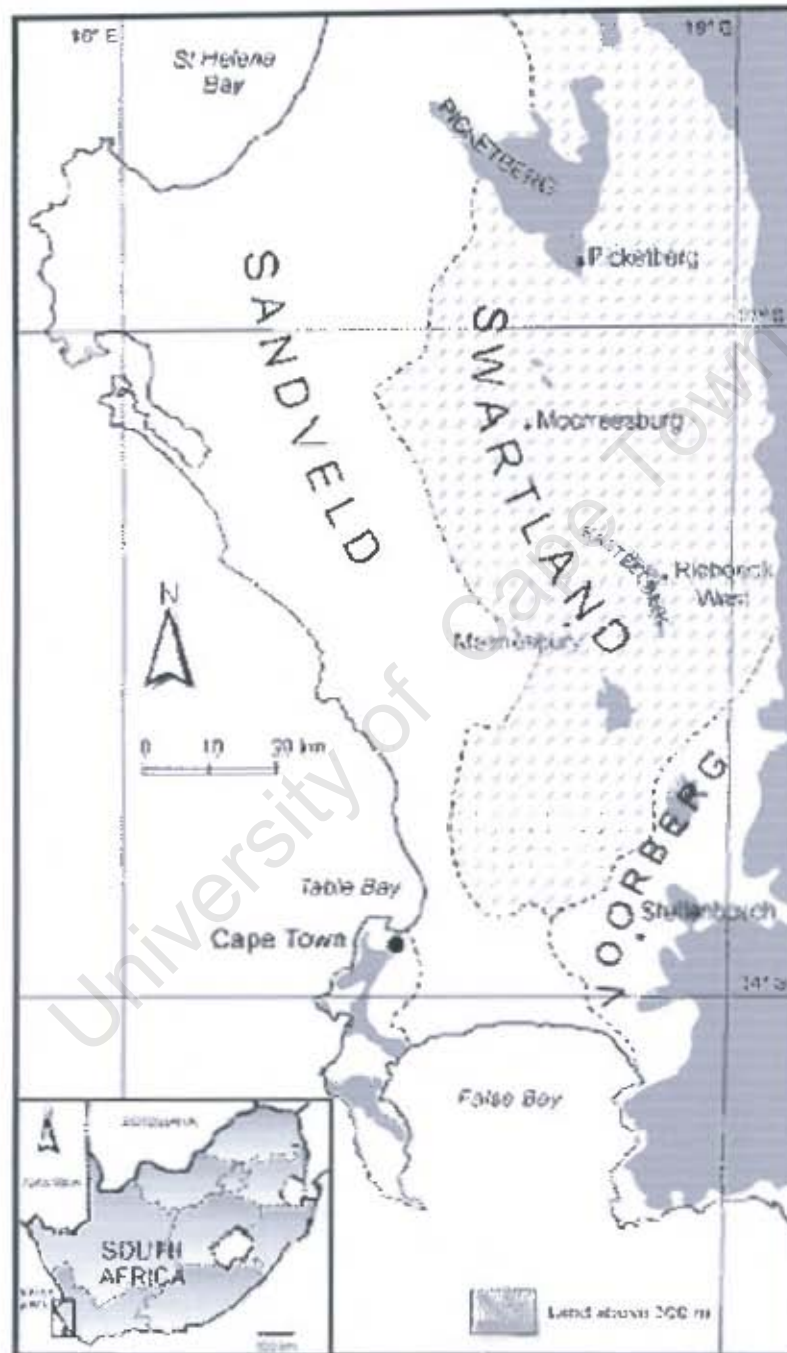


Figure 3.1: The southwestern Cape distinguishing the Swartland's geographical location among other natural regions (Meadows, 2003a)

Another distinctive feature of Mediterranean regions is their location on a coastal plain being backed by mountains (Dietrich *et al.*, 2004). The cold ocean current washing the shores of the Western Cape is the Benguela Current, coming directly from the Southern Ocean. Mountains in Mediterranean-type climatic regions are usually formed through folding geological processes, as is the case in the Western Cape, and have marine origins. Thus white limestones, dolomites, and karstic landscapes feature prominently, with the occasional granitic outcrop also present in the landscape.

The Western Cape region is floristically and geomorphologically diverse, due to the geological and climatic heterogeneity of the region. The southwestern Cape is the only region of South Africa experiencing a winter rainfall peak, and it is important as it represents the equatorward boundary of direct influence of mid-latitude storms.

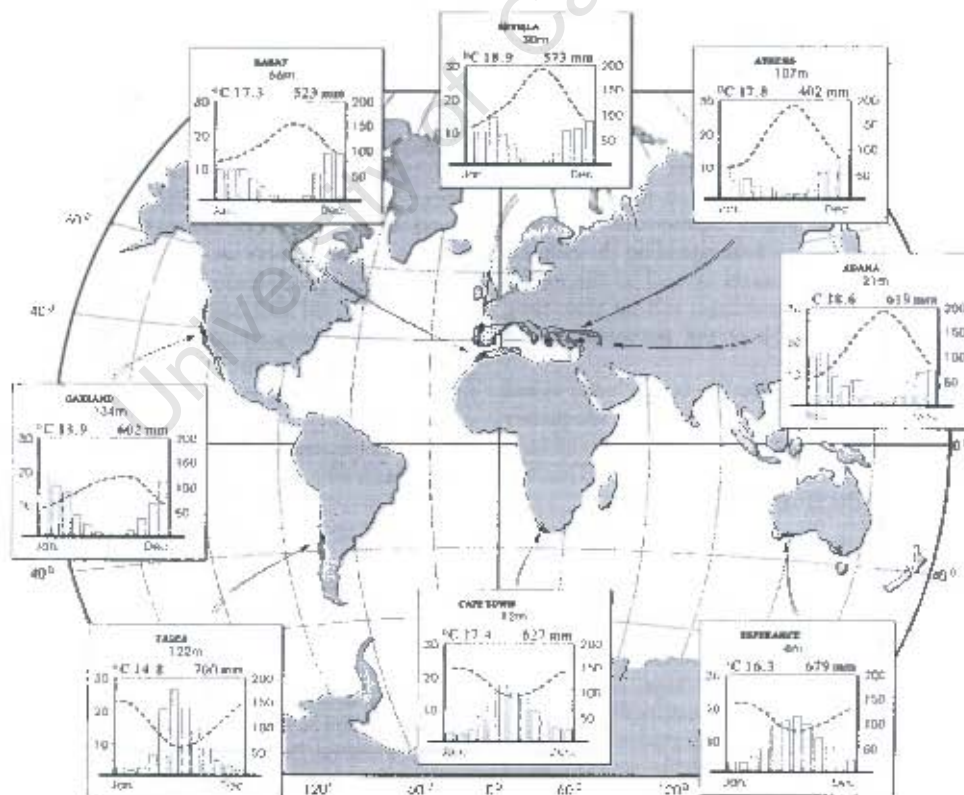


Figure 3.2: The Mediterranean regions of the world (after Conacher and Sala, 1998).

The Swartland falls into the heart of the southwestern Cape's winter rainfall region, and is the primary area chosen for this study (Figure 3.3). It is primarily an agricultural region producing winter wheat, oats, barley and also containing vineyards, with less than 5% natural vegetation remaining (Dietrich *et al.*, 2004). It is this low percentage of remaining natural vegetation that gives it a distinct vulnerability with respect to land use and climatic conditions as natural vegetation would be better able to adapt to climate change than an agriculturally modified landscape.

The majority of agricultural land in South Africa falls into the summer rainfall region and largely consists of maize, sugar-cane and a small proportion of wheat, with only a small percentage of agricultural land falling into the winter rainfall region. It is this imbalance of agricultural land distribution between summer vs. winter rainfall regions that arguably has contributed to an imbalance in climate change research, favouring the summer rainfall region. Hence this study is to help correct the imbalance by focussing on the winter rainfall region, and to highlight the importance of climate change on the crops being grown in the Swartland.

Desertification (land degradation in arid, semi-arid and sub-humid lands – UNCCD, 1995) is considered a serious threat to the semi-arid areas of Mediterranean-type environments, and particularly to the marginal hilly lands of the region (Kosmas and Danalatos, 1994). This also stands true for the hilly lands experiencing a Mediterranean-type climate in the Swartland. Soil erosion, resulting from ignorance, negligence and apathy in land use – especially during the years 1850 to 1950 – has caused an increase in the silt-content of many South African streams, therefore accentuating the naturally highly irregular character of their discharge (Talbot, 1961). This is particularly evident in the more arid regions of the southwestern Cape and notably in the Swartland, as Talbot identified in his 1947 report. Thus a more comprehensive study into the geology of the area and past agricultural history is examined following the next section on the current climate of the Swartland.

### 3.2 Current climate of the Swartland

As noted above, the Swartland falls into the winter rainfall region of South Africa, which corresponds to conditions experienced in the Mediterranean regions having hot, dry summers and cool, wet winters. The Swartland experiences an average of 250-400mm of rainfall per annum, and temperatures range between 8°C and 41°C. Table 3.1 shows the climate statistics for Moorreesburg, which is in the heart of the Swartland at 33.15°S and 18.67°E, to give an idea of local conditions.



Figure 3.3: The agricultural districts of the Western Cape of South Africa, showing the Swartland in the southwest as the study region (van der Merwe, 2003).

Winter in the Swartland rarely sees very low night temperatures, with mean daily minima varying from about 4°C to 9°C (Talbot, 1947). Frost is unknown over most of the region, occasionally occurring in the valleys and low lying areas for roughly four nights in total over the winter months (Lambrechts, 1998). Winter days are warm with average daily maxima of over 15°C along the coast and over 18°C inland being typical (Tyson *et al.*, 2002). On notably warm days, shade temperatures of over 24°C are not unusual in winter. These temperatures enable the native vegetation and crops such as wheat, rye, oats

and barley, and vegetables such as potatoes, cabbage, peas and turnips to continue growth even in mid-winter (Talbot, 1947).

Table 3.1: Average climate statistics for Moorreesburg, located at 33.15°S 18.67°E at a height of around 280m above mean sea level, for the period 1970-1999. Shaded cells denote maximum and minimum temperatures and maximum precipitation –the latter occurring in winter.

Month	Temperature (° C)				Precipitation	
	Highest Recorded	Average Daily Maximum	Average Daily Minimum	Lowest Recorded	Average Monthly (mm)	Highest Monthly Rainfall (mm)
January	41	29	15	7	8	25
February	40	30	15	9	8	45
March	39	28	14	7	15	59
April	38	25	12	5	32	98
May	32	21	9	2	54	145
June	29	18	7	1	65	142
July	27	17	6	0	57	111
August	30	18	7	1	55	238
September	32	20	8	1	36	100
October	38	23	10	4	21	59
November	41	26	12	4	18	164
December	40	28	14	6	17	63
Year	41	23	11	0	386	238

The winters of the southwestern Cape are generally moist, with the area having its rainfall restricted by the mountain ranges of the Cape fold belt (Preston-Whyte and Tyson, 1993). The dry, anticyclonic high-pressure systems, which are a prominent feature over southern Africa, migrate north in the winter months and allow the westerly winds into the southwestern Cape (Preston-Whyte and Tyson, 1993). This provides the winter rainfall and produces the

Mediterranean-type climate. The rainfall in the Swartland is closely linked to altitude; with rainfall increasing with increased height above sea level. In the upper regions of the Riebeek Mountains, in the eastern part of the Swartland, rainfall can be as high as 700mm, in a region experiencing an average of 500mm per year (Morel, 1998). These rainfall figures make the Swartland clearly well suited to growing winter grains, such as wheat and barley (Eisenburg, 1991).

The summers on the other hand are arid, caused by the Benguela current, which creates strong upwelling on the west coast particularly during the summer months, thus intensifying summer aridity (Shillington, 1998). The occasional more humid day interrupting the marked aridity is brought on by relatively cool air being brought in from the ocean by prevalent south-southeasterly winds, when upwelling is weakened. Average temperatures range from about 20°C in the southwest to 24°C in the northeast, with mean daily maxima varying around 24-32°C. Further inland temperatures have occasionally been recorded as high as 38°C, and even up to 42°C (Table 3.1). Strong southerly winds are frequent in summer and thus evaporation is high. The force of the wind can sometimes damage crops, and vines often suffer from desiccating or 'scorching' effects (Talbot, 1947).

Wind erosion and soil drifting are common on cultivated and cleared areas of light soils. Little rain falls between October and April, so despite favourable temperatures, summer is a period of reduced vegetative activity except in the case of plants and cultivated crops not directly dependent on rainfall (Talbot, 1947), i.e. plants with well developed rooting systems such as vines, and crops under irrigation.

Spring and autumn are the seasons of optimal plant growth in the Swartland. In September and October lengthening days, rising temperatures and soils still moist from winter rains stimulate a vegetative growth. In autumn when the first winter rains begin to replenish the soil moisture after the arid summer, thus promoting a secondary maximum of vegetative activity.

The rainfall is mainly cyclonic in origin, being associated with the passage of cold fronts moving over the sub-continent in the winter months. This frontal rain, in the vicinity of mountains can be generally more intense as the rising air is induced to rise more rapidly by the orographic obstacles in its path. The autumn and spring rains are of greatest importance to the farmer with optimum dates of seeding being 15<sup>th</sup>-30<sup>th</sup> May for wheat (Agenbach *pers. comm.*, 2003). Should the autumn rains come later or be of an insufficient amount, the sowing and germination of the crops are delayed, often resulting in retarded crops. Late spring rains, such as those at harvest time that continue into October, can impair the quality of the grain (Talbot, 1947), thus the timing of the rain events is also a critical component.

Recurrent droughts are part of the climatic pattern in arid regions of the world, and South Africa is no exception (Rouault and Richard, 2003). The variable rainfall conditions of the Swartland make grain production and especially wheat production a hazardous branch of farming, where stock-raising would appear to be the most economic form of land use (Neethling, 1941). Political pressures have created an agricultural region more inclined to crop farming, where wheat, sorghum, barley and oats are favoured over stock-raising. This makes the region one of distinct vulnerability, and particularly with respect to future climate change, where little is known of the impact climate change will have on the Swartland.

This particular study area is important due to its situation at the southern tip of Africa. Any change in sea surface temperatures, ocean currents and Antarctic ice extents greatly affect the dynamics of the atmospheric circulation and hence rainfall systems in the region, with resultant climatic change (Mulock-Houwer, 2001). At the same time, should the atmospheric circulation patterns change, this would directly affect sea surface temperatures, ocean currents and Antarctic ice extents.

### 3.3 Geological and geomorphological history of the Swartland

Geomorphologically, the Swartland is a region of mainly gentle relief where erosion has truncated the highly folded Malmesbury Formation (Figure 3.4), forming a surface of moderate slopes with locally almost level areas. Steeper slopes and occasional lowbluffs along river courses are also a feature. The undulating lowland is occasionally interrupted by broad granitic masses and steep-sided outcrops of Table Mountain Sandstone (Kasteelberg and Piketberg).

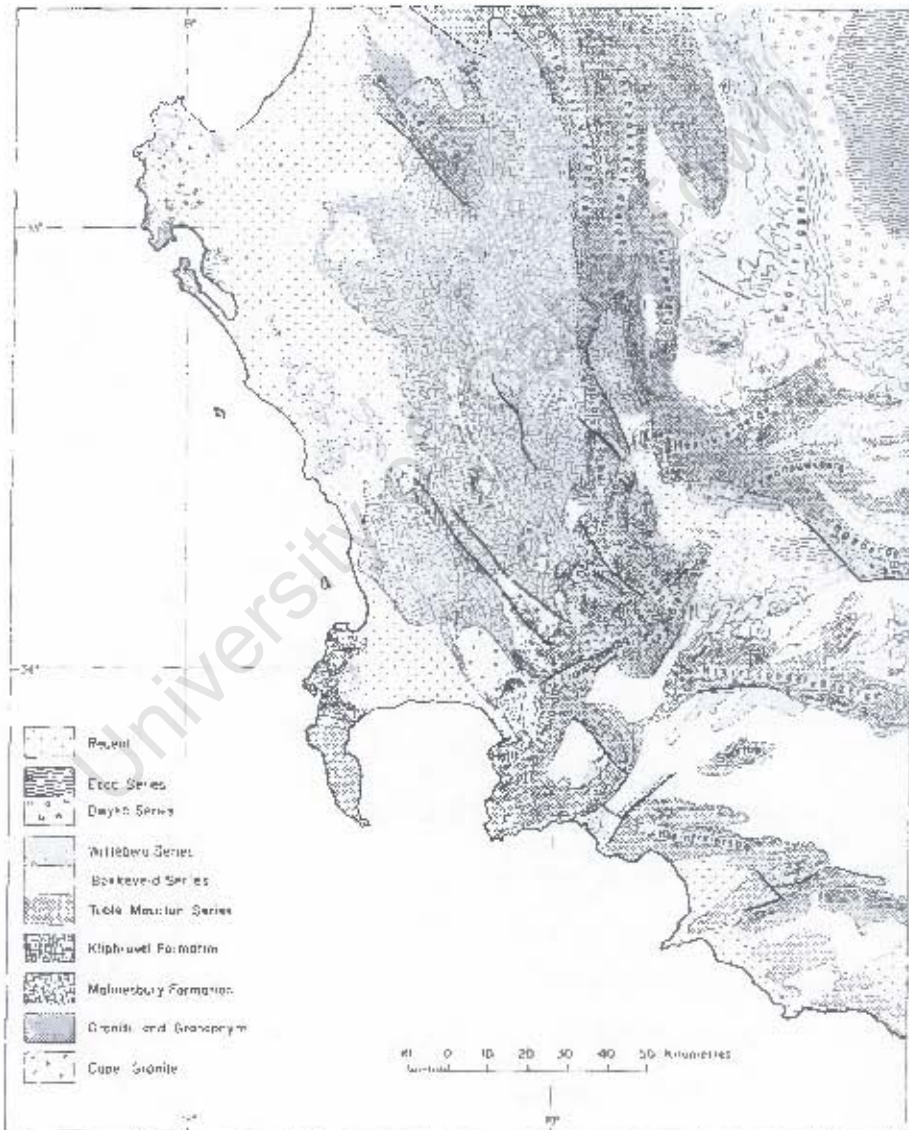


Figure 3.4: Geology of the Swartland, with the study area being primarily defined by the presence of Malmesbury Formation shales.

The Malmesbury Formation consists of sedimentary and meta-sedimentary rocks, which are combined to form the Malmesbury Group shales in the Western Cape Province (Tankard *et al.*, 1982; SACS, 1980). The Malmesbury Group is mainly of marine origin, with sediments being laid down in Precambrian seas, forming the bedrock that underlies the brown loamy soil of the Swartland (Talbot, 1971). These sediments have been subject to folding, upliftment and erosion during the Precambrian, and this has decreased their resistance to weathering (SACS, 1980).

The Precambrian rocks are associated with fine grained quartzites in the region, thus when the rocks weather, exchangeable cations are released which are used by plants. These cations include magnesium, calcium, potassium and sodium (Deacon *et al.*, 1992). Deep soil profiles are usually found in valleys where the deposition of the weathered material accumulates, causing fertile soils to be drained by rivers and streams. Thus the Swartland, with its undulating hills makes for prime agricultural land.

The Malmesbury group is estimated at around 600-950 million years old (Tankard *et al.*, 1982). This group is then divided into three separate areas, divided by two zones of dislocation, (a) the south-western domain; (b) the central domain; (c) the north-eastern domain (Morel, 1998), with the later forming the majority of the Swartland.

The northeastern domain reflects the dominantly marine sedimentation with the Piketberg Formation forming the geosynclinal setting. The rocks of the Piketberg Formation closely resemble those of the Franschoek Formation, with evidence of folding and faulting and a presence of granite (Morel, 1998). A Piketberg-Wellington fault zone runs in a northeasterly direction through the Swartland. Folding and faulting are found extensively in this region, as it common in all Mediterranean regions of the world (Conacher and Sala, 1998).

The Swartland landscape is smooth, except for the more resistant hills and mountains made up of marine sediments. Downfaulted outliers of the

Klipheuwel Formation and the Table Mountain Series form low hills or prominent ridges, such as the Kasteelberg (Morel, 1998). Outcrops of Klipheuwel Formation also occur between Piketberg-Porterville and Riebeeck Kasteel. This lies on steeply dipping Malmesbury shale, and is overlain by the basal beds of the Table Mountain Group. None of the Malmesbury strata is particularly resistant to erosion and therefore resulted in the gently rounded landforms and gentle slopes characteristic of the Swartland (Figure 3.5).



Figure 3.5: The gently sloping, undulating topography characteristic of the Swartland

Gully erosion has been shown in the past to be a force capable of drastically altering the landscape of the Swartland (Muller, 1999; Morel, 1998; Talbot, 1942). The relief of the Swartland with its undulating landscape is extremely susceptible to water erosion, and therefore increased impacts from gully erosion. The next section deals with soils of the Swartland and their general susceptibility to erosion.

### 3.4 *Soils of the Swartland*

Soils derived from different parent materials, react differently to soil erosion, vegetation and desertification. Acidic igneous parent materials produce shallow soils with high erodibility risk and high desertification risk (Kosmas and

Danalatos, 1994). These soils are present in the Swartland as being derived from the Malmesbury shales. Soils on conglomerates and shale-sandstones usually have a restricted effective rooting depth resulting from erosion. The tolerance of these soils to erosion is low, and under hot and dry climatic conditions and severe soil erosion, rain-fed vegetation can no longer be supported, leading to desertification (Kosmas and Danalatos, 1994).

The Swartland exhibits a whole host of soil types, with deep, well-drained soils, highly leached soils and shallow calcareous soils all being common (Meadows, 1998; Germishuys, 1992). Swartland soils are relatively in-situ, showing a direct relationship to the parent material and surrounding terrain. Cowling (1992) showed that shallow weakly developed soils (lithosols) are found on the granitic mountainous outcrops, while soils on the more undulating areas are more clayey and of residual and duplex nature (Talbot, 1947). This duplex nature is reflected in the textured contrast between the A and B horizons, where the A tends to be of a sandy nature and the B horizon of a clayey nature, thus making them more easily erodible. Some paleosols are found in the region, having been formed under previous climatic conditions. For example, silcretes and red apedal soils developed from ferralitic weathering.

Kosmas *et al.* (1993) conducted a case study in the European Mediterranean region on soils similar to those found in the Swartland, which showed that in dry years, gravel and stones are extremely important for the prevention of desertification by conserving appreciable amounts of soil water from evaporation through surface mulching. Stony soils along slope catenas of conglomerates and shale-sandstones, despite their normally low productivity, were found to supply appreciable amounts of previously stored water to water stressed plants and ensure an adequate biomass production in extremely dry years (Kosmas *et al.*, 1993).

Generally the soils in the Swartland that are derived from granites are red and yellow in colour with a well-developed internal drainage system (Morel, 1998). In the eastern parts of the Swartland, around the Riebeeckberg, the soil consists

of medium textured sands with varying depths. The sands overlying the Malmesbury shales, on the more undulating landscape, form residual soils.

Soils of the Malmesbury Group are usually shallow, with a narrow horizon of small ferruginous concretions and rock fragments at a depth varying from 10-46cm (Talbot, 1947). Beneath these soils is yellowish brown, reddish brown or brown sandy clay that is impervious, compact and plastic when wet (Drew, 1999), and below this is the shale parent rock. The soils are poor in phosphates and nitrogen, and are usually fairly acidic. They tend to cake after heavy rains due to their high content of fine sand and low organic matter content (Talbot, 1947). The soil types of the Swartland include the following: Mispha, Gelnrosa, Cartef, Swartland, Sterkspruit, Hutton, Clovelly, Kroonstad, Escourt, Pinedene, Bainsvlei, Fernwood, Constantia, Lamotte, Westleigh, Dundee, and Longlands.

### **3.5        *Vegetation of the Swartland***

A region experiencing a Mediterranean-type climate, the Swartland forms part of the *fynbos biome* of the southwestern Cape. Fynbos is a highly species-rich vegetation type, forming one of the six major Floral Kingdoms of the world known as the Cape Floral Kingdom. Fynbos is a mosaic of mainly shrubland types, where some are 'heath' and others 'non-heath', depending on the species composition of the area. In terms of numbers of plant species and genera, the fynbos rivals even tropical rain forests and suggest a long-term evolution over a complex course in time (Meadows, 1998). Taxa indicative of the Cape Floristic Kingdom include numerous members of the Restionaceae, Proteaceae and Ericaceae families.

The natural vegetation of the Swartland itself falls into the category of West Coast Renosterveld (Low and Rebelo, 1996), which is associated mainly with the more nutrient-rich shales of the Malmesbury Group (see section 3.3). Although also species rich and forming part of the mosaic of the fynbos biome, it phytogeographically has more in common with the vegetation of the interior of

South Africa. Renosterveld includes semi-dense to dense evergreen plants with small leaves from the Asteraceae family. Small clumps of tall broad-leafed shrubs also occur (Dietrich *et al.*, 2004), as with the presence of grasses in more frequently burned patches (Low, 1995).

The Swartland today has very little natural vegetation remaining, being primarily a wheat and grape producing area. As mentioned in section 3.1, the Swartland has no more than 5% of its original natural vegetation remaining, being taken over by agricultural practices as early on as the late 1600's (Meadows, 2003a). This lack of natural vegetation makes the region even more vulnerable to climate change. From this point, future climate change impacts will be examined with respect to the crops grown in the region, rather than the natural vegetation.

Inadequate rainfall is usually the most limiting factor of crop production in Mediterranean environments (Fischer, 1979). For the Swartland, Talbot (1947) identified autumn and spring rains to be of greatest importance to farmers, as crops are seeded around May (autumn) with optimum warming for rapid growth in August and September (late winter to spring). Thus early rains would cause the crops to sprout early and risk loss due to ploughing, and decreased spring rains may prevent proper development of the crop and impair development of grains. Lopez-Bellido *et al.* (1996) found that differences in rainfall during the growing season had a marked effect on wheat yield and responses to effects of tillage, crop rotation and nitrogen fertilisation on the crops. It is for these reasons that examining the present and future climate of the region has major implications towards the continuing of present agricultural practices and soil erosion management. Thus, one needs to consider the past practises first, before extrapolating a future trend.

### **3.6 Swartland land-use history**

Wheat forms one of the most important food crops in the world, as it serves as the staple food for many countries and thus plays an important part in

economics, politics and culture (Maali, 2003). Wheat and other crop farming have formed the primary activity in the Swartland for the last 100 years. Deacon (1992) mentions evidence of structured cultivation of land in the southwestern Cape beginning as recently as 300 years ago, with stock farming as far back as 2000 years.

The earliest inhabitants to the Swartland region were Acheulean people, who were predominantly scavengers who had to compete with wild animals such as hyaenas for their meat supply and tended to live in more riverine environments (Humphreys, 1998). They would have had little impact on the natural environment. Later Stone Age Sun hunter-gatherers (the “San” or “Bushmen”) also displayed little environmental impacts, living a highly mobile existence by moving seasonally to exploit varying resources in complementary ecological zones (Humphreys, 1998). This continual movement meant that family groups were small and therefore their impact on the environment also negligible.

The first pastoralists were thought to be the “Khoekhoe” (also known as “Hottentots”) who probably originated in present-day Botswana, moving south with a domestic form of sheep and cattle. Evidence of their presence in the Western Cape is from as early as 1300 years ago (Humphreys, 1998). These groups tended to be large, competing with the earlier hunter-gatherer inhabitants and would have had a more marked effect on the environment. Like the San people, they also migrated seasonally as their large herds needed good pasturage. The impact of the Dutch colony around the mid 1650s, in the southern parts of the Swartland and around the Cape Flats region, caused the displacement of these previous indigenous people and eventually they were taken into the colony as slaves (Wesson, 1998).

Farming methods of the 19<sup>th</sup> Century were generally sustainable, where farmers used oxen and mules to plough the fields. It was also standard practise to leave considerable intervals between cropping times, thus allowing the soil sufficient time to recuperate lost nutrients and maintain soil fertility

(Morel, 1998). Up until the early 20<sup>th</sup> Century, the Swartland participated in mainly mixed farming of grain, grape, vegetables and stock (Wesson, 1998).

The concern with over-cropping began around the time of mechanisation in the early 1900's, when the growing urban population placed increased demands on farmers to produce greater yields. The effect of the Anglo Boer War and the two World Wars saw a worldwide depression, with farmers being encouraged to produce greater yields, as imports were scarce. Farmers were expected not only to provide sufficient wheat for the population, but also for provisions on passing ships (Talbot, 1947). Thus land previously unsuitable for cultivation was used; the rest period between cropping was shortened; and rotational cropping slowly fell away (Dietrich *et al.*, 2004; Morel, 1998).

Urban population growth was not the only reason for increased cultivation. Import control and rail transportation restrictions were implemented in the 1920's, which provided farmers with protection from low-priced imports (Morel, 1998). The government then introduced wheat importation restrictions in the 1930's, which caused domestic prices to be higher than the prices available in the free market, thus being an incentive to expand cultivation into more marginal areas so as to maximise yields (Talbot, 1971). Other crops were also grown in the Swartland, consisting of other cereal crops of barley, oats and rye, as well as grapes for wine making and table grapes. However these other crops were on a much smaller scale than the wheat industry, particularly when the government began manipulating wheat prices so as to entice farmers to plant wheat in their fields for better economic gains. It is for this reason that the rest of this section will concentrate on farming in general in the Swartland, with specific references to the growth and yields of winter wheat.

The new farming practices on marginal lands were hard hit in the 1930's when a prolonged drought hit the southwestern Cape. The unfavourable climate, combined with deficits in wheat production during war times, aggravated the situation and farmers proceeded to plant less suitable areas with wheat to gain greater overall yields. A survey of the Swartland conducted by Talbot showed

that the use of contour ploughing on grain farms was completely absent and only a few farmers were making attempts to stop soil erosion (Talbot, 1947) while concentrating instead on achieving greater yields off the land. These erosion control attempts mainly consisted of badly constructed water ditches, which quickly led to excessive rill and gully erosion (Morel, 1998).

It was quickly realised that the complicated problem of soil erosion could not be solved by means of reclamation alone and that steps for the prevention of soil erosion were also necessary (Viljoen, 1945). The government introduced state funded soil erosion combating schemes in 1933 to draw attention to the growing problem of soil erosion (Dept of Agric. & Forestry, 1935), and the "Division of Soil and Veld Conservation" was established early in 1939 (Viljoen, 1945). Unfortunately war conditions stemming from World War II led to the temporary suspension of government schemes to control soil erosion, but it was realised that this was of national importance and so the most important of these schemes were reinstated in 1942 (Meadows, 2003a; Viljoen, 1945).

In the 1942/43 season, the winter rainfall region did not get rain until late in the wheat growing season, then heavy precipitation was experienced in a relatively short time (Dept of Agric. & Forestry, 1944). This resulted in leaching of arable lands and a much reduced wheat crop than usual. In addition, this was the second consecutive drought at the commencement of the winter sowing season (Dept of Agric. & Forestry, 1944). Farmers were now more encouraged than ever to implement soil erosion practises, and many went for the application of rotational cropping between contour banks. These methods were combined with the introduction into the rotational system of a perennial grass for the restoration of the good structure of the soil (Dept of Agric. & Forestry, 1944). This was then the favoured method to maintain the fertility of the soil and to strengthen the soils ability to resist erosion.

In 1947 official attempts, encouraged by government incentives, to control gully erosion began. These included incorporating conservation strategies such as contour ploughing and rotational cropping. Lupin was also introduced as a

rotational crop as it was well suited to the Swartland area, being tolerant of slightly acidic soils and annual rainfall of around 300mm (Morel, 1998). Lupins grow well in sandy soils and apart from being valuable post-war fodder crops rich in protein, they also improve the soil as, being legumes, they enrich the soil with nitrogen (Marais, 1949). Contours, check-banks and new field patterns started becoming more familiar sights in the Swartland, and so marked the beginning of conservation-minded farms aimed at reducing soil erosion (Talbot, 1971).

The causes of soil erosion by the mid-late 1940s were both climatic and cultural. Climatically induced erosion was evident from heavy rains combined with drought periods. Culturally, the replacement of indigenous fauna with exotic farm animals, thereby changing the ecological conditions affecting vegetation (Talbot, 1961), proved to be a more cost effective means of gaining fertilizer which was unavailable in the post-war years (Marais, 1949). The Soil Conservation Act (No. 45 of 1946) was passed as a response to the nationwide demand for better provision for combating soil erosion and for conservation of the natural resources of the country in its soil, veld and water supplies (Dept of Agric., 1947).

Greatly increased mechanisation of farming methods occurred around the mid-1950s (Du Toit, 1960). Around this time unfavourable climatic conditions were experienced, in the form of extreme drought followed by heavy rains, resulting in increased soil erosion and flood damage (Dept of Agric., 1955). These led farmers to adapt their farming practices in a manner calculated to counter the ill-effects of extreme climatic conditions, so being better able to deal with climatic variability than in previous years (Du Toit, 1960). These changes could not only be seen in the decreases in frequency of previously mentioned erosion features, shown later by Sebataolo (2003); Muller (1999) and Morel (1998), but also by the increased wheat yields during unfavourable climatic conditions.

The next serious drought recorded in the Swartland was during the mid-1980s. Excellent wheat yields were observed from 1980-1983, in the years preceding

the drought where tons of wheat gained per hectare was high. However serious drought conditions in the Swartland forced the government to institute the "Conservation of Agricultural Resources Act" (Act 43 of 1983) where the government would take immediate action against the misuse of agricultural resources (Immelman, 1986). This Act replaced the Soil Conservation Act of 1969 and became effective in the middle of 1984, when drought conditions were at their peak in the mid-1980s.

The drought of the mid-1980s was broken in the Swartland when good winter rains fell from April to August 1987, and resulted in good winter grain crops (Hattingh, 1988). It is about this time during the 1980's that agricultural changes are noted, possibly due to political changes in the country. Dietrich *et al.* (2004) note that land sown to grain over the years 1960-1977 remained fairly constant at around 80-84% of the Swartland. However by 1988, the amount of land sown to wheat fell slightly to 77% (Dietrich *et al.*, 2004). This figure seems to have continued to decline up until 2000 where 67% of agricultural land in the Swartland was planted to grain, the rest represented by a substantial increase in grape cropland and a small percentage of other land use.

These latest changes are thought to be due to the change over of political parties from a Nationalist government to a democratic rule under the African National Congress. These political changes brought the cancelling of economic sanctions, thus reopening exports and entrance into free trade on the international markets (Dietrich *et al.*, 2004). This extra competition lowered the price of wheat and with local government subsidies no longer favouring white farmers; these farmers were forced to re-evaluate their chosen crops for economic sustainability. Another important reason for this increased trend in planting grapes is that the farmers can now take advantage of global markets, with the ending of apartheid induced sanctions after 1992, especially with respect to the wine market (Dietrich *et al.*, 2004).

### 3.7 *Agricultural trends in the Swartland*

Currently the Western Cape Province is the largest producer of wheat in South Africa, with the Free State Province coming in a close second. All the nine provinces of South Africa produce wheat, with the Western Cape producing around 33-40% of the total for the country (2002 wheat production figures from Dept of Agric., 2004). The Swartland (north of Cape Town) and Ruens (Overberg region, east of Cape Town) regions are the primary regions within the Western Cape, with the production per hectare almost evenly distributed between both areas.

Wheat is one of the industries "most dependent on climatic and other natural factors, with the result that the wheat crop fluctuates from one extreme to the other in the course of a few successive years" (Dept of Agric. & Forestry, 1938, p490). Past historical records have shown that when marginal climatic conditions prevail in the winter rainfall region, the Swartland seems to maintain the highest yield per hectare when compared to the other regions.

In 1953 the Swartland produced as much as 47% of the total wheat production in the (then) Cape Province<sup>1</sup> and 21% of the total for the country. In 2000 this figure stood at around 34% in the "Cape Province<sup>1</sup>" and 15% of the total for the country (Dept of Agric., 2004). Maali (2003) showed that wheat quality and wheat yield varied largely between years due to annual variation in total precipitation and distribution of rainfall. Dietrich *et al.* (2004) however attribute these changes to an increase in land use for grape production, with the southern parts of the Swartland containing the "third highest percentage of total vines less than ten years old out of the eight major wine producing regions" (pg 28).

As mentioned previously, climate is one of the main factors affecting desertification in Mediterranean-type regions. Here rainfall amount and

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<sup>1</sup> The Cape Province, up until 1994, consisted of what are today the Northern Cape, Western Cape and Eastern Cape Provinces. For comparison's sake, these three current provinces are combined when considering statistics.

distribution are the major determinants of biomass production on hilly lands under Mediterranean conditions (Kosmas and Danalatos, 1994). Talbot (1961) cites Kokot (1942) as providing ample evidence to support the view that serious desiccation was taking place in many parts of South Africa in the 1930's and early 1940's.

By the 1960's there was little or no vegetation in South Africa that was in its original condition, but it was the arid regions and the broad marginal zones adjacent to them that have suffered the most changes (Talbot, 1961) and continue this trend today. On the whole however, the Swartland is remarkably different to the eroded hills noted in the 1930's and 1940's. Stringent erosion laws and attractive government subsidies encouraged farmers to combat erosion and change farming practises for the better.

Climate and weather patterns are crucial to farmers and agricultural research continues in all the major agricultural areas of the country to ensure adequate yields. Maali (2003) recommends minimum tillage or reduced tillage being performed on wheat in the Swartland during low rainfall years than conventional tillage. In general these tillage systems should be combined with crop rotation to ensure that yields are comparable to that obtained with conventional tillage. This section continues with an examination of Swartland wheat yields from historical records; climate effects on Swartland wheat; and a case study of climate impacts on crop yields in the Swartland.

### *3.7.1 Historical wheat yields in the Swartland*

The government reports of annual wheat yields, rainfall conditions and temperature were examined with respect to the Swartland. Figure 3.6 shows these factors combined against an index of favourable or unfavourable leading to high/low wheat yields respectively. Unfavourable precipitation was ranked as too much or too little; unfavourable temperature was where conditions were too hot or too cold; and unfavourable wheat yield was where the yield produced was below that required. Satisfactory precipitation, temperature and wheat

yield are plotted in between. Unfortunately the historical records are incomplete, one of the main reasons being that as the Department of Agriculture changed its staff, so their methods, style and content of the reports also changed.

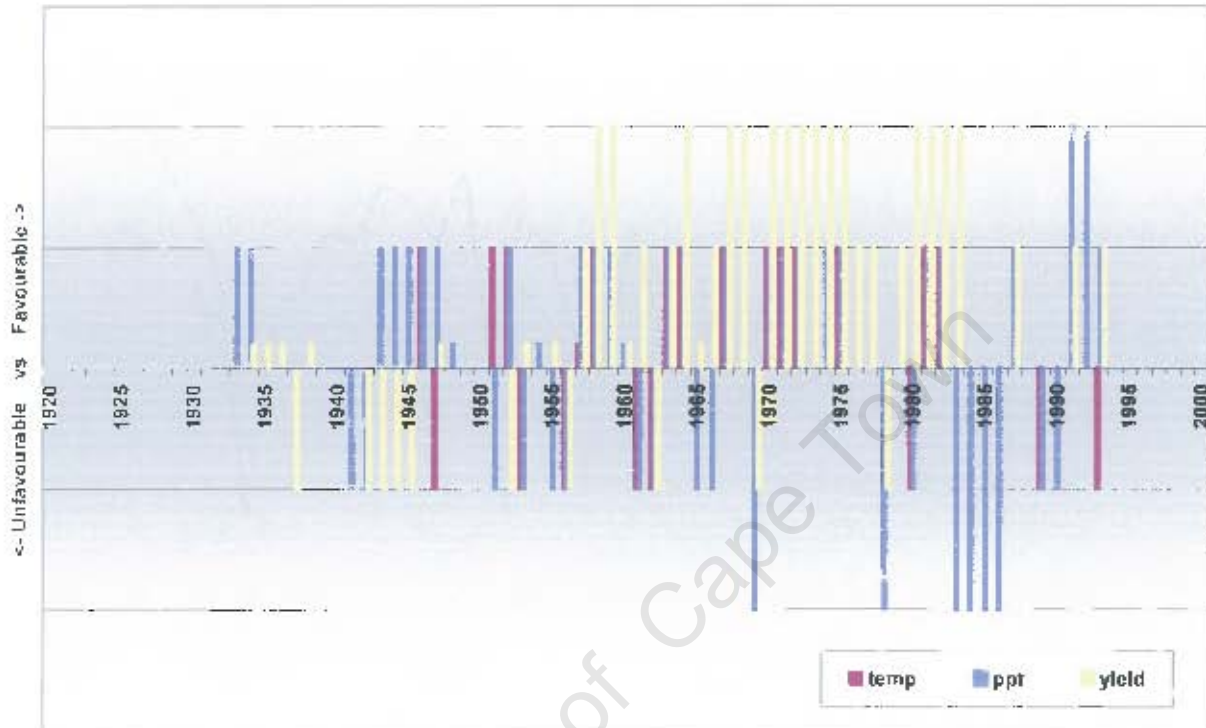


Figure 3.6: Swartland climatic conditions plotted with wheat yield from historical government records (see text for classification of favourable/unfavourable).

From the historical records of wheat yields, the Swartland is the main wheat producing region in the Western Cape Province of South Africa, with Ruens in the Overberg (east of Cape Town) being the other significant region. The Free State Province also produces wheat, but experiences a summer rainfall climate, thus their wheat cultivars are different, as are their yields produced. The Swartland has been producing wheat historically for longest out of all the regions, but more intensely with the discovery of gold and diamonds in the interior of South Africa during the late 1800s, thus increasing the demand (Newton and Knight, 2005). In the Swartland, yields of wheat have more than doubled per hectare between 1955 and 1987 (Dept of Agric., 1994) as shown

in Figure 3.7 and tabulated in *Appendix E*. Although the wheat subsidies of the past have now been withdrawn, there remains a tax of R196.00 per tonne on imported wheat<sup>2</sup> encouraging local farmers to maintain their wheat crops as a viable source of income even with impending climate change.

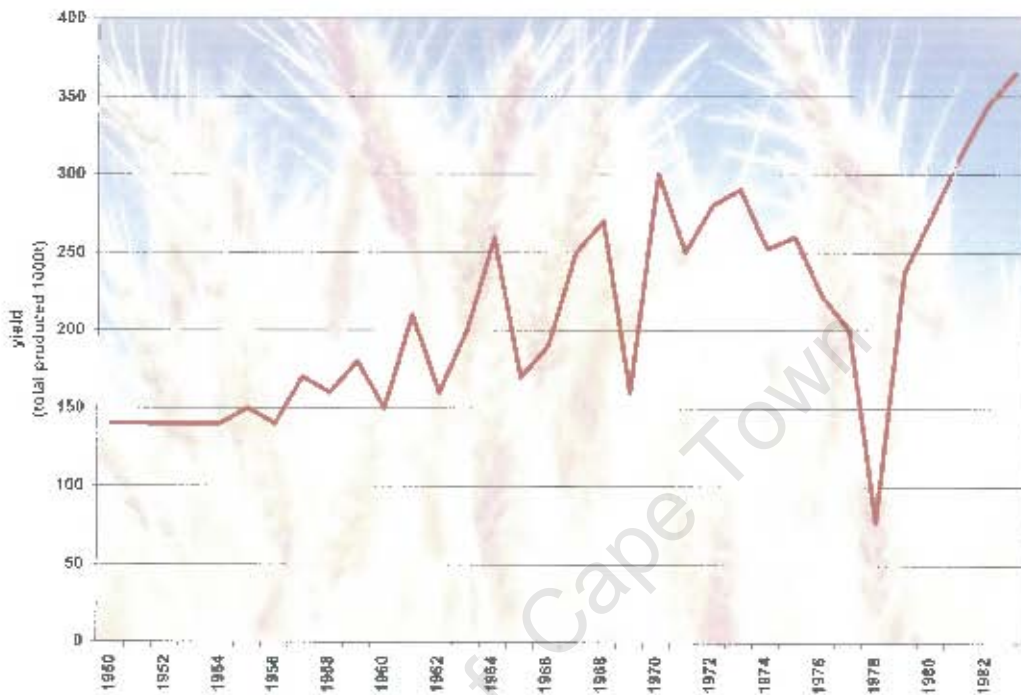


Figure 3.7: Total wheat produced in the Swartland from 1960-1983, measured in 1000t units.

### 3.7.2 Climate effects on Swartland wheat

One main point that stands out from the data and literature reviews of climate in the Swartland is that, in terms of farming and growth of crops, the Swartland does not experience true winter temperatures, i.e.: present temperatures are not a limiting factor for crop growth in the Swartland. Crop growth begins at around 5°C where a *mean daily* temperature of 6°C would be one degree-day above the critical temperature (George *et al.*, 1988), of which the *daily average minimum* temperatures experienced in the Swartland fall around 6-7°C (see Table 3.1).

<sup>2</sup> South African Customs and Excise Tariff Tables, <http://www.rapidtp.co.za/tariff/10/10019000.html>, accessed 24th June 2005.

Future climate change shows temperatures to be increasing in the Swartland (see *Chapter Four*), thus temperature change would not be a limiting factor on the growing season. However high temperatures can lead to high evaporative demand and can compound the effect of scarce rainfall in low rainfall areas (Sadras and Angus, 2005). For example, it has been shown in parts of Australia with similar environmental conditions to the Swartland, that if rainfall decreases by 20%, wheat yield would increase slightly for a 1°C warming, but decrease for warming greater than 1°C (Augustin, 2002). This is because higher temperatures increase the speed of crop development, thus reducing grain yields.

### 3.7.3 Case study of Boshof farm

The Boshof farm (33°21.01'S 18°48.72'E) was chosen for a case study as it is in the heart of the Swartland, being just outside Malmesbury at an elevation of 301m above sea level. *Appendix F* contains monthly rainfall from January 1966 to May 2005 on the Boshof farm. From a crop farmer's point of view, the months from May to September are the most crucial rainfall months in the Swartland (Damp, pers comm.). Figure 3.8 shows the number of years in the 38-year record which fall into a particular interval of total rainfall received for the months of May to September – "Swartland winter". The average rainfall over this 38-year period for the Boshof farm is 276mm for this same winter period.

Particularly bad farming years identified by the farmer at the Boshof farm, Gerry Damp, were those of 1978, 1997, 2003 and 2004. These years not only coincided with rainfall on the lower end of the spectrum, but also experienced enhanced dry spells during the winter rainfall period. 1978 was, from the perspective of agricultural productivity, the worst climatic year during this record, where the dry spell lasted for a full three months, experiencing a total of only 24mm of rain over the months of June, July and August. This coincides with the flowering season of the wheat crop, where crops suffer a yield loss of around 1.25% per stress day (Agenbach, pers comm.). The total wheat yield

for the Swartland in 1978 was around 49% less than the average for the 1970s (Figure 3.7).

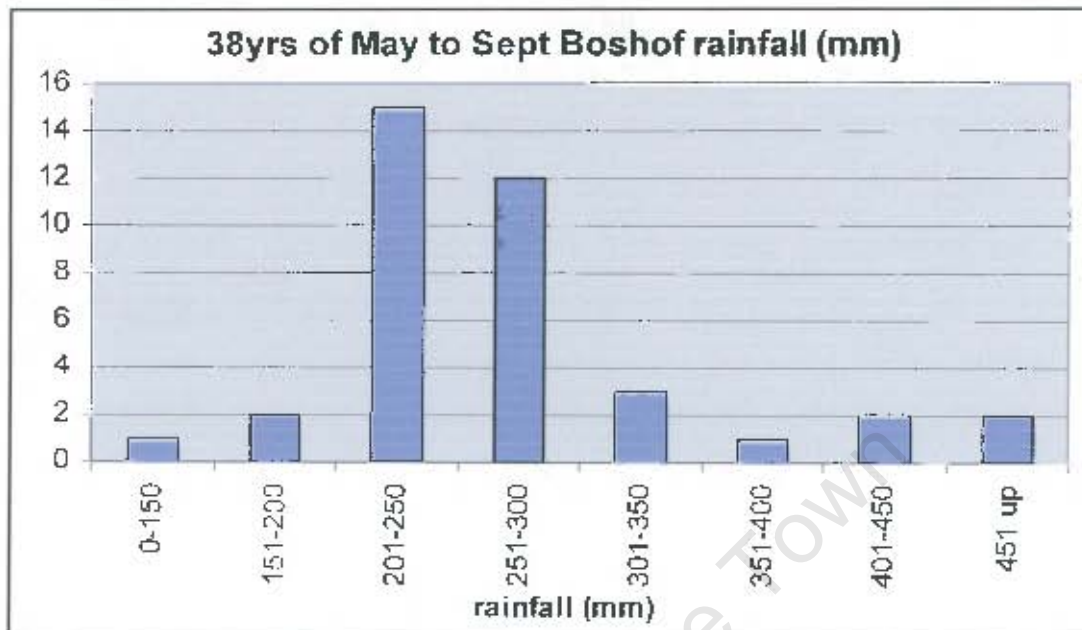


Figure 3.8: Years grouped into 50mm intervals of rainfall received over the recorded 38 years on the Boshof farm near Malmesbury in the Swartland. This identifies the most common range of rainfall experienced

### 3.8 In summary

There is a large amount of evidence to support the theory that farmers in the Swartland are moving over from wheat to grape farming (Dietrich *et al.*, 2004), and this is thought to be initiated since the lifting of trade sanctions in 1992 (Fairbanks *et al.*, 2004). There is concern as to whether further expansion of the wine industry, which would benefit the economy through increased foreign exchange (Fairbanks *et al.*, 2004), would be sustainable when considering climate change and the encroachment on the little remaining natural vegetation.

Wheat cultivars are constantly being adapted to cope with changing climatic conditions. Viticulture on the other hand, relies on particular cultivars, which are characterised by soil type and climate, to produce wines of a certain style

and quality to be recognised internationally<sup>3</sup>. It is for this reason that grape cultivars are not able to adapt to suit changing climates as this would affect the quality of the grape and ultimately the wine produced (James, 2002). The wheat farmers are better able to cope with changing climatic conditions with the options to plant different cultivars depending on which climatic conditions are prevalent.

The main question to be dealt with from this point forward is how will the climate change that the wheat farmers will have to adapt to? And how is this likely to affect soil erosion and possible resultant land degradation in the Swartland? *Chapter Four* begins with a look at how climates are simulated through the use of climate models, and how accurate they are at projecting regional climate changes.

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<sup>3</sup> [http://www.wosa.co.za/origin\\_cultivars.asp](http://www.wosa.co.za/origin_cultivars.asp)

University of Cape Town

***CHAPTER FOUR:  
CLIMATE MODELLING***

University of Capetown

## 4.1 Introduction

Climate models were initially designed as an attempt to understand the processes that produce climate and to predict the effects of changes in those processes (Preston-Whyte and Tyson, 1993). Models are basically deductive and are formulated from the fundamental equations governing the physical processes under consideration, making them powerful in their representation of climate dynamics (Tyson and Preston-Whyte, 2000).

Climate models can be fully three-dimensional in character, and comprise a series of equations with prescribed initial boundary conditions and physical constraints. A climate model represents a controlled environment, within which the impact of anomalies on the climate system can be studied (Hudson, 1998). By comparing an anomaly simulation to the control simulation, the nature, degree and extent of climatic variability can be identified.

Many different models are being used to predict future climate changes and, although there is broad agreement among the models, there are also many differences in the details of their predictions (Joussaume and Taylor, 2000). The main advantage is that climate models are continually improving in their ability to simulate the major features of contemporary climate (IPCC, 2001b) as illustrated in Figure 4.1.

Where future climate change is concerned, the actual magnitude of change cannot be directly interpreted, as this is highly dependent on global emissions and global actions towards climate change. Natural variability plays an important part in affecting and changing climate, and therefore the models need to be more refined where a clear signal is not initially present before assuming the climatic changes are relevant for the area in question and not just "noise" within the climate system.

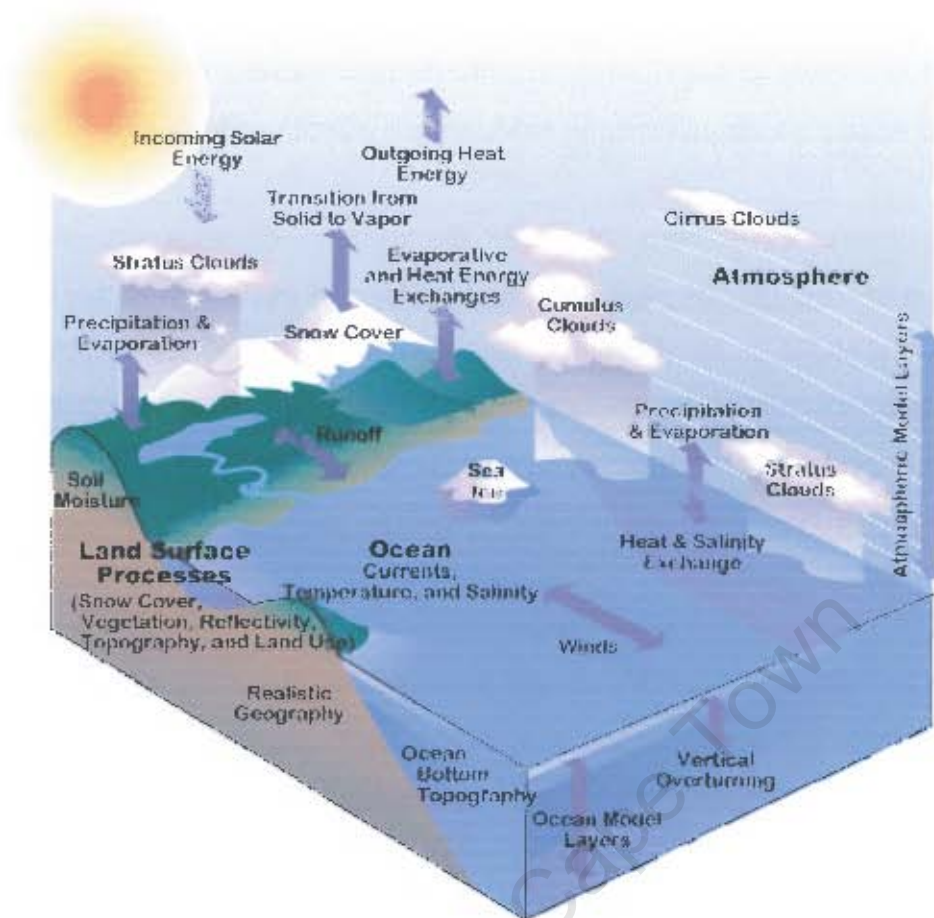


Figure 4.1: Climate models simulate many interconnected events that drive the Earth's climate. These include changes in the atmosphere, oceans, sea ice and impacts of forests and rivers on the overall system (CCSM, 2004)

There is however, general consensus that the increasing atmospheric concentrations of greenhouse gases are causing an increase in global temperatures and in climate variability, with many models predicting more extreme climatic events occurring in the future (IPCC, 2001c). These climatic changes are likely to impact all aspects of the climate system, and beyond.

A prime example of the projected changes that could occur as a result of increased greenhouse gas forcing is that "large climate-induced changes in soils and vegetation may be possible and could induce further climate change through increased emissions of greenhouse gases from plants and soil, and changes in surface properties (e.g., albedo)" (IPCC, 2001c, pg15). Some ecosystems respond to the effects of climate change rapidly, while others do so

more slowly, thus it is important to examine and predict what the future changes are likely to be in order to enforce preventative measures and make informed decisions about how the systems will adapt under climate change.

Climate change projections come in the form of General Climate Models (GCMs) and Regional Climate Models (RCMs). At this stage RCMs are still in their infancy as far as simulations of regional climate in southern Africa go, with current studies being carried out in the interior of the subcontinent where summer rainfall conditions predominate (Zhao *et al.*, 2005; Jury *et al.*, 2004; Engelbrecht *et al.*, 2002; Jury, 2002).

For the Swartland, as a winter rainfall region of southern Africa, a combination of six GCMs are used here to examine the envelope of projected future climate change. Initially the GCMs are validated against station data, both archived from historical records and NCEP data to establish their credibility for the study region. As mentioned in *Chapter Two*, NCEP data are reanalysis data generated from forecast charts that are public domain and created by a global medium range forecast model in the USA (Kalnay *et al.*, 1996).

The methods used in this chapter, as well as constraints and caveats of using GCMs for regional climate studies have been described in detail in *Chapter Two*. The next section examines the results from the six GCMs for the Swartland.

## **4.2 GCMs validation for the Swartland**

The following are the results of the model bias and model validation analyses of the GCM data for the Swartland:

### *4.2.1 Temperature*

All six models showed a very close agreement with NCEP, when examining temperature. The average temperatures clearly depicted the summer-winter

seasonality (Figure 4.2), while the minimum and maximum temperatures conformed to the same special pattern as NCEP, with similar values (Figure 4.3). Temperature extremes were noted as being well depicted, with all the models being within 1-1.5°C of NCEP throughout the year, both when examining the average temperatures (Figure 4.2) and the minima and maxima (Figure 4.3).

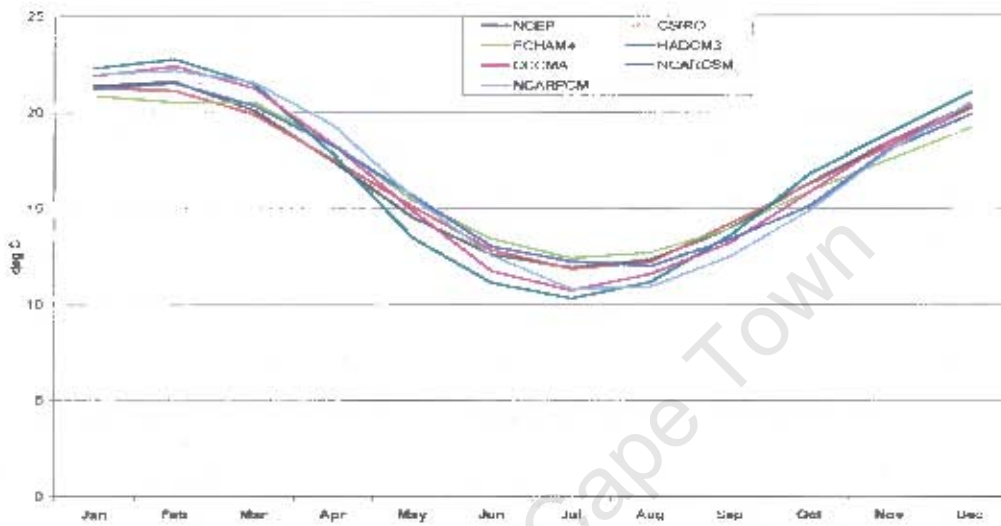


Figure 4.2: Swartland average temperatures, simulated by the six models in the study and compared to NCEP as observed. These values have been adjusted for model bias as described in the text.

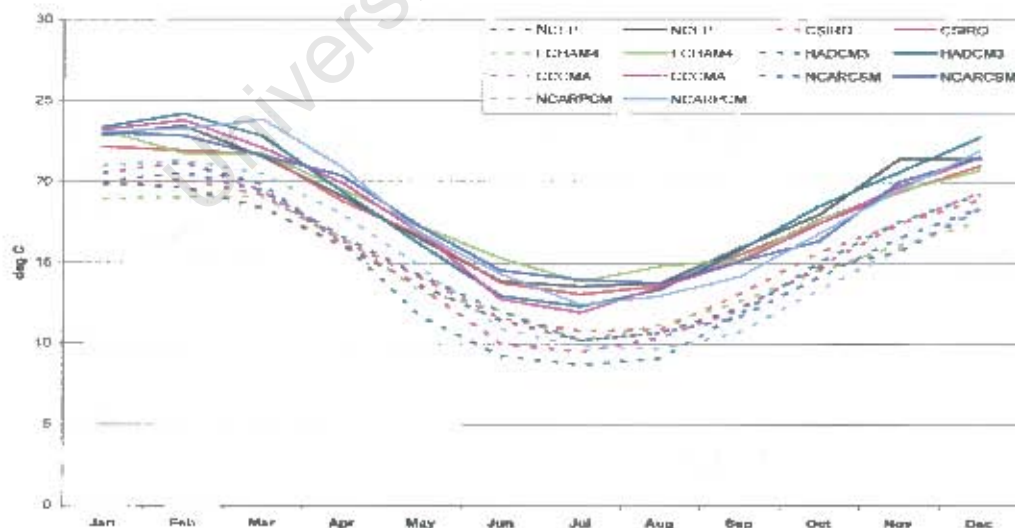


Figure 4.3: Swartland minimum (dashed line) and maximum (solid line) temperatures, simulated by the six models in the study and compared to NCEP as observed. These values have been adjusted for model bias as described in the text.

The conclusion for temperature is that all six GCMs seem to simulate monthly temperature well for the study region, when compared to NCEP as observed. They all manage to simulate the correct seasonal changes, as well as the maximum and minimum extremes.

#### 4.2.2 Precipitation

The six models seemed to diverge in their patterns of average precipitation simulations for the Swartland region, when compared to NCEP. CSIRO, ECHAM4, HADCM3 and CCCMA were closely clustered in their depictions, while the two NCAR models were clustered together. The first group of models, that being CSIRO, ECHAM4, HADCM3 and CCCMA, showed the summer-winter rainfall seasonality well, with lower rainfall in summer than in the simulated winter months (Figure 4.4). ECHAM4 seemed to be the most closely related overall to NCEP, showing a more defined summer dry period, with greater rainfall in the winter months.

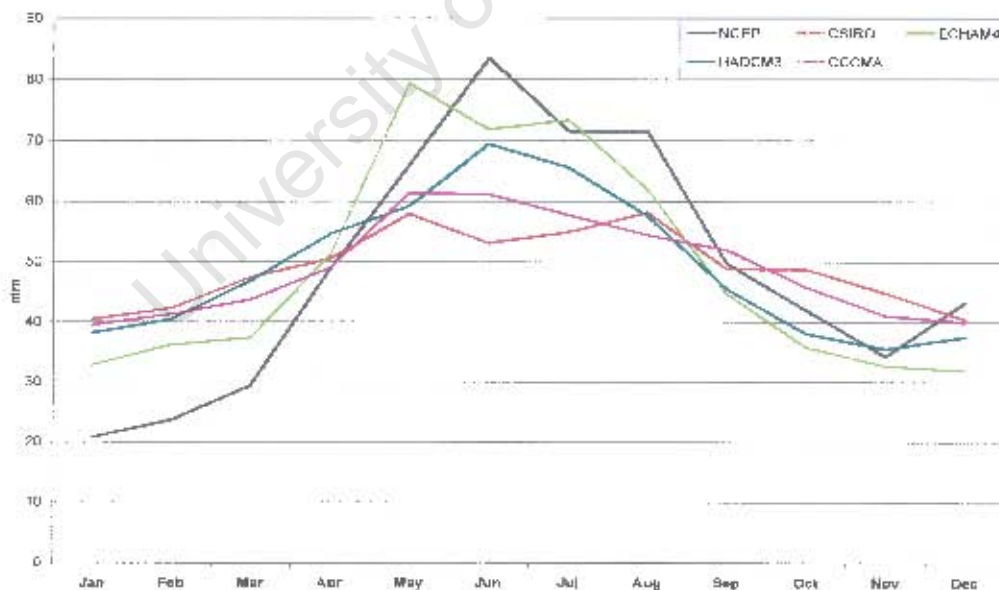


Figure 4.4: Swartland average precipitation, simulated by the six models in the study and compared to NCEP as observed. These values have been adjusted for model bias as described in the text. (note: NCARCSM and NCARPCM are overlain for easy of comparison only and are not excluded from the study at this stage).

The two NCAR models, that being NCARCSM and NCARPCM, seemed to have little agreement with NCEP at all (Figure 4.4). They showed two rainfall peaks in the year, being around February/March and then again in July/August. The only reasonably appropriate connections with NCEP are the spring and early summer months of September to December.

When examining precipitation minima and maxima, the model minima's are linearly clustered between 20-45mm precipitation per month (Figure 4.5). NCEP is much less than this, and shows a clear summer-winter relationship, with a slight increase in the winter months. Once again the models overestimate the minima and underestimate the maxima precipitation, and only the CSIRO, ECHAM4, HADCM3 and CCCMA GCMs manage to depict the seasonal cycle of increased precipitation in the winter months.

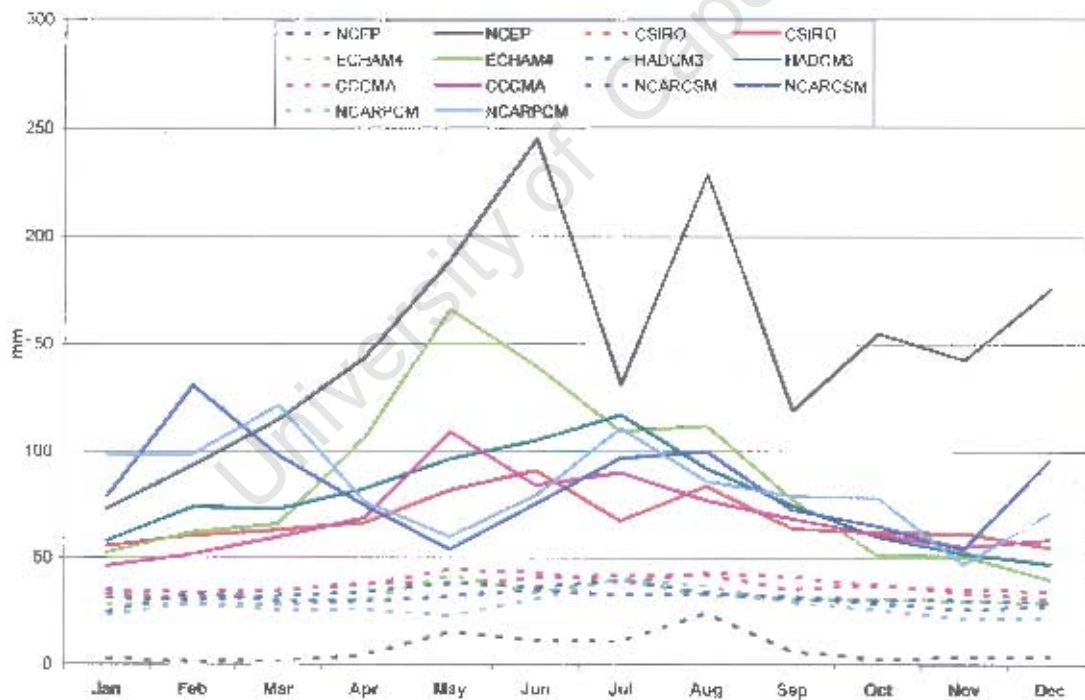


Figure 4.5: Swartland minimum (dashed line) and maximum (solid line) precipitation, simulated by the six models in the study and compared to NCEP as observed. These values have been adjusted for model bias as described in the text.

Thus, in conclusion for modelled present day precipitation, it is seen that the CSIRO, ECHAM4, HADCM3 and CCCMA GCMs best depict precipitation for

the Swartland when compared to NCEP, while NCARCSM and NCARPCM fail to simulate correct seasonality. None of the models are particularly good at simulating extreme minimum precipitation, with ECHAM4 being the closest to NCEP's simulation of the monthly precipitation maximum.

### 4.2.3 Wind Speed

NCARCSM did not have wind speed data available at the time of this study, so has been excluded from the wind speed evaluation. All the other models were examined with regards to their monthly average, minimum and maximum wind speed over the Swartland. Generally the models do not seem able to simulate the minimum and maximum extremes, particularly relating to wind speed (Figure 4.6). They do however manage to identify the general increase in wind speed in the summer and winter months, with the associated slight decreases during spring and autumn months of April/May and August/September respectively (Figure 4.7).

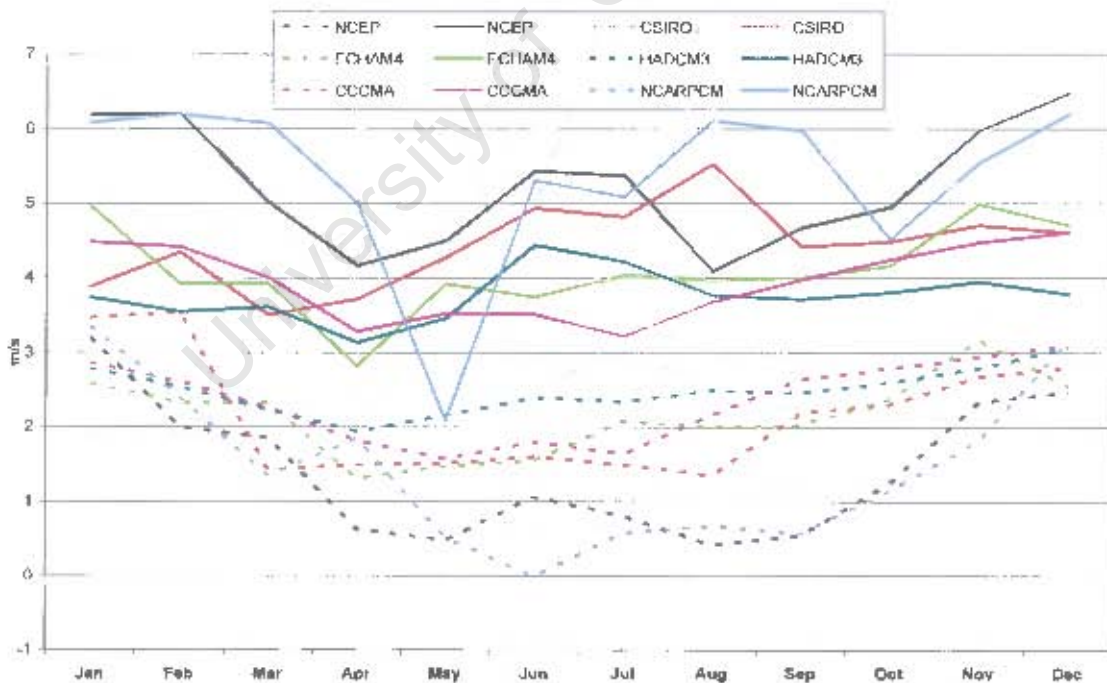


Figure 4.6: Swartland minimum (dashed line) and maximum (solid line) average wind speed, simulated by five models in the study and compared to NCEP as present day. These values have been adjusted for model bias as described in the text.

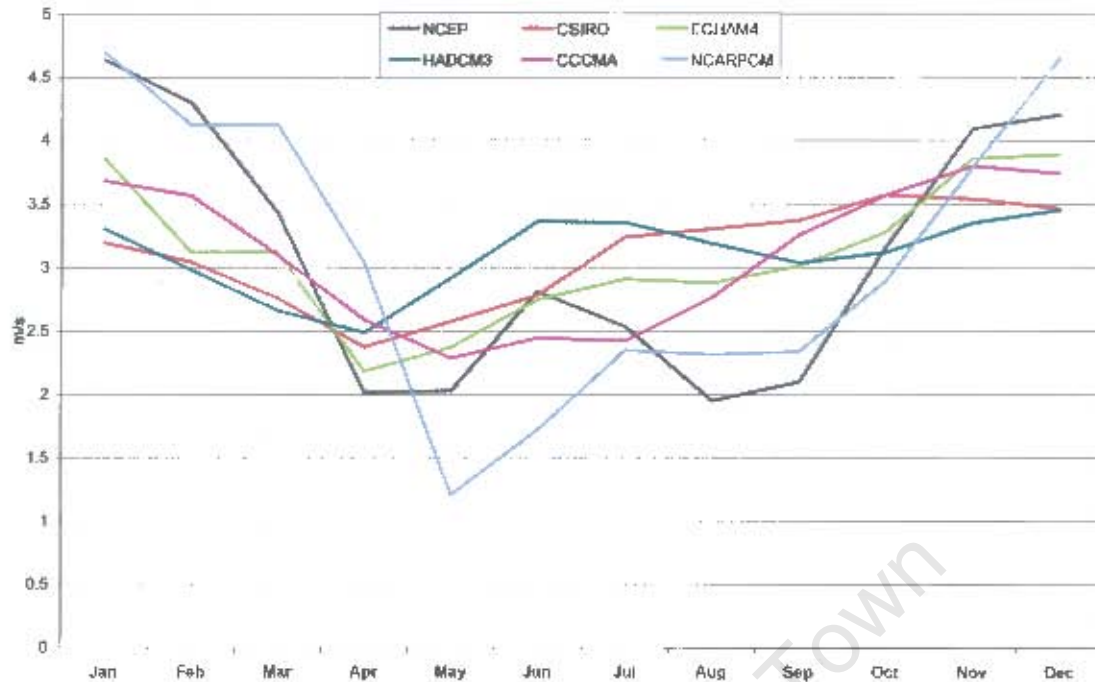


Figure 4.7: Swartland average wind speed, simulated by the six models in the study and compared to NCEP as observed. These values have been adjusted for model bias as described in the text. (note: NCARCSM excluded as no there was no data available at this stage).

### 4.3 GCMs present climate results

The raw GCMs are too coarse to compare directly to NCEP (as observed) for the study without taking into account model sensitivity and model bias analyses (as in section 4.2 above). Once these were examined with respect to how they represent present climatology, the model results of present and future climate averages were statistically clustered using Single Linkage and Ward's Method with Euclidean distance measures (see *Chapter Three*). The results from the cluster analysis are presented below:

It was thought that the NCARCSM and NCARPCM models, although well related in the analyses of temperature, would be inappropriate for use in this study due to their poor representation of the present day climate for the region

when considering other variables, in particular precipitation (Figure 4.4). While NCARCSM has no wind data available, NCARPCM's wind speed data is a clear outlier when considered for the Single Linkage clustering technique (Table 4.2), another reason to discard these two models for this particular regional study.

Table 4.2: The results from the cluster analyses for average monthly climatology model output. Single Linkage clustering identifies outliers and Ward's Method identifies cohesive groups.

Variable	Scenario and time	Model outliers	Cohesive model groups	
			1	2
Temperature	A2 present	HADCM3	CSIRO/ECHAM4/ NCARCSM	HADCM3/CCCMA/ NCARPCM
Precipitation	A2 present	NCARCSM and NCARPCM	CSIRO/CCCMA/ HADCM3/ECHAM4	NCARCSM/ NCARPCM
Wind Speed	A2 present	NCARPCM	CSIRO/HADCM3	ECHAM4/CCCMA

Therefore the study will continue from this point only examining the model output from the CSIRO, ECHAM4, HADCM3 and CCCMA GCMs, all of which are automatically adjusted for model bias so that they are better representative of the study region.

#### 4.4 GCMs future climate projections

Initially temperature, precipitation and wind speed variables for GCM simulations forced by the SRES A2 and B2 scenarios were examined to establish the window of change over the Swartland for future climatic impacts on the region. The A2 scenario from the IPCC-DDC represents a more extreme case, while the B2 scenario is a more conservative approach of future climate change (see section 2.3.2), in order to develop an envelope of change for the study region.

Average future temperature change for the Swartland shows that every month and for each model, there is an agreement that average monthly temperatures will be higher than those experienced presently (Figure 4.8). When comparing the A2 vs B2 scenarios for each individual model, the A2 scenarios show higher temperatures than those of the B2 scenario. The CCCMA A2 scenario shows the highest summer temperatures, being almost 5°C higher in February than NCEP. In the winter months, CSIRO A2 and ECHAM A2 temperatures are around 2.5°C warmer than NCEP.

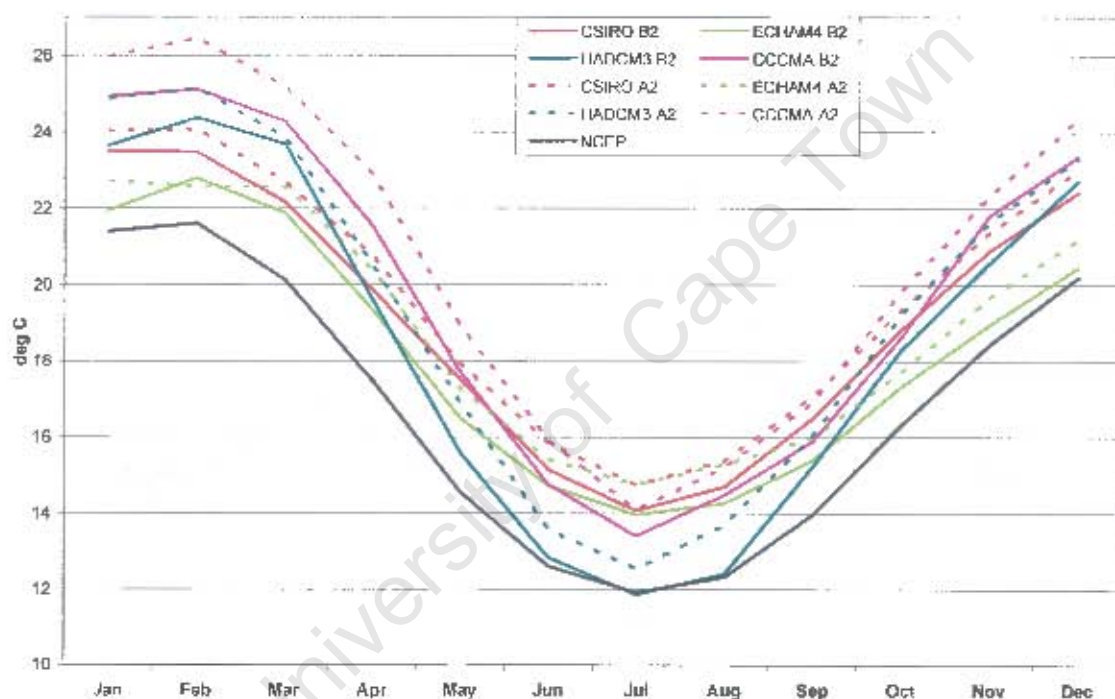
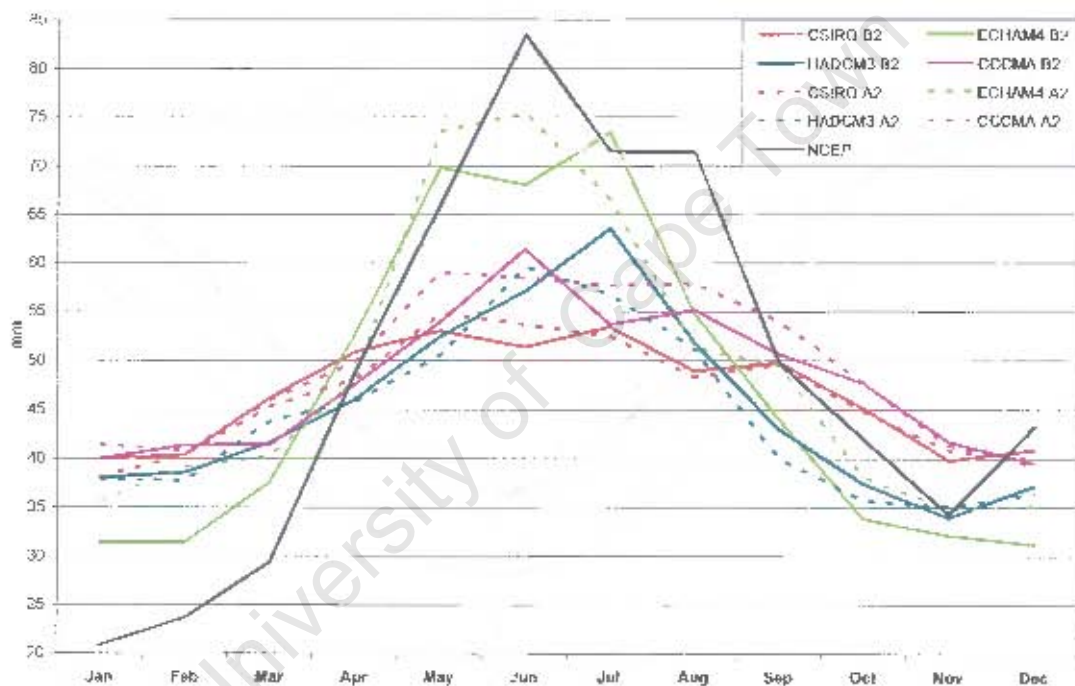


Figure 4.8: Swartland A2 (dashed line) and B2 (solid line) average future temperatures, simulated by the four models in the study and compared to NCEP as present day. These values have been adjusted for model bias as described in the text.

Future precipitation changes look possibly to simulate more rainfall during the summer months, with less winter rainfall occurring. These results are reflected in all the GCMs, however the region still remains a winter rainfall region, with the majority of precipitation for the year occurring during the winter months

(Figure 4.9). CSIRO and CCCMA reflect the greatest increases in summer rainfall, at around 15-20mm per month more than currently experienced. However in winter, CSIRO's B2 scenario reflects the greatest decrease in rainfall at over 30mm less at the peak rainfall period in June. As NCEP is well within the range of changes between the A2 and B2 scenarios, the signal from the models is not strong enough to be more precise as to expect increasing or decreasing precipitation. One needs to remember that natural variation is always a factor, and where the models cannot clearly identify a positive or negative change, the future remains unknown until such time as the models



can become more refined.

Figure 4.9: Swartland A2 (dashed line) and B2 (solid line) average future precipitation, simulated by the four models in the study and compared to NCEP as present day. These values have been adjusted for model bias as described in the text.

Future average wind speed modelled from both the A2 and B2 scenarios reflects a general decrease during the summer months, with a possible increase during the winter months (Figure 4.10).

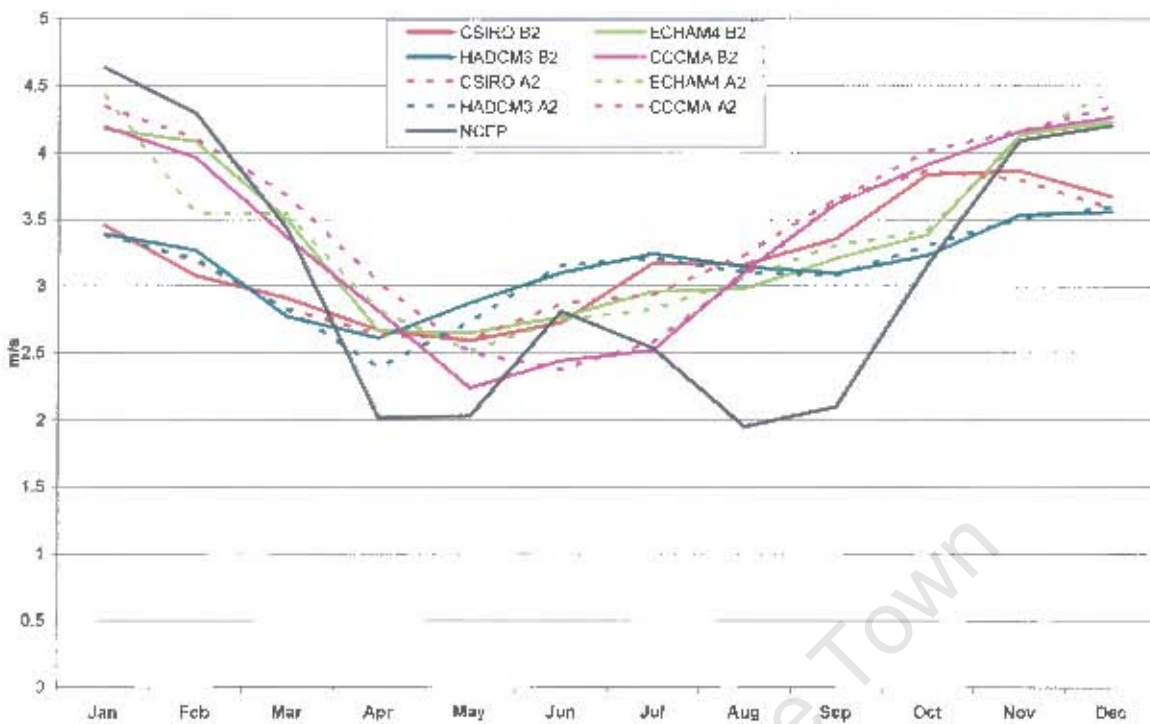


Figure 4.10: Swartland A2 (dashed line) and B2 (solid line) average future wind speed, simulated by the four models in the study and compared to NCEP as present day. These values have been adjusted for model bias as described in the text.

The models simulating the A2 and B2 future climate changes were also clustered using Single Linkage and Ward's Method clustering, and with Euclidean distance measures. Table 4.3 shows the outliers and cohesive groups resulting from the clustering techniques for the future climate change scenarios, while all the joining tree-clustering graphs examined in the study can be found in *Appendix B*.

The clustering technique clearly showed an envelope of change is existent in the Swartland region as there were clear "outliers" and groups for both temperature and precipitation. However one needs to remember the constraints and caveats behind such a modelling approach to a regional study

in order to gain a clearer understanding of the mechanisms involved (see *Chapter Two*). Thus *Chapter Five* follows, where downscaling is examined as an aid to understanding the smaller scale dynamics of regional climate change.

Table 4.3: The results from the cluster analyses for average monthly climatology model output. Single Linkage clustering identifies outliers and Ward's Method identifies cohesive groups.

Variable	Scenario and time	Model outliers	Cohesive model groups	
			1	2
Temperature	A2 future	CCCMA	CSIRO/ECHAM4	HADCM3/CCCMA
	B2 future	HADCM3	CSIRO/CCCMA	ECHAM4
Precipitation	A2 future	ECHAM4	CSIRO/CCCMA/ HADCM3	ECHAM4
	B2 future	ECHAM4	CSIRO/CCCMA/ HADCM3	ECHAM4
Wind Speed	A2 future	-	CSIRO/HADCM3	ECHAM4/CCCMA
	B2 future	-	CSIRO/HADCM3	ECHAM4/CCCMA

***CHAPTER FIVE:  
REGIONAL CLIMATE  
MODELLING & FUTURE  
TRENDS***

## 5.1 Introduction

Modelling climate using a Global Climate Model (GCM) can have major drawbacks when examining regional climate (see section 2.3.1). Impact studies particularly, require a spatial scale much finer than that provided by GCM's. Thus climate modellers have adapted a number of techniques to get around the problem of scaling down to a regional level.

Regional Climate Models (RCM's) have recently become a tool of favour for many climate modellers, especially in the northern hemisphere where European modellers have found it necessary to develop finer resolution models for a more complex physical environment, as with the new RegCM3 model (Pal *et al.*, in press). RCM's, as with GCM's can be fully three-dimensional in character, and comprise a series of equations with prescribed initial boundary conditions and physical constraints. Generally an RCM will use a GCM to force the model parameters at a higher resolution for the regionally based study area.

The CSAG<sup>1</sup> research group at the University of Cape Town have examined the MM5 regional climate model developed in the USA for central and southern African. Preliminary results have revealed that the model is quite sensitive to selection of parameterisation options. CSAG and the South African Weather Service (SAWS) are also involved in examining the RegCM3 RCM over Africa south of the equator, but this research is very much in its infancy and at this stage cannot be relied upon for valid results. However at this stage, there remains a degree of uncertainty in RCM's, as they have not yet proven themselves viable to simulate regional and future climate changes reliably (Hewitson pers. comm., 2005), particularly in southern Africa.

There are many different techniques for generating high-resolution climate change scenarios. Some of these other methods of modelling regional future climate changes include the construction of spatial/temporal analogues using historical climate data; climate sensitivity analysis of impact models; spatial interpolation of grid-point data to the required local-scale; and the stretched grid model. The University of Pretoria is currently exploring the use of the stretched grid model for regional analysis in southern Africa under

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<sup>1</sup> Climate Systems Analysis Group based at the University of Cape Town: <http://www.csag.uct.ac.za>

Dr CJ de W Rautenbach, but it is also still experimental at this stage (Hewitson pers comm., 2005).

The technique for examining regional climate changes used in this study is that of empirical downscaling. This is where output from a GCM is downscaled using nesting techniques in order to gain a more regional, higher resolution indication of climatic changes. Regional rainfall changes were successfully developed for southern Africa as early as the mid-1990s, when Joubert and Hewitson (1997) used a regional-scale model nested in a GCM, described as “downscaling” the GCM environment to a finer resolution, and therefore at a more regionally applicable scale.

One of the major advantages of downscaling, and particularly empirical downscaling, is that its computational demand is very low when compared to RCMs. This allows the generation of large ensembles of climate realisations and the exploration of some aspects of uncertainty due to natural climate variability. This technique is what is utilised to further the understanding of regional climate change in this study, as was described in detail in *Chapter Two*. The following sections contain the results gained from the regional analysis of the Swartland:

## **5.2 Regionally downscaled climate results for the Swartland**

The following variables were examined in the context of the Swartland, from the regional downscaling: total precipitation; number of rain days greater than 20.00mm; dry spell duration; and the 90<sup>th</sup> percentile. Only precipitation was examined as the GCMs currently reflect temperature acceptably well over the study region, and temperature increases have little direct influence on hydrology or erosion (Favis-Mortlock and Boardman, 1995).

The following are the results from the examined downscaled precipitation using the HadAM, ECHAM4 and CSIRO climate models under the SRES A2 emission scenarios, unless otherwise stated. These are obtained from anomalies of future climate change minus present climate change. Where increases occur, then this reflects a future climate change increase and *visa versa*. Once again it is necessary to stress that the magnitude of change is not a reliable forecast of future climate change. Here the strength of accuracy is placed on the *direction* of change, ie: increasing or decreasing (Note: all the anomalies examined can be found in *Appendix G* at the end of the thesis):

### 5.2.1 *Total precipitation*

The summer months of December, January, February (DJF) show very little change at all in precipitation for all the models over the Swartland (Figure 5.1). The little change there is, occurs over the Cape Fold Mountains and is thus largely orographically induced (Figure 5.2). This is expected, as it is a winter rainfall region and therefore receives very little precipitation, the large majority of what is received in summer being orographically induced.

The autumn months of March, April, May (MAM) on the other hand show a different picture. There is a definite decrease in total precipitation expected in the future during this season. HadAM shows the drying to be more pronounced at the start of autumn, and ECHAM4 emphasizes it at the end, closer to winter, while CSIRO agrees in the general pattern of drying throughout the autumn season (Figure 5.3).

The winter season of June, July, August (JJA) is when most of the Western Cape and the Swartland in particular, currently receive the majority of its annual rainfall. This rainfall pattern has fluctuated in the past with the region experiencing winter rainfall growing and shrinking in size over many thousands of years (Mulock-Houwer, 2001), however the winter rainfall region as it is known currently will still be prevalent in the next one hundred years, where the models agree that the amount of winter rainfall is more likely to increase in the future for the Swartland (Figure 5.4).

September, October, November (SON) are the spring months in the Swartland and have been known in the past to experience late winter rains. Future trends however reflect a definite decrease in rainfall during these months, following the winter rainfall period (Figure 5.5). This decrease, combined with the decreased rainfall reflected for autumn suggests a possible reduction in the length of the winter rainfall season in the Western Cape in the future.

The total precipitation anomalies for CSIRO A2 and B2 simulations were also examined. The CSIRO B2 simulation shows less of the autumn drying that the other models show, with almost no change in the future vs. the present scenario. Spring is however concurrent with the other models, but with much less total rainfall. The CSIRO B2

scenario winter rainfall is much more pronounced than the other models, but also over a reduced time period of the winter rainfall season, thus in agreement with the A2 scenario of the other models (see Appendix G).

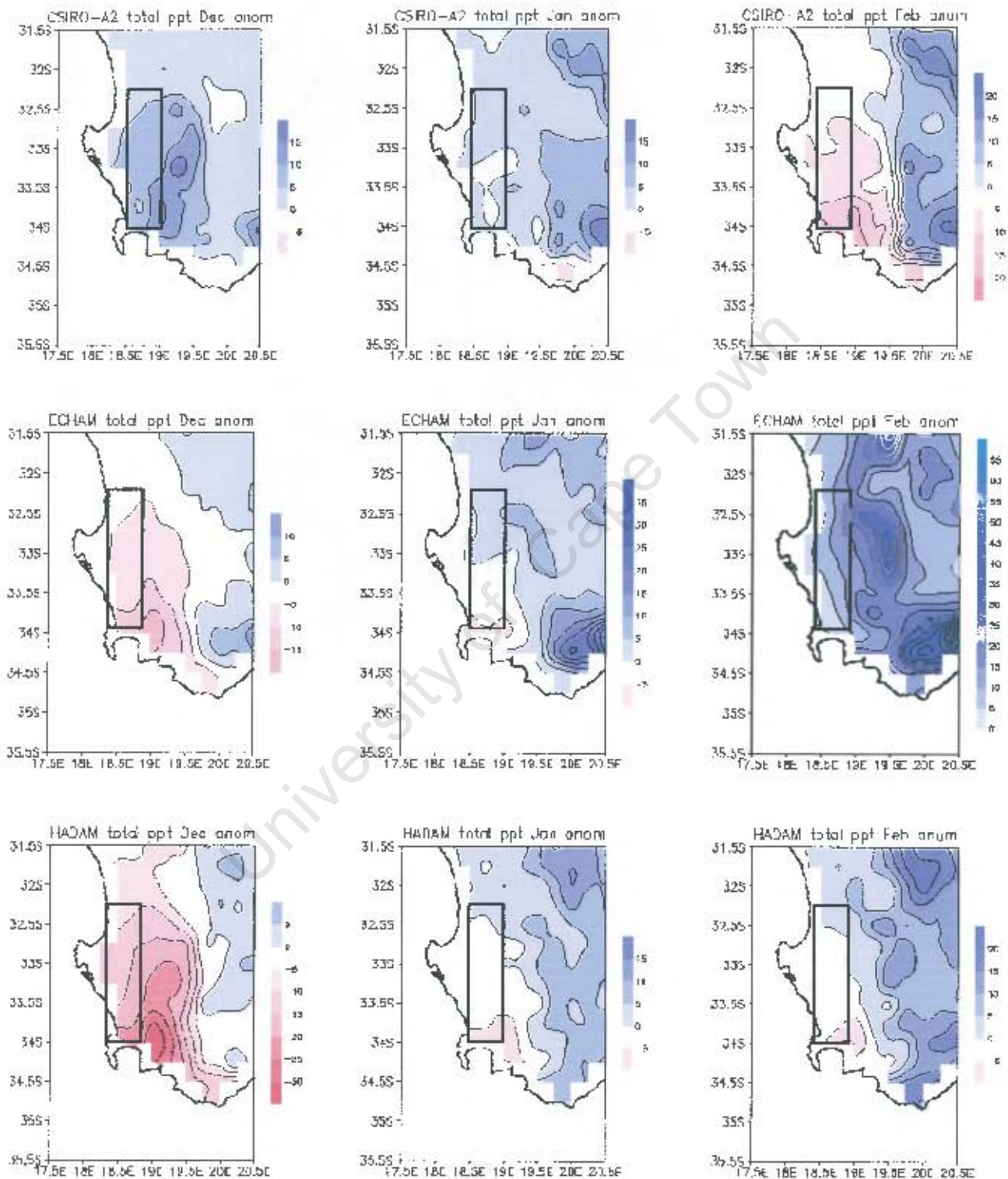


Figure 5.1: Anomaly of total summer precipitation for parts of the Western Cape Province, with the Swartland outlined in the block. These show good agreement between models that little change in future precipitation is likely to occur over the summer months, where red reflects decreases and blue reflects increased rainfall.

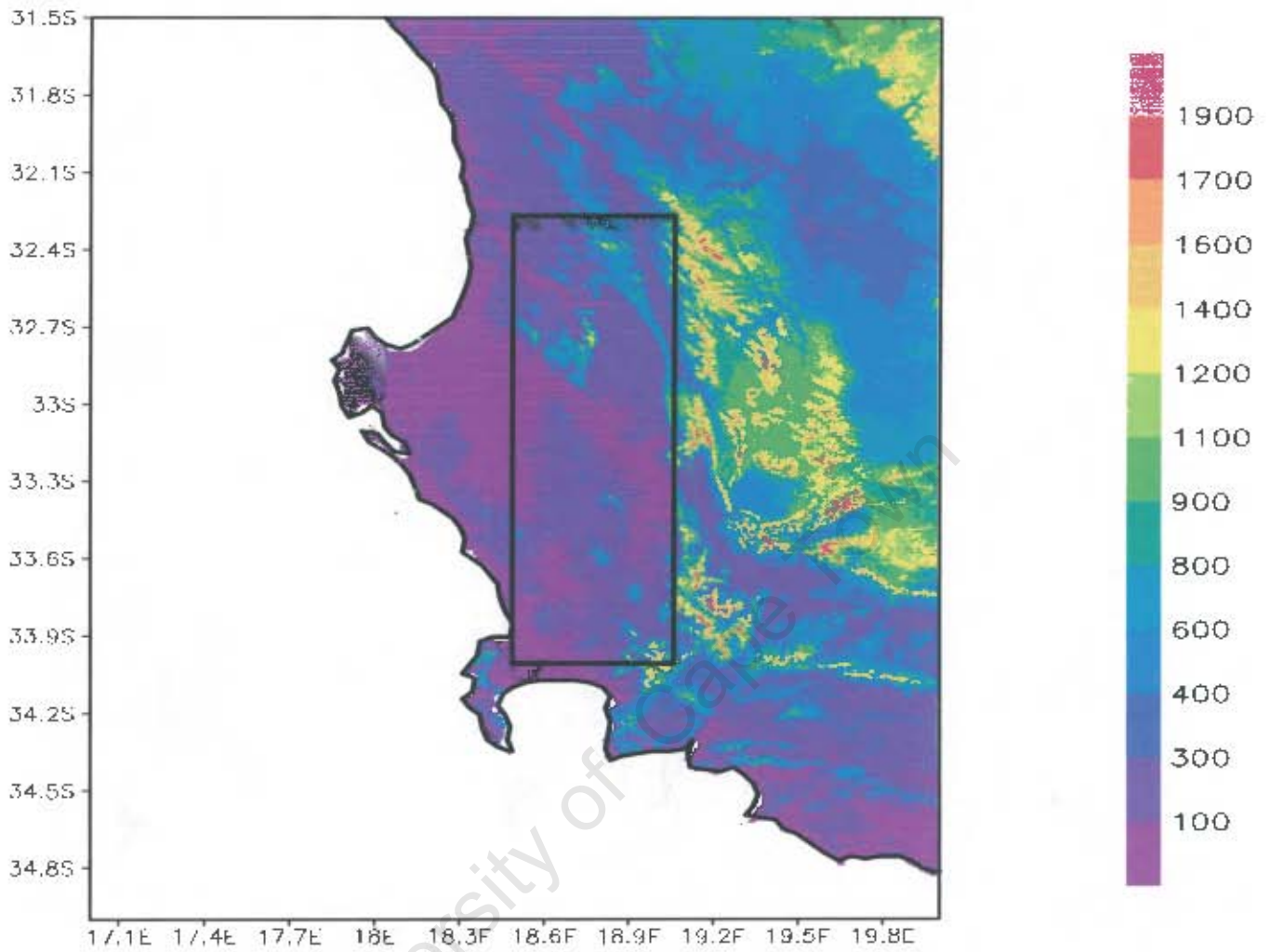


Figure 5.2: An elevation map of the Swartland (block) and surrounding areas, shows mountains to the east of the study area causing the resultant orographically induced precipitation changes to the region.

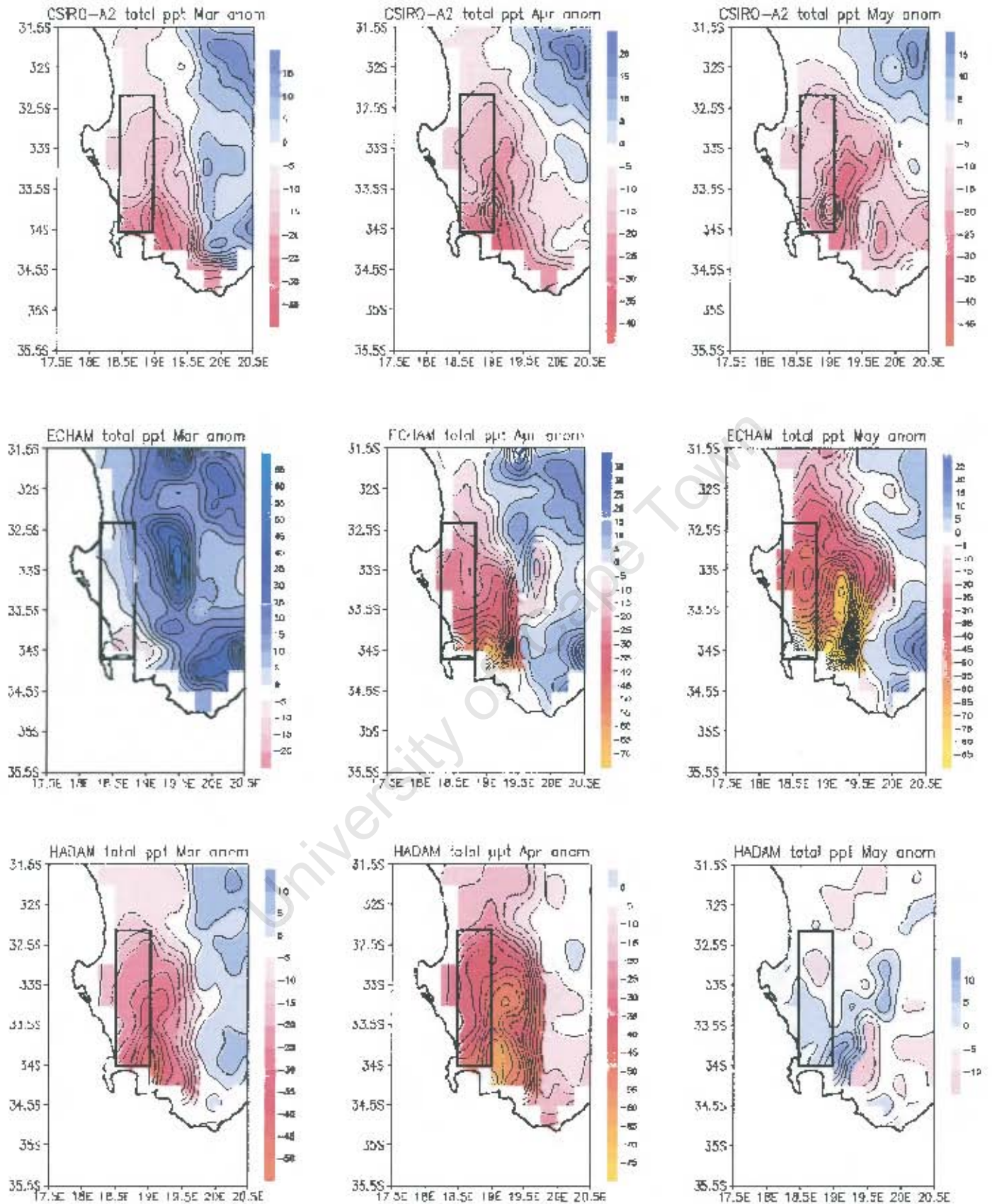


Figure 5.3: Anomaly of total autumn precipitation for parts of the Western Cape Province, with the Swartland outlined in the block. These show good agreement between models that the autumn season will reflect drying in the future, where red reflects decreases and blue reflects increased rainfall.

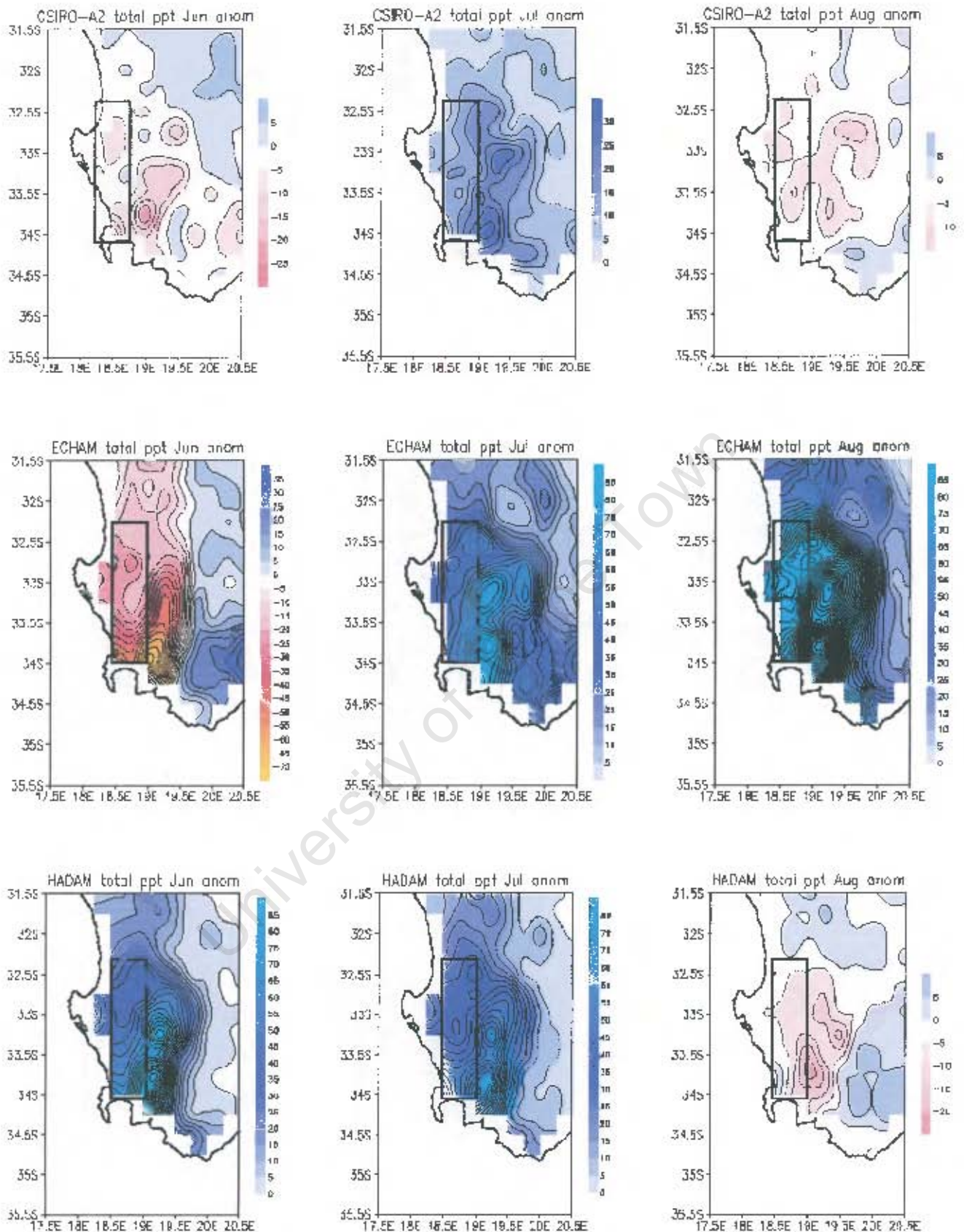


Figure 5.4: Anomaly of total winter precipitation for parts of the Western Cape Province, with the Swartland outlined in the block. These show good agreement between models that the winter rainfall will continue in the Western Cape, however possibly over a shortened time period, where red reflects decreases and blue reflects increased rainfall.

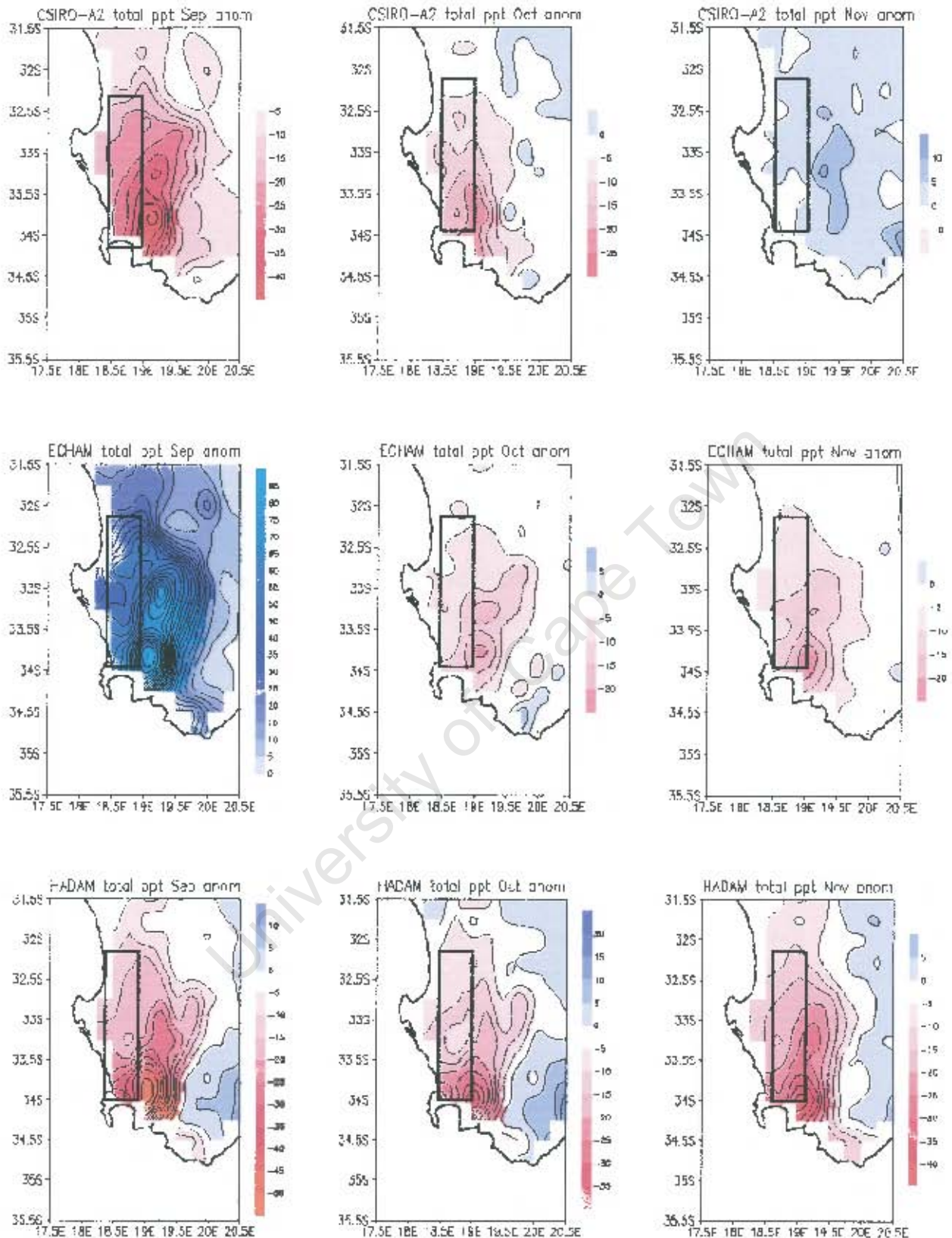


Figure 5.6: Anomaly of total precipitation for the spring months for parts of the Western Cape Province, with the Swartland outlined in the block. These show good agreement between the models that a drying will follow the winter rainfall, possibly shortening the winter rainfall season, where red reflects decreased and blue reflects increased rainfall.

### 5.2.2 *Dry spell duration*

Dry spell duration was examined to gain an idea of the months that would experience increased periods of drying in the future. DJF showed very little change, if any, in the number of days per month without precipitation. In accordance with the total precipitation anomalies in section 5.2.1, the future trends in dry spell duration decreases in the winter months (Figure 5.6), but increases in the autumn (Figure 5.7) and spring (Figure 5.8). This hints again at a shortened winter rainfall season.

CSIRO A2 vs. B2 scenario for dry spell duration shows less change for the B2 scenario than the A2 scenario for autumn (Figure 5.9), but concurs with the enhanced drying at the end of the winter rainfall season (Figure 5.10). The CSIRO B2 scenario shows more intense spring drying in the future than the CSIRO A2 scenario. CSIRO B2 also reflects possibly more moisture during summer when compared to CSIRO A2 scenario; however the Swartland would still receive the majority of its rainfall over the winter months.

### 5.2.3 *Number of rain days > 20.00mm*

The number of rain days greater than 20mm was examined to determine if the future climate would hold an increase or decrease in the current heavier rainfall events. After examining the anomalies of all the seasons (*Appendix G*), the most significant results show that there is a definite decrease in heavier rainfall events after winter (Figure 5.11). The models also suggest an increase in heavier rainfall during the winter months (Figure 5.12), but this is thought to be more orographically induced due to the topography directly east of the study region (Figure 5.2). The CSIRO A2 vs. B2 scenarios for number of rain days greater than 20.00mm show rather insignificant changes between future and present simulations.

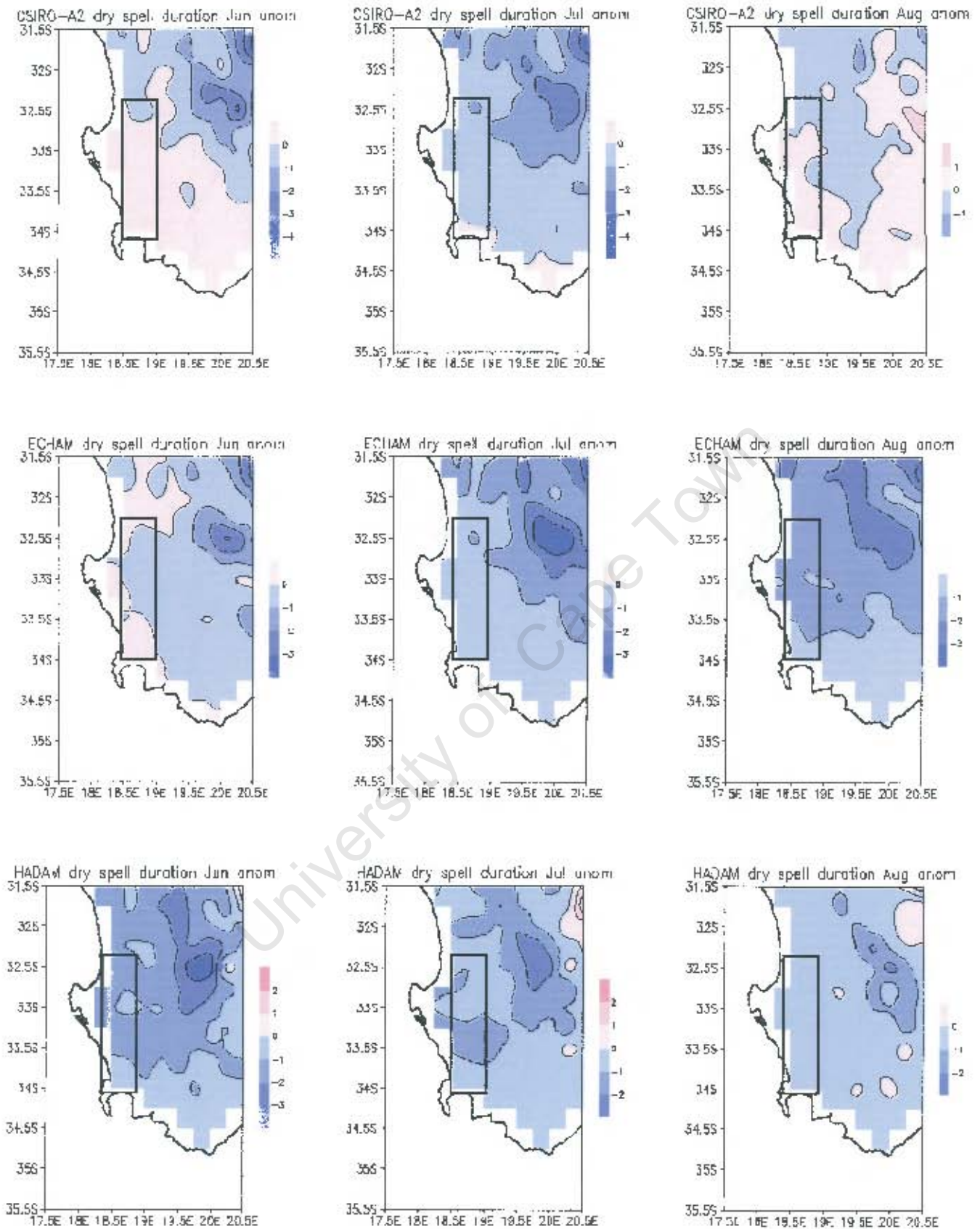


Figure 5.6: Anomaly of dry spell duration for the winter months for parts of the Western Cape Province, with the Swartland outlined in the block. These show good agreement between models that the winter season will remain moist, where red reflects drying and blue reflects more moist conditions.

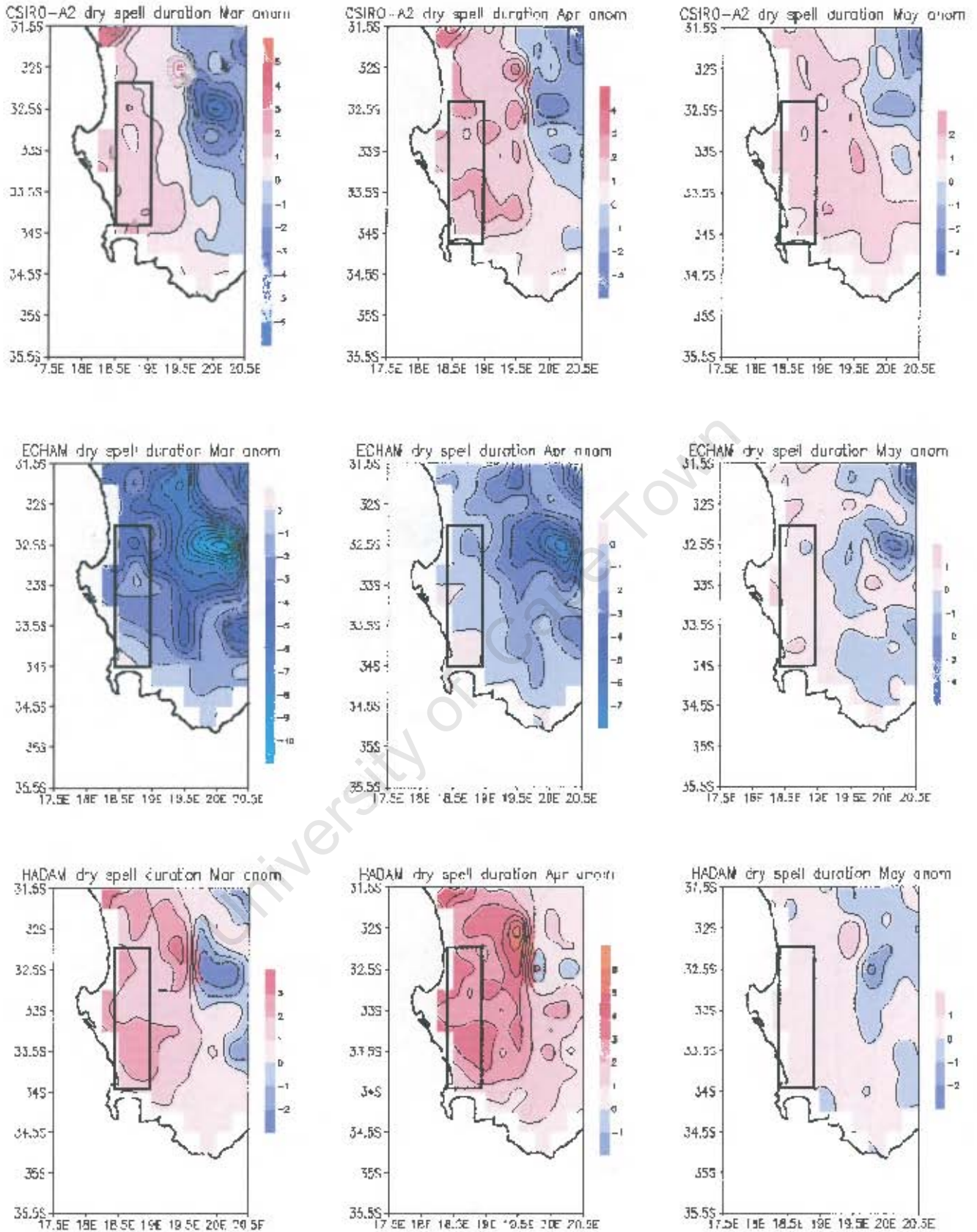


Figure 5.7: Anomaly of dry spell duration for autumn for parts of the Western Cape Province, with the Swartland outlined in the block. Autumn is clearly drying in the future, where red reflects drying and blue reflects more moist conditions.

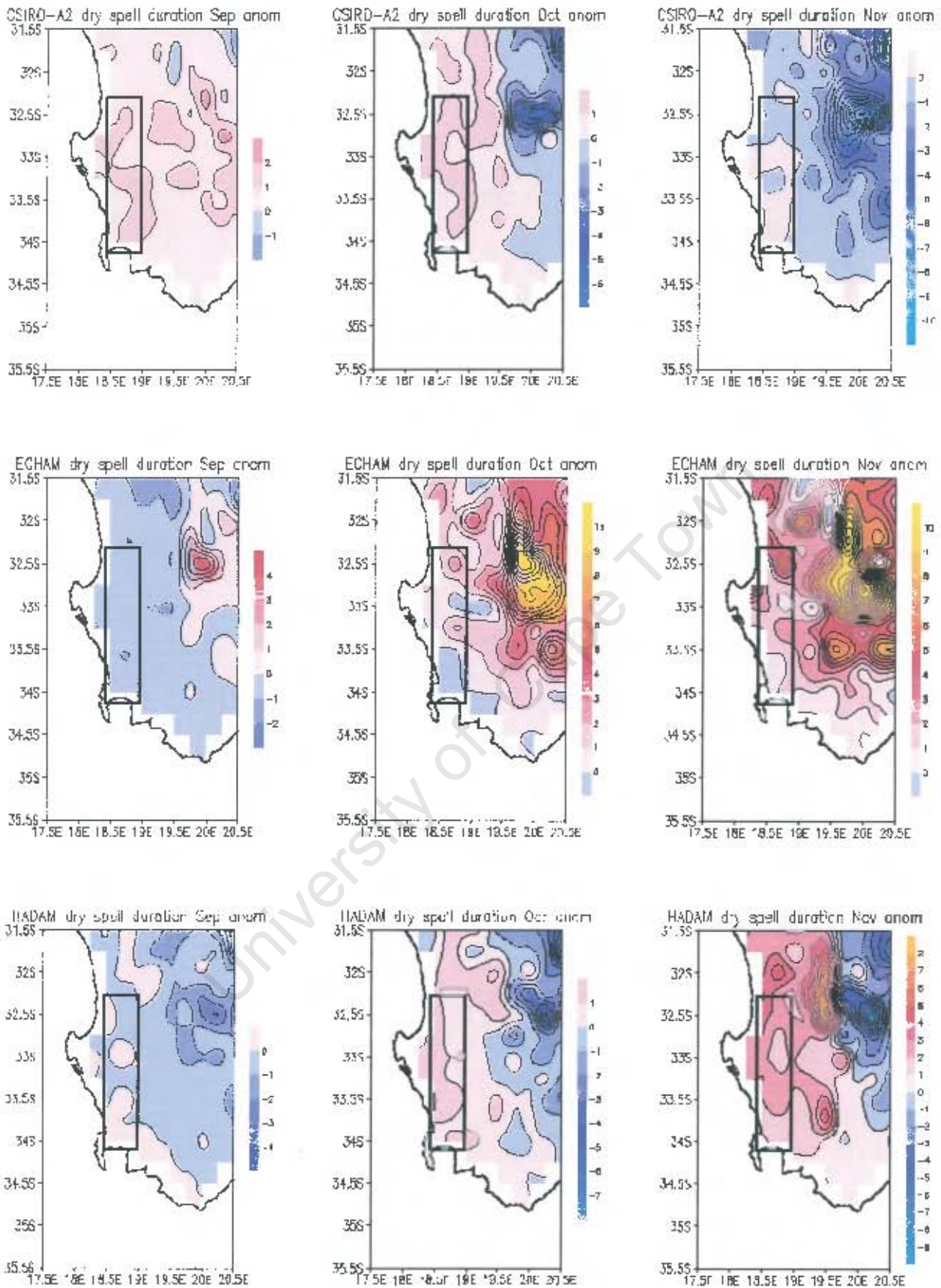


Figure 5.8: Anomaly of dry spell duration for the spring months for parts of the Western Cape Province, with the Swartland outlined in the black. These show good agreement between models that a drying will follow the winter rainfall, helping to possibly shortening the winter rainfall season, where red reflects drying and blue reflects more moist conditions.

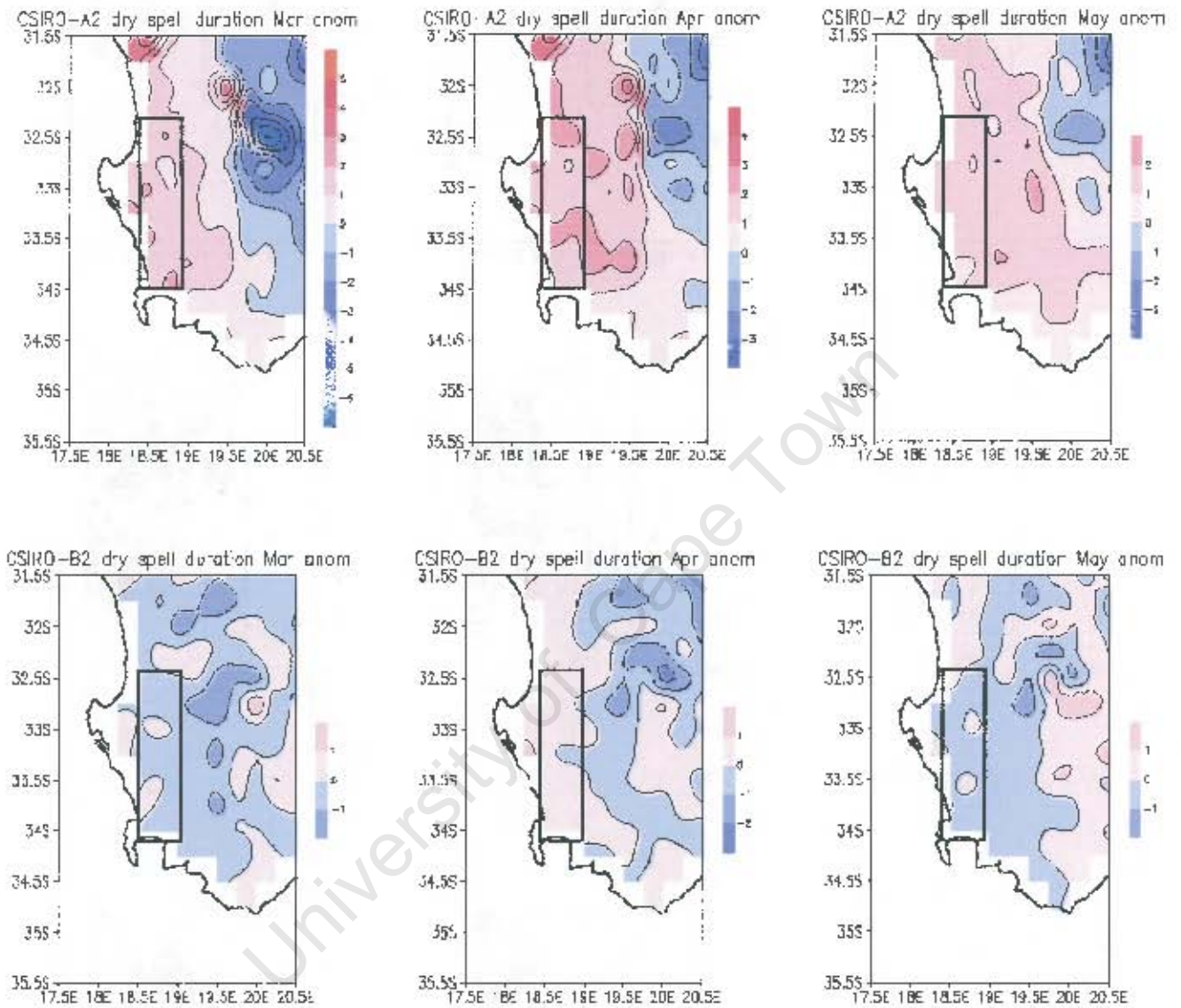


Figure 5.9. Anomaly of dry spell duration for autumn for parts of the Western Cape Province, with the Swartland outlined in the block. The CSIRO A2 vs. B2 reflects less future change in the B2 scenario, where red reflects drying and blue reflects more moist conditions.

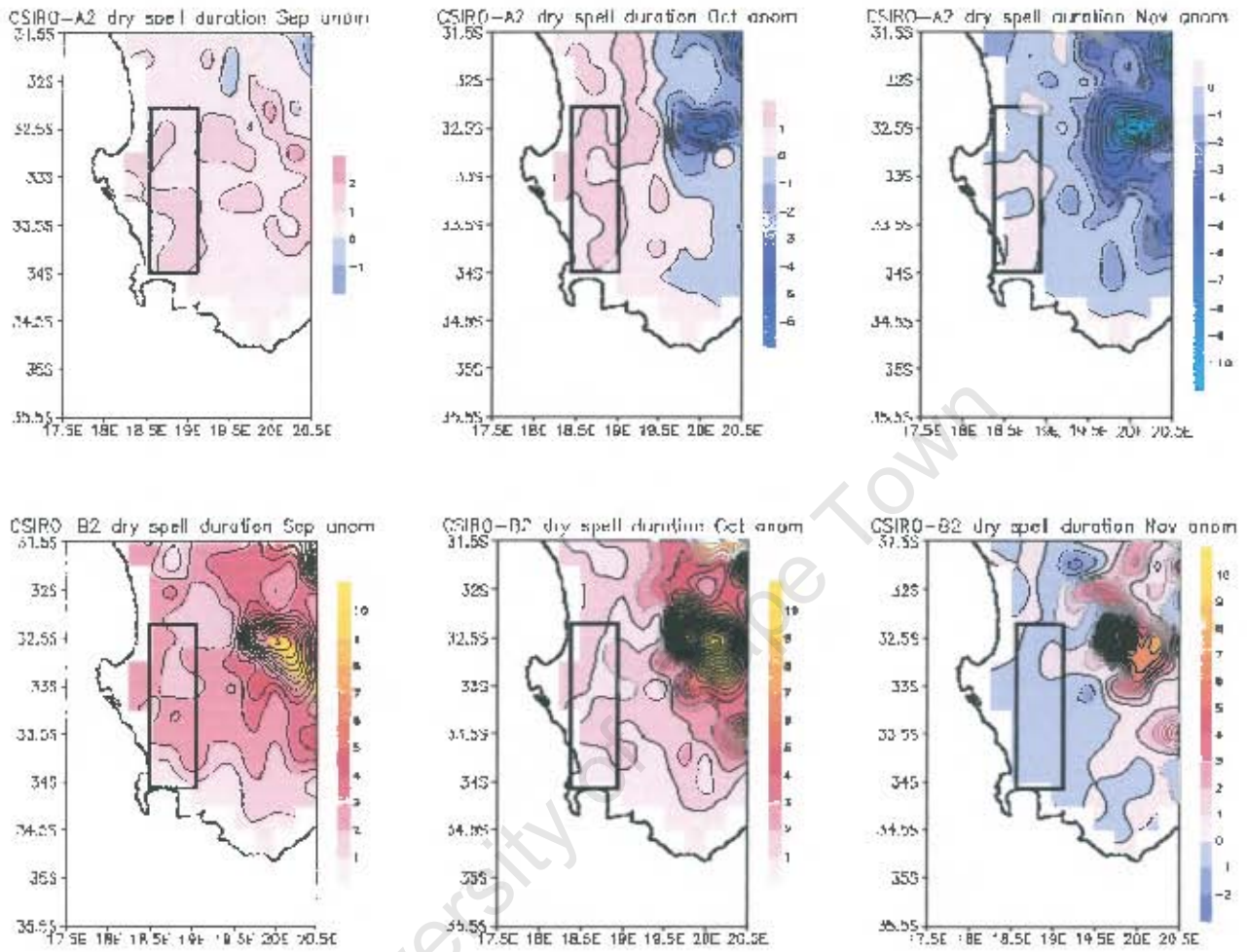


Figure 5.10: Anomaly of dry spell duration for the spring months for parts of the Western Cape Province, with the Swartland outlined in the block. These CSIRO A2 vs B2 scenarios show good agreement that a drying will follow the winter rainfall season, where red reflects drying and blue reflects more moist conditions.

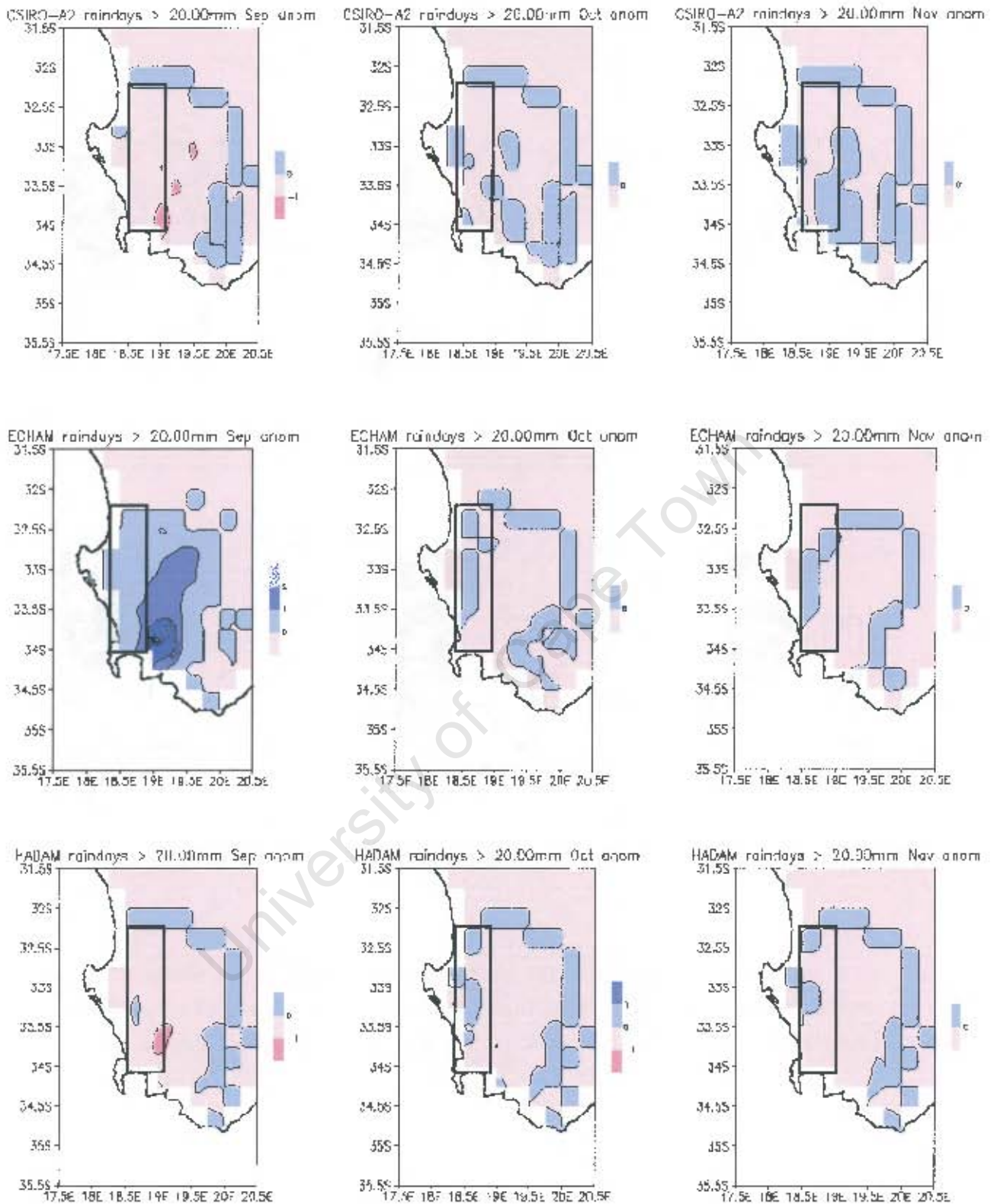


Figure 5.11: Anomaly of the number of rain days greater than 20.00mm for the spring months for parts of the Western Cape Province, with the Swartland outlined in the block. All the models reflect a definite decrease in heavier rainfall immediately after the winter rainfall events, where red reflects decreased and blue reflects increased heavier rainfall events.

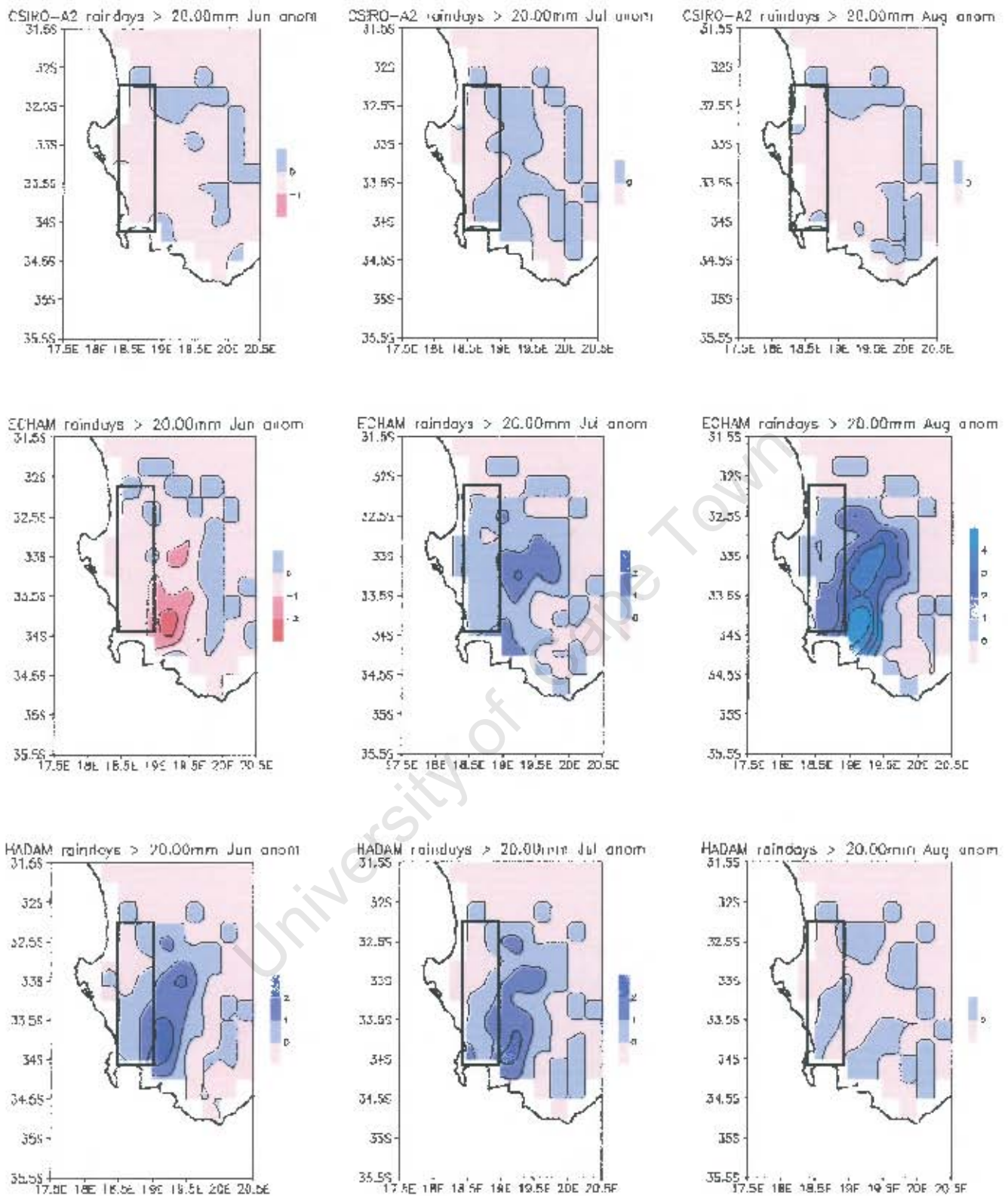


Figure 5.12: Anomaly of the number of rain days greater than 20.00mm for the winter months for parts of the Western Cape Province, with the Swartland outlined in the block. The models suggest an increase in heavier rainfall events in winter, where red reflects decreased and blue reflects increased heavier rainfall events.

#### 5.2.4 90<sup>th</sup> percentile

The 90<sup>th</sup> percentile of precipitation change for the Swartland was examined to determine the range of heavier rainfall/ greater drought in the future, from the size of the tail of the distribution. All the models simulated, including the CSIRO B2 scenario, agree with the results from the number of rain days greater than 20.00mm (section 5.2.3) and that of the dry spell duration (section 5.2.2). These show that there is a definite decrease in the precipitation prior to and following the winter rainfall season.

### 5.3 Summary of regionally downscaled results

Precipitation was examined in the context of regional downscaling, as results from GCMs are not well represented on a regional scale. The main features emerging from an examination of the four variables of total precipitation; dry spell duration; number of rain days greater than 20.00mm; and the 90<sup>th</sup> percentile are the following:

The winter rainfall which is the dominant feature of the region is still prominent in the future simulations, and possibly also of a slightly greater intensity than experienced currently. What is noticeable is the drying of the months prior to and proceeding the winter rainfall season. This drying may possibly result in the winter rainfall season becoming much shorter.

Future precipitation patterns also seem to indicate increased orographic rainfall occurring as many of the increases are situated over the Cape Fold Mountains to the east of the Swartland. A known decrease in intensity of frontal systems passing through during the winter months also causes less rainfall and more orographic precipitation. The decreased intensity of these fronts is thought to be due to their passage further south in the future than currently observed. It is necessary to note here that research shows ECHAM4 to simulate wetter conditions over the subcontinent of southern Africa (Hewitson and Crane, in press).

#### **5.4 Implications for the Swartland**

Future climate change, of any magnitude at any place, is of major concern both at a social and economic level. Climate change will affect everyone, with rapid climate change possibly jeopardising agriculture, forestry and biodiversity worldwide (Pimentel, 1993). These changes would have serious social repercussions, not least of all being food supply.

The Swartland is an agriculturally productive region, with little natural vegetation remaining for adaptation to future climate change (see *Chapter Three*). From this point of view it is necessary to examine what the future climate change impacts would have on such an agriculturally important region of South Africa. The next chapter deals with how climate change is likely to affect the Swartland, in terms of agricultural yield and land degradation –two important aspects of food production.

University of Cape Town

**CHAPTER SIX:**  
**SWARTLAND CLIMATE**  
**& SOILS INTO THE**  
**FUTURE**

## 6.1 *Future Swartland climate effects on land degradation*

“Land degradation in arid and semi-arid areas” has been defined by the South African Department of Environmental Affairs and Tourism as *desertification*, and “can contribute to climate change as well as be a result of climate change” (DEAT, 1998, p19). It is therefore important in a largely semi-arid South Africa to examine the effects of impending climate change. The problem with making reliable predictions of climate change is that they occur at different rates in different regions primarily due to a wide range of local environmental factors (Augustin, 2002). Thus, examining climate change effects on a regional basis has some merit for farmers in that region as they are more than likely to produce more reliable results if the methods used are proven robust for that region, than globally forecast climate changes.

Broadly speaking, climate change has major implications for land degradation in the Swartland. Historically, the region has proven highly susceptible to soil erosion, and with such a small amount of remaining natural vegetation (*Chapter Three*), there is little chance of adaptation to climate change occurring naturally. Hoffman and Todd (2000) showed that veld degradation in South Africa is generally higher in communal areas than commercial areas, although many commercial areas are subject to bush encroachment and alien plant invasions (Damp, pers comm.). Soil erosion however, seems to be a common concern in both communal and commercial farming regions.

Biophysical and climatic environmental factors are also crucial to consider for any examination of soil degradation (Hoffman and Todd, 2000). Regions with steeper slopes, higher annual temperatures and with more erodible soils possess higher soil degradation index values, as explained in detail in Hoffman and Todd (2000). The Swartland has been described earlier as being a region of undulating slopes, with highly erodible duplex soils (*Chapter Three*) and qualifies as a potential region of vulnerability to soil and land degradation.

Changes in vegetation cover and/or changes in climate lead to changes in the amount of overland flow runoff generated (Kirkby *et al.*, 1998). With climate

change and greenhouse gas emissions being recognised as realities, it is necessary to look at how agriculture may be impacted by changed weather conditions over a more long-term scale (Augustin, 2002). The next section deals with climate effects on agriculture, with specific reference to the Swartland region.

## **6.2 Future Swartland climate effects on agriculture**

South Africa is self-sufficient in food supply, except for periods of widespread drought, despite two-thirds of the country falling below the rainfall limit for reliable wheat and maize crops. At the end of the last century, it was estimated that a 10% increase in rainfall coupled with an increase in carbon dioxide would lead to a 10-20% increase in wheat and maize production, while a 10% decrease in rainfall would be approximately balanced by the rising carbon dioxide content of the atmosphere (DEAT, 1998).

These figures need to be understood in the context of wheat farming practised in the Swartland. This understanding is achieved with a review of wheat yields produced and the related climatic conditions experienced (*section 3.7*). Wheat crops in low-rainfall areas commonly fail to realise their yield potential because of low water-use efficiency (Sadras and Angus, 2005), where Mediterranean-type climatic regions generally fall into the category of "low-rainfall areas". This is a typical characteristic of dry environments and dry-land crop farming (Damp, pers comm.), as is common in the Swartland.

The timing of rainfall is a crucial determinant of grain yields and water-use efficiency, as it can impose agronomic and physiological constraints on the crop (Sadras and Angus, 2005). A late start to winter rainfall, as well as intermittent dry spells during the winter rainfall season result in reduced vegetative growth (Damp, pers comm.). Poor rainfall during late winter/early spring inhibits grain fill as September is the grain-filling stage in the life cycle of the wheat in the Swartland (Agenbach, pers comm.), and this causes the wheat to be of a lower quality grade.

The onset of rainfall determines sowing opportunities, which influence the season length and crop yield (Sadras and Angus, 2005). The average yield of wheat drops roughly 17kg/ha per day delay in sowing from mid-April (Sadras and Angus, 2005), thus a later start to the winter rainfall season would cost the farmer dearly. Currently the optimum planting time for wheat in the Swartland is in May (Agenbach, pers comm., 2003) therefore winter rains commencing later than May would have negative results to the overall wheat crop produced.

A severe water deficit during the critical growing stages of flowering, grain set and filling, would significantly reduce crop yield (Sadras and Angus, 2005). Rainfall around flowering time (mid-August to mid-September) is critical as plant development is particularly susceptible to environmental stresses at this time (Sadras and Angus, 2005). The years when the Swartland saw below average wheat yields correspond to the years with pronounced dry spells during the rainfall period of May to September (*Chapter Three*).

Other factors also affect wheat yield, some of which farmers can have a certain degree of control over. For example one of these factors is fertiliser inputs to the wheat crop, which results in an increase in the quality of grain due to the nitrogen content. At planting, 60-90% of nitrogen-rich fertiliser is applied, with roughly 30% around 30-60 days after planting (Agenbach, pers comm.). Soil evaporation, run-off and drainage serve no production benefit to the crop (Sadras and Angus, 2005), but can be detrimental to the crop when combined with the removal of applied fertilisers. Should heavy rainfall occur during this planting stage when fertiliser is applied, the fertiliser is washed off resulting in a decrease in the quality of the grain (Agenbach, pers comm.).

Heavy rainfall events, frequency and timing of dry spells, as well as the start and duration of winter rainfall all impact on the wheat crop grown in the Swartland. Wheat is, however, not the only component of farming affected by changing rainfall conditions. Soil erosion is also an important component of farming in the Swartland that cannot be ignored here. These climatic factors

directly affect wheat yield produced and soil erosion, and are thus important when considering future climate change.

*Chapter Two* considered some of the many soil erosion models available for examining erosion and land degradation. Basically, the type of soil erosion model used is dependent on the input factors known and output required. SLEMSA was concluded as an adequate soil erosion model to be used in this study as it has proven reliable for research in other parts of southern Africa, and has been successfully modified each time for the study areas in question. The next section deals with examining the probable impacts of future climate change on soil erosion in the Swartland using SLEMSA.

### **6.3 SLEMSA**

SLEMSA (Soil Loss EstiMator for Southern Africa) is an approach to estimating soil loss taking into account the consequences of various management decisions. The purpose of a soil loss estimator is to bring together all sources of information into a formal arrangement which represents the best advice available (Elwell, 1981; 1978). SLEMSA was designed for arable lands in regions of high intensity rainfall, and for a wide variety of cropping conditions (McKyes, 1989). The methodology used is described in more detail in *Chapter Two*. The key assumptions and results are, then, as follows:

#### **6.3.1 Key assumptions**

Some key assumptions were made in the utilisation of SLEMSA for the Swartland. The creation of SLEMSA was as a ready means of predicting erosion losses given a limited amount of time and expensive experimental data (Stocking, 1981). The following assumptions were based on the need for an indication of possible future climate change impacts on the region as a whole rather than per specific agricultural plot, so some generalisations were made. The constraints and caveats of using SLEMSA for the Swartland are discussed

in section 2.5.1, but further assumptions were made within the analysis, and are considered here:

Historical station data from 1970-1999 were used to calculate an average observed annual precipitation. This was calculated excluding stations with annual rainfall above 1000mm as these are assumed to be orographically induced and therefore not representative of the study region. The study region particularly includes the areas where farming activities are conducted, and these would not be in the upper mountainous regions experiencing the much greater rainfall at the eastern boundary of the Swartland.

The Swartland was classified as “non-guti”, as opposed to “guti” due to the fact that the stations with orographically induced rainfall were excluded, as mentioned above. “Guti” refers to those stations receiving significant amounts of orographic rainfall which tends to depress the proportion of high intensity rainfall received in a season (Stocking, 1981). Thus the “non-guti” graph was used, so as to exclude possible minor orographic influences on the region.

SLEMSA’s soil erodibility was not taken from an individual plot or site. The aims of this study are to examine a general impact of climate change on the Swartland as a whole area, and therefore taking one or two specific sites would have been assuming that the entire region was represented. For soil erodibility soil group, soil family, soil texture, land management factors and crop management are all taken into account. These were gauged from the literature review (*Chapter Three*) and selected to broadly represent the Swartland. This is necessary to note, as the results are then more generalised and should be examined in this light.

The soil correction factor was determined also using some key assumptions. They include the following:

- Average soil loss in the previous year needed to be calculated. This is highly dependent on the individual farm and the conditions thereof and thus needed to be generalised for the Swartland as a whole. Historically

the Swartland is a region susceptible to soil erosion, thus the value in the middle of the range was taken.

- Ridging practices were assumed to be normal tilth, with crops generally being on small ridges (<200mm). The Swartland consists of gently undulating hills with periodic granitic rocky outcrops. The slope is then taken as an angle of >2%, reflecting the undulating nature of the region (*Appendix D*).
- The planting direction of crops in the Swartland is generally as per the contours. This is presently standard practice in the Swartland, although it was not so until after the 1930s (Talbot, 1947). Even those farmers now planting grapes on the less favourable steeper slopes, are all opting for planting on the contours.
- Tillage is very dependent on the actual farmer's techniques, so for this study a generalisation had to be made. Tillage techniques of ploughing and rolling were assumed for this study, which are the techniques generally practiced in the Swartland.
- Fallows and leys are prime contributing factors of soil erosion if they are not vegetated. An index of how long these features have been vegetated for is considered in the model. From field trips to the Swartland, it is evident that any possible fallows and leys have been vegetated for more than the past three years. The farmers in the Swartland are generally very soil conservation conscious as stringent conservation laws have been inflicted on them in the past.
- The last assumption made for the soil correction factor is that all the crops are mechanically cultivated dry land crops. The wheat in the Swartland is almost entirely dry land cropping, with mechanical cultivation being the cultivation method favoured by farmers.

SLEMSA was originally designed for the summer rainfall region of Zimbabwe, where they are not known to plant winter wheat. Thus the table for calculating the rainfall energy interception proportion for various crops does not include winter wheat. As sorghum has also been grown successfully in the Swartland and produces roughly the same yield per hectare as winter wheat, it was

assumed that the emergence time after the start of the rainy season would be similar for the two crops. This would need to be validated in future research, but is adequate for the study of climate change being conducted here.

SLEMSA does make provision for evergreen orchard trees (except apples) and coffee plantations, which are not relevant for the Swartland but worth noting as this reflects its possible broader application for the southern African region.

A topography factor is another component to the soil loss model. This is once again very site specific, however a generalisation can be made to consider the Swartland, as it has a very uniform geomorphological appearance (*Chapter Three*). The topography factor assumed a standard field length and slope for the study, as once again it would not be practical to use one plot as being representative of the entire study region. The actual standards of 30m field length and 4.5% slope are recommended by McKyes (1989) when examining a region as opposed to a specific site.

General limitations of SLEMSA include the restriction of consideration of sheet erosion only and the fact that quantity and not quality of soil loss is predicted, however this is also a common limitation to other techniques (Stocking, 1981). SLEMSA is also crudely based on annual precipitation, not considering any other climatic variables such as dry spell duration or “extreme” precipitation events into account. This model, like any other, can therefore only be as good as the information upon which it is based. Soil erodibility values can be a major potential source of error, for example an error of one unit in the value of F will affect prediction greatly, yet the means for deriving F are relatively insensitive and liable to misinterpretation, having been designed originally for contour layout programmes and not soil loss estimation (Stocking, 1981).

SLEMSA as a whole manages to meet four basic criteria for the suitability of a soil loss estimation procedure, as set out by Stocking (1981) and include the following:

- SLEMSA is reasonably accurate. Both predicted and annual soil losses have been demonstrated to correspond closely;
- It has a certain degree of flexibility. As information becomes available, it can be incorporated into the design procedure;
- SLEMSA's method relies partially on physical processes such as rainfall penetrating canopy cover, rather than purely empirical techniques. This makes a certain degree of extrapolation possible;
- In comparison to the USLE, SLEMSA is a simple technique, therefore easy to apply and teach out in the field.

Taking these assumptions and previously mentioned constraints and caveats into consideration, the next section discusses the results found.

### 6.3.2 *Results*

This section takes into account the key assumptions mentioned above. Thus the results are exploratory and should be supported by further field measurements, applicable to the individual plots being analysed. They do however provide estimates from which to deduce how future climate change may be expected to impact on agriculture and soils in the Swartland as a region. This is achieved by calculating SLEMSA using current precipitation scenarios as well as projections of future climate change precipitation.

The SLEMSA model calculates mean annual soil loss in tons per hectare per year by using current mean annual precipitation. The impact of future climate change on mean annual soil loss in the Swartland is calculated through the use of projected future mean annual precipitation estimates taken from the three climate models used in the regional downscaling –namely ECHAM4, HadAM, and CSIRO. A brief comparison of mean annual soil loss under the SRES A2 and B2 emission scenarios, calculated using the CSIRO model, is also examined. The annual soil loss from both the current and projected future climate change scenarios are presented below:

Table 6.1 and Table 6.2 show the results for mean annual soil loss calculated in tons per hectare per year for the various modelling scenarios, under present-day and future precipitation respectively. The results also consider differing yields obtained, whose factors are more than just climate dependant. As the Swartland is generally a dryland irrigation area, i.e.: little to no irrigation is applied to crops planted as they rely entirely on precipitation, this study of climate change impacts on the crops and soils of the region is imperative.

Table 6.1: Mean annual soil loss, Z (t/ha/yr) as calculated from SLEMSA for the various downscaled *present-day precipitation* scenarios as compared to historical data.

	Yield (t/ha)	Emergence time after start of rainy season				
		-1 month	0	1 month	2 months	3 months
<b>Historical data</b>	1.0	0.90018	0.90018	1.260252	2.160432	4.5009
	2.0	0.630126	0.630126	0.720144	1.530306	3.60072
	6.0	0.540108	0.540108	0.45009	0.630126	2.070414
<b>ECHAM4</b>	1.0	0.40008	0.40008	0.560112	0.960192	2.0004
	2.0	0.280056	0.280056	0.320064	0.680136	1.60032
	6.0	0.240048	0.240048	0.20004	0.280056	0.920184
<b>HADAM</b>	1.0	0.40008	0.40008	0.560112	0.960192	2.0004
	2.0	0.280056	0.280056	0.320064	0.680136	1.60032
	6.0	0.240048	0.240048	0.20004	0.280056	0.920184
<b>CSIRO-A2</b>	1.0	0.30006	0.30006	0.420084	0.720144	1.5003
	2.0	0.210042	0.210042	0.240048	0.510102	1.20024
	6.0	0.180036	0.180036	0.15003	0.210042	0.690138
<b>CSIRO-B2</b>	1.0	0.30006	0.30006	0.420084	0.720144	1.5003
	2.0	0.210042	0.210042	0.240048	0.510102	1.20024
	6.0	0.180036	0.180036	0.15003	0.210042	0.690138

Table 6.2: Mean annual soil loss, Z (t/ha/yr) as calculated from SLEMSA for the various downscaled *future climate change precipitation scenarios*.

	Yield (t/ha)	Emergence time after start of rainy season				
		-1 month	0	1 month	2 months	3 months
<b>ECHAM4</b>	1.0	0.20004	0.20004	0.280056	0.480096	1.0002
	2.0	0.140028	0.140028	0.160032	0.340068	0.80016
	6.0	0.120024	0.120024	0.10002	0.140028	0.460092
<b>HADAM</b>	1.0	0.10002	0.10002	0.140028	0.240048	0.5001
	2.0	0.070014	0.070014	0.080016	0.170034	0.40008
	6.0	0.060012	0.060012	0.05001	0.070014	0.230046
<b>CSIRO- A2</b>	1.0	0.05001	0.05001	0.070014	0.120024	0.25005
	2.0	0.035007	0.035007	0.040008	0.085017	0.20004
	6.0	0.030006	0.030006	0.025005	0.035007	0.115023
<b>CSIRO- B2</b>	1.0	0.05001	0.05001	0.070014	0.120024	0.25005
	2.0	0.035007	0.035007	0.040008	0.085017	0.20004
	6.0	0.030006	0.030006	0.025005	0.035007	0.115023

Initially the results show that with an increased yield (t/ha) there is a decrease in soil loss. This is expected as the increased crop size would retain more soil, and so less soil would be lost to soil erosion. The emergence time of the crop after the start of the rainy season is also important. The later the crop emerges after the rainy season starts, the less vegetation there is available to prevent the soil from erosion. Therefore the greatest erosion takes place with the lowest yield and the latest emergence time after the start of the rainy season. It was interesting to note that when the crops emerge prior to the rainy season, the soil erosion is the same as if they emerged at the start of the rainy season. This indicates the effects of sheet wash considered by the model.

Examining the present day precipitation as produced from the models, against the historical data, one notices that the models grossly underestimate the mean annual soil loss. This issue has been addressed in *Chapter Two* and *Chapter Five* where the direction of change is stressed as the indication of the result and not the magnitude of change when considering future climate change scenarios. Thus the results are obtained from an increase/decrease in mean annual soil loss when the models are compared to each other, i.e.: anomaly of future minus present scenarios (Table 6.3).

Table 6.3: Anomaly of mean annual soil loss, Z (t/ha/yr) as calculated from SLEMSA for the various downscaled *future vs. present climate precipitation scenarios*.

	Yield (t/ha)	Emergence time after start of rainy season				
		-1 month	0	1 month	2 months	3 months
<b>ECHAM4</b>	1.0	-0.20004	-0.20004	-0.280056	-0.480096	-1.0002
	2.0	-0.140028	-0.140028	-0.160032	-0.340068	-0.80016
	6.0	-0.120024	-0.120024	-0.10002	-0.140028	-0.460092
<b>HADAM</b>	1.0	-0.30006	-0.30006	-0.420084	-0.720144	-1.5003
	2.0	-0.210042	-0.210042	-0.240048	-0.510102	-1.20024
	6.0	-0.180036	-0.180036	-0.15003	-0.210042	-0.690138
<b>CSIRO-A2</b>	1.0	-0.25005	-0.25005	-0.35007	-0.60012	-1.25025
	2.0	-0.175035	-0.175035	-0.20004	-0.425085	-1.0002
	6.0	-0.15003	-0.15003	-0.125025	-0.175035	-0.575115
<b>CSIRO-B2</b>	1.0	-0.25005	-0.25005	-0.35007	-0.60012	-1.25025
	2.0	-0.175035	-0.175035	-0.20004	-0.425085	-1.0002
	6.0	-0.15003	-0.15003	-0.125025	-0.175035	-0.575115

Most noticeable from the results of climate change scenarios of the future applied directly to SLEMSA is that the impacts will possibly have very little negative effect on the region as a whole when considering annual soil loss. All the models predict that there would actually be a decrease in soil erosion,

along with the decrease in future precipitation, if current agricultural practices being conducted are maintained. This is thought to be highly unlikely with the presence of duplex, highly erodible soils and increasing heavier rainfall events in many parts of the Swartland. Further examination with the characteristics of the Swartland and historical soil erosion reputation in mind, has resulted in the need to modify SLEMSA to be more applicable to the Swartland region.

### 6.3.3 SLEMSA modified

It is evident that SLEMSA relies on the basic assumption that any decrease in precipitation would naturally lead to a decrease in soil erosion. The model implies that a lower mean annual precipitation would have fewer high intensity rainfall events, and therefore lower rainfall energy to erode away the soil. This possibly stems from the model being originally designed for regions of high intensity rainfall (McKyes, 1989) and simulating rather simplistic scenarios for easy application in the field.

The Swartland experiences a Mediterranean-type climate and does not receive the high intensity rainfall that would be experienced in places like Zimbabwe and other summer rainfall regions. Thus factors other than rainfall intensity need to be examined, especially where the predictions for the Swartland include possible increases in heavier rainfall events in some parts, accompanied by a shorter rainfall season and more dry spells of longer duration (*Chapter Five*). These climatic factors would result in increased soil erosion in any Mediterranean-type terrain, as a shorter rainfall season would mean that the ground would be exposed to increased desiccation and the other elements of erosion for a longer period of time. Any increases in overland flow as a result of increased dry spell duration would also lead to increased sediment transport, producing greater erosion upslope and greater deposition at sites further downslope (Kirkby *et al.*, 1998), as is seen in Figure 6.4.



Figure 6.4: A typical slope being farmed in the Swartland shows the difficulties the area experiences with soil erosion, even with erosion controls in place.

In order to apply SLEMSA to the Swartland, the downscaled precipitation variables examined in *Chapter Five* need to be re-considered. These include not only total precipitation, as addressed by SLEMSA, but also mean number of rain days greater than 20mm and mean dry spell duration. The long-term 30-year average of the mean of these two variables was examined for the Swartland as a region (between 32°S and 34°S and 18°E and 19.5°E). It was noted that for the average number of rain days greater than 20mm there was little future change predicted over the entire region. There was however a significant difference in dry spell duration for the region as a whole when examining future climate change (see Table 6.4).

Table 6.4: Long-term 30 year time average mean of dry spell duration taken from the regionally downscaled climate data.

Model	Present	Future	Ratio of change
ECHAM4	4.18187	6.23249	1.49
HADAM	3.51649	5.31189	1.51
CSIRO-A2	3.34007	4.34561	1.30
CSIRO-B2	3.34806	3.13675	0.94

The ratio of change between the future and present results of mean annual dry spell duration (Table 6.4) were then factored by the annual future precipitation as was originally input into the model (see Table 2.2). This resulted in an increase in the estimate of "annual precipitation" as was the original variable required in the model.

Future climate change projects that precipitation will occur in roughly the same quantity, but over a shorter period of time (*Chapter Five*). When considering the increase in dry spell duration over this same period, these two factors equate to an increase in precipitation per unit time, when examined over the winter rainfall season. If this increase per unit time were taken into account evenly across the year, there would be a net increase in precipitation and therefore a definite increase in the erosion impact on the landscape. These results called factor "A" (Table 6.5) were then used to determine the rainfall energy ( $E_A$ ) from SLEMSA once again (*Chapter Two*), being more representative of the possible future climatic conditions.

Table 6.5: Mean annual precipitation as calculated from historical station data, and regionally downscaled data for the Swartland (latitude 32°-34°S and longitude 18°-19.5°E), with future precipitation adjusted for dry spell duration (A).

	Present day (mm/yr)	A (mm/yr)
Historical station data	461.5033	
ECHAM4	333.886	468.407
HADAM	332.499	453.889
CSIRO-A2	319.185	351.105
CSIRO-B2	319.197	260.975

Once SLEMSA was re-examined with the adjustments made for rainfall energy, the results found became quite different. Table 6.6 shows the mean annual soil loss as re-calculated using the new factor "A" representing the future precipitation multiplied by the ratio of change between the dry spell duration of future vs. present. Table 6.7 then shows the anomaly of the future (adjusted for factor A) vs the present to gain an idea what effect future climate change will have on soil loss in the Swartland, also graphically represented in Figure 6.5.

Table 6.6: Mean annual soil loss,  $Z$  (t/ha/yr) as calculated from SLEMSA for the various downscaled *future climate precipitation* scenarios, adjusted for increased dry spell duration (A).

	Yield (t/ha)	Emergence time after start of rainy season				
		-1 month	0	1 month	2 months	3 months
ECHAM4	1.0	1.20024	1.20024	1.680336	2.880576	6.0012
	2.0	0.840168	0.840168	0.960192	2.040408	4.80096
	6.0	0.720144	0.720144	0.60012	0.840168	2.760552
HADAM	1.0	1.0002	1.0002	1.40028	2.40048	5.001
	2.0	0.70014	0.70014	0.80016	1.70034	4.0008
	6.0	0.60012	0.60012	0.5001	0.70014	2.30046
CSIRO-A2	1.0	0.5001	0.5001	0.70014	1.20024	2.5005
	2.0	0.35007	0.35007	0.40008	0.85017	2.0004
	6.0	0.30006	0.30006	0.25005	0.35007	1.15023
CSIRO-B2	1.0	0	0	0	0	0
	2.0	0	0	0	0	0
	6.0	0	0	0	0	0

The results from Table 6.7 show that all the SRES A2 emission scenarios predict an increase in soil erosion in the Swartland under future climate change scenarios. These scenarios reflected increase dry spell duration during the winter rainfall season, increased temperatures and a shortened winter rainfall period but with roughly the same overall amount of precipitation. By adjusting SLEMSA to approximate these future precipitation scenarios which are reflected from downscaling the models, there is a clear indication that current farming practises will not be sustainable in the future: soil erosion is likely to increase as the climate changes.

An interesting result was that there is no difference in annual soil losses predicted by the CSIRO SRES B2 emission scenarios for future climate

change. This is possibly due to the small changes in soil loss predicted generally and that the B2 emission scenarios produce less extreme climate changes for this particular region than originally thought.

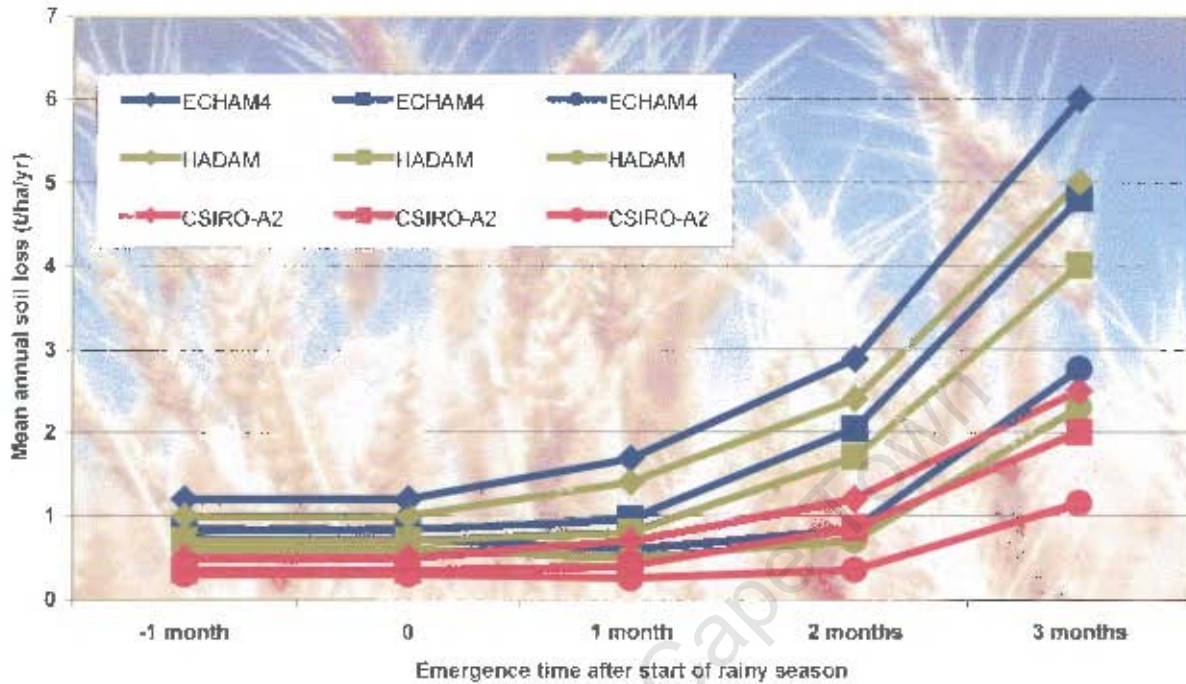


Figure 6.5. Mean annual soil loss (t/ha/yr) as calculated from SLEMSA under *future climate precipitation scenarios*, adjusted for increased dry spell duration (A). Diamonds represent a yield of 1 t/ha, and squares and circles 2 t/ha and 6 t/ha respectively.

As mentioned previously with the initial SLEMSA results, an increased yield (t/ha) equates to less soil being lost to soil erosion. The emergence time of the crop after the start of the rainy season, shows that the later the crop emerges after the rainy season starts, the less vegetation there is available to prevent the soil from erosion. The greatest erosion therefore takes place with the lowest yield and the latest emergence time after the start of the rainy season. SLEMSA, when modified to more realistically reflect the impact of future climate change by incorporating dry spell duration, also shows that when the crops emerge prior to the rainy season, the soil erosion is the same as if they emerged at the start of the rainy season.

Table 6.7: Anomaly of mean annual soil loss,  $Z$  (t/ha/yr) as calculated from SLEMSA for the various downscaled *future vs. present-day precipitation* scenarios, adjusted for increased dry spell duration (A).

	Yield (t/ha)	Emergence time after start of rainy season				
		-1 month	0	1 month	2 months	3 months
ECHAM4	1.0	0.80016	0.80016	1.120224	1.920384	4.0008
	2.0	0.560112	0.560112	0.640128	1.360272	3.20064
	6.0	0.480096	0.480096	0.40008	0.560112	1.840368
HADAM	1.0	0.60012	0.60012	0.840168	1.440288	3.0006
	2.0	0.420084	0.420084	0.480096	1.020204	2.40048
	6.0	0.360072	0.360072	0.30006	0.420084	1.380276
CSIRO-A2	1.0	0.20004	0.20004	0.280056	0.480096	1.0002
	2.0	0.140028	0.140028	0.160032	0.340068	0.80016
	6.0	0.120024	0.120024	0.10002	0.140028	0.460092
CSIRO-B2	1.0	-0.30006	-0.30006	-0.420084	-0.720144	-1.5003
	2.0	-0.210042	-0.210042	-0.240048	-0.510102	-1.20024
	6.0	-0.180036	-0.180036	-0.15003	-0.210042	-0.690138

The results from the modified SLEMSA are therefore plausible and conform to logic as applied to the particular characteristics of the study area and the projected future climate change. Increasing overall temperatures will result in reduced available soil moisture due to evaporation. This, combined with increased dry spell events over the region and with the same amount of precipitation occurring over a shorter period of time, will certainly increase the chances of soil erosion in the future, even where parts of the region are possibly not currently experiencing soil erosion due to sufficient management techniques. Hence it is advisable for farmers to be prepared to adjust their farming practices with the projected changing climate.

Climate change research is a continuing, evolving field that is constantly being updated and modified to achieve better, more accurate results. *Chapter Seven* then concludes this study with a summary of all the results found and suggestions towards further research.

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***CHAPTER SEVEN:  
SUMMARY &  
CONCLUSIONS***

University of Cape Town

## 7.1 Overview

In response to the critical need to better understand our changing climate, the aim of this study was to investigate how potential future climatic changes may affect geomorphic processes in the Swartland. The thesis applied a focus in particular to soil erosion and other processes related to the degradation of agricultural land that result since the Swartland is an important part of the agricultural sector of the South African economy.

There are just two main possible options in response to climate change and its consequences, *viz.* mitigation and adaptation (Parry and Carter, 1998). Scientists say that "...major investment is needed now to mitigate the threat" of climate change which is a lot "more serious" than it was supposed to be just four years ago (Jones, 2005, p563). A basic distinction is drawn between responses to climate change that are automatic or built-in societal responses, and responses that require deliberate decisions, described as adaptation strategies (Parry and Carter, 1998). In order to adapt or mitigate, it is essential to assess what the future potentially holds concerning climate change to be able to prepare for an adequate response.

It is accordingly essential to gain an understanding of future climate change and what it means regionally rather than just at a generalised global scale. Regional climate change is particularly appropriate when conducting impact studies (Kurukulasuriya and Rosenthal, 2003; Easterling *et al.*, 2001). Initially, this study considered future climate projections from Global Climate Model output, and then examined from the perspective of regionally downscaled projections, particularly regarding precipitation.

In order to analyse the effect of potential future climate change on soil erosion and land degradation, an analysis of past and present soil erosion and climate patterns was made in this thesis. These patterns were then combined using a soil loss model in order to evaluate how the projected climate change would

impact on the agriculturally important region of the Swartland. The soil erosion predictions were then analysed with respect to current farming practices. The following section presents a summary and synthesis of the results obtained against the initial objectives, followed by a discussion of the constraints and caveats faced in conducting this research. The chapter then concludes with recommendations for further research.

## **7.2 Summary and synthesis of results**

Since there is always some scientific uncertainty attached to future climate change projections, it may be useful to express possible changes in terms of the probability of their occurrence (Parry and Carter, 1998). The results of this study deal with a subset of climate change possibilities which may occur in the Swartland, and that need to be considered when planning for future climate change. The various possibilities that could occur are more important than comparing the actual magnitude of change, which is reliant on different scenarios chosen to represent climate change. Therefore the main indicator when examining climate change is the direction of the suggested change, not the magnitude. This section deals with a summary of the results presented in the previous chapters.

### **7.2.1 GCM future climate projections**

All six of the GCMs examined concur around the likelihood of increased future temperature for the Swartland region. They show that, on a monthly basis, each month will experience higher mean temperatures than are currently experienced. The SRES A2 emission scenarios provided more extreme predictions than those of the SRES B2 emission scenarios, revealing two possible evolutionary paths for future temperature change over the Swartland.

Future predictions based on outputs using both the SRES A2 and B2 emission scenarios suggest a general decrease in wind speeds during the summer months. The winter months, however, appear to reflect a possible increase in

wind speeds for both scenarios. This increased wind speed during winter could affect soil erosion if rainfall occurred later in the season than normal, or decreases in precipitation occurred in conjunction with increased wind speed, as the fields would be bare with the farmers having planted their crops at the start of the winter season. Certainly the Sandveld, to the west of the Swartland, is susceptible to wind erosion (Talbot, 1947) and this may include the western, or more coastal, parts of the Swartland where soils are distinctively sandier.

Future precipitation changes from the SRES A2 emission scenarios are shown to simulate more rainfall during the summer months than is currently experienced. On the other hand, winter rainfall is seen to decline in relation to current values, although the region should still receive its dominantly winter rainfall pattern, as reflected by all the GCMs. Outputs of the SRES B2 emission scenarios indicate a decrease in monthly precipitation for the entire year. This placed NCEP as the observed data, well within the envelope of change between the A2 and B2 scenarios, thus needing a more accurate future precipitation signal, as discussed in *Chapter Four*.

The projected future climate change signal is expected to reflect a range of change above or below the observed climate signal. It is an important result that the observed precipitation falls within the range of predicted GCM precipitation changes from the SRES A2 and B2 emission scenarios. This result therefore does not confidently claim a future increase or decrease in precipitation and therefore it becomes necessary to explore more refined regional precipitation outputs instead. The refining in this case took the place of the regional downscaled scenarios for projected future precipitation over the Swartland.

### 7.2.2 Regionally downscaled future climate projections

It was decided to focus on precipitation as the only variable examined using the regional downscaling method, since the GCMs currently reflect temperature

acceptably well over the Swartland, with all models being within a range of 3°C. Precipitation changes are much more localised and at a finer spatial scale than temperature changes and therefore need to be examined at a higher resolution. The regional downscaling proved to be much more appropriate to the regional study, reproducing observed precipitation patterns well over the area; for instance orographic rainfall features could even be identified.

The resolution of the downscaled precipitation models was much higher over the study region and revealed a greater inter-model consensus and replication of the control climate than the raw GCM outputs. This was particularly evident from the presence of a distinct north-south gradient in precipitation identified within the study region from the downscaled precipitation. Orographic influences on precipitation were simulated to the east of the study area from the downscaled precipitation, as further justification for greater accuracy of the downscaled results. These features were not evident from the raw GCM data where the entire study area fell into one grid cell. The ability to simulate these local features provides confidence that the regional downscaled scenarios are much better than the GCM scenarios for precipitation in this particular regional study.

The most marked changes in monthly and, particularly seasonal precipitation from the regionally downscaled scenarios are reflected in the autumn (MAM) and spring (SON) months. These seasons tend to show overall decreased precipitation totals, as well as increased dry spell durations and a decrease in heavier rainfall events for the region. Winter (JJA) reflects slight increases in future total precipitation, linked with a decrease in dry spell duration, thus the rainfall season in the Swartland is predicted to get shorter and possibly more intense in future for both SRES A2 and B2 scenarios.

The SRES B2 emission scenarios from CSIRO suggests more intense drying in spring, with relatively small changes in the frequency of heavier rainfall events (i.e.: greater than 20mm) when compared to CSIRO's SRES A2 emission scenario for dry spell duration and precipitation greater than 20mm

respectively. This increase in dry spell events, with little change in total precipitation in spring, suggests an intensified drying period leading into the dry summer season. Since climate changes of this sort can have serious repercussions for agricultural productivity in the Swartland, their implications were examined with respect to soil erosion.

### 7.2.3 *Future climate projections and soils*

SLEMSA (Soil Loss EstiMator for Southern Africa) when utilised with regionally downscaled model outputs proved to be overly simplistic as a predictor of the future soil erosion situation in the Swartland. The initial result obtained indicated that future decreased precipitation meant reduced soil erosion susceptibility for the region. But given the complexity of climate change, particularly in relation to precipitation, where increased dry spell duration and frequency coupled with more extreme individual precipitation events could accelerate soil erosion, SLEMSA's initial findings needed to be questioned. SLEMSA was thus modified in order to attain a more appropriate judgment of future climate change impacts in this region, where soil erosion could increase if rainfall was less but distributed differently with respect to timing. The adjustment considered the projections of increased future temperatures in the region, coupled with an increase in dry spell duration, and a shortened winter rainfall season.

SLEMSA considers the physical systems of crop, climate, soil and topography. These systems are integrated to make up three main submodels: crop ratio (C); soil loss from bare soil (K); and a topographic ratio (X) (Figure 2.1). The climate system combines with the soil system to produce the K submodel. Rainfall energy is compared to soil erodibility to establish a value for K which is applied to the main model to gain an understanding of soil loss from cropland. This is the key part of the model that required adjustment to become more representative of conditions in the Swartland. Merely using rainfall energy (correlated simply with rainfall amount) as the main climate input to the model

misses the point that that dry spell duration combined with rainfall energy has a significant impact on the soil erodibility of the region.

The modified SLEMSA was then examined in conjunction with CSIRO, ECHAM4 and HadAM SRES A2 emission scenarios, as well as the CSIRO SRES B2 emission scenario to project future soil erosion. The modelled results were all in agreement and demonstrated that decreased precipitation, coupled with the climatic adjustments mentioned above, would lead to increased soil erosion if farming continued using the current practices and methods being employed. This resolution of the modified SLEMSA is only a very basic assumption and further research would need to be conducted to employ the use of SLEMSA in this region with greater accuracy. However there is reasonable credibility behind results using a modified SLEMSA and the method is therefore worth consideration by farmers and other affected parties in the region when planning for the future.

### **7.3 Constraints and caveats**

The more significant constraints and caveats found in this study are concerned with two main areas, that of GCMs and their application to regional studies, and SLEMSA and its application to a particular region other than where it was designed. The following section further explores these issues and provides suggestions as to how they may be overcome:

#### **7.3.1 Climate modelling**

The changing climate, and the particular vulnerability and dependence of South African society to the variable nature of the climate system, make it imperative that suitable tools are available for process-based research on the climate system. For the most part this implies the need for computationally intensive climate modelling. The primary constraint in this regard within southern Africa has been limited computing resources, and too few model-literate researchers

(Hewitson, 2001b). Many international funding organisations, i.e.: START<sup>1</sup>; USAID<sup>2</sup>; IRI<sup>3</sup>; DEFRA<sup>4</sup>; WWF<sup>5</sup>, currently support climate change research, and modelling in Africa, which may help rectify the problem of a lack of skilled modellers and assist in furthering climate change impact studies over time.

GCMs have been shown to capture large-scale features accurately, but have difficulty capturing smaller scale features. GCMs also cannot take into account all the processes effective in the climate system, as modelling then becomes too computationally intensive. For example, processes such as plant physiology, ocean processes, land-use changes, and biospheric responses to climate change add complexity not normally accounted for in generally available GCM simulations (Mearns *et al.*, 2003; Gitay *et al.*, 2002; Hewitson, 2001b).

Simulation of precipitation by GCMs is a major limitation when assessing climate scenarios on a regional scale from raw GCM output. In order to compensate for the low resolution of GCMs on a regional basis, this study examines a method for downscaling GCM output. The downscaled regional precipitation seems most satisfactory for the study region when compared to the raw GCM output. This was proven by the regionally downscaled precipitation being able to accurately identify localised features which were not evident from the GCM output.

Regional downscaling is seen to form an effective means of interpreting the local and regional consequences of large-scale processes at work in the climate system. Downscaling particularly assists with providing a mechanism for assessing changes in regional climate at scales more beneficial to society than those provided by GCMs. However, further validation studies of the control scenarios need to be made before any type of *magnitude* of change can be examined regarding future climate change. There is confidence in this

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<sup>1</sup> Global Change System for Analysis, Research and Training (<http://www.start.org>)

<sup>2</sup> U.S. Agency for International Development (<http://www.usaid.gov>)

<sup>3</sup> International Research Institute for Climate Prediction (<http://iri.columbia.edu/>)

<sup>4</sup> U.K. Department for Environment, Food and Rural Affairs (<http://www.defra.gov.uk>)

<sup>5</sup> World Wildlife Fund for nature ([http://www.panda.org/about\\_wwf/what\\_we\\_do/climate\\_change/index.cfm](http://www.panda.org/about_wwf/what_we_do/climate_change/index.cfm))

technique for credible regional application as far as direction of change is concerned (Hewitson and Crane, in press) and within the limits of the skill shown by the GCM.

### 7.3.2 SLEMSA

The soil loss estimator for southern Africa (SLEMSA) proved from the literature to be the most suitable soil erosion model to apply to this particular regional study. However it was applied in its simplest form and as with previous studies using the model, some modifications needed to be made in order to apply it directly to the Swartland.

With a thorough understanding of the workings of the model, however, there is reason to believe that reasonable and appropriate modifications can be made to SLEMSA to accurately predict soil loss in the Swartland under changed rainfall conditions. Many other studies in southern Africa have successfully modified SLEMSA to enable it to be more applicable to the relevant study region in which it is applied (Igwe *et al.*, 1999; Mughogho, 1998; Hudson, 1987). Thus it is with a fair degree of confidence that the modifications done to SLEMSA for use in the Swartland are defensible in terms of the understanding of the physical processes underpinning the change, and have therefore produced constructive results.

As SLEMSA is a relatively simple model, it cannot take into account all the complex interactions involved in the soil erosion process (Elwell, 1981). For example, gully erosion is hardly incorporated into soil erosion models (Jetten *et al.*, 1999) and often erosion is considered to occur equally across the whole landscape (Evans and Brazier, 2005). Hence SLEMSA is used here merely as a guide and indicator of possible future soil erosion scenarios. The results shown from SLEMSA in this study are basic and need to be accepted in that light, as it would be necessary to conduct field trials and calculations relating to particular sites within the Swartland in order to further validate the use of a modified SLEMSA for the region. Researchers involved in erosion modelling

have generally found that results need to incorporate field-based assessments to better aid soil erosion predictions (Jetten, *et al.*, 1999; Gobin *et al.*, 2004). This is beyond the scope of this PhD thesis.

However the conclusions drawn relating to soil erosion and the projected climate changes modelled in the study, all comprehensively concur on the point that soil erosion is likely to increase with future climate change, particularly where farmers remain using their current farming practices.

In order to fully understand soil erosion and its impacts on an agriculturally important area such as the Swartland, policy makers need to have good quality information on which to base their decisions (Evans and Brazier, 2005). An area already affected by erosion, or affected in the recent past as the Swartland has been, can be a key indicator for future soil erosion (Jones *et al.*, 2004). Hence the reason the Swartland was chosen for such a study.

Adaptations will certainly be possible to reverse this projected scenario by applying further soil conservation techniques or other forms of land use management. Applying conservation techniques to combat soil erosion has major global benefits, being beneficial to conservation of biodiversity; control of climate change impacts; as well as the prevention of land degradation all being achieved simultaneously (Gisladdottir and Stocking, 2005).

#### **7.4 Recommendations and future research in this area**

Other types of farming, such as stock and game farming, are relatively more adaptable to climate change than crop farming (Hattingh, 1990). One option for crop farmers, which needs further research into its viability, is genetically modifying crops to cope with projected climate changes and then the correct crop cultivar planted at the start of the season for a successful yield. This includes being forewarned as to what the climate holds in the future for the farming region, so that the correct cultivar choices can be made. Currently many debates exist as to the moral grounds of genetically modifying crops and

their resultant nutritional value (Mills, 2005; Williams, 2005; Gaskell, 2004; Vogel, 2004). Hence much research is necessary into the field of climate change impacts directly on various existing crop cultivars, at least until the genetically modified crops are at acceptable standards, in order to prepare for farming under a future climate.

There is also scope for further research into the potential for future climate changes affecting soil erosion. Future climate projections are much in their infancy as far as regional studies go, particularly in southern Africa. There is scope for further regional climate change research and its projected impacts. Giles' (2005) research on aerosols shows simulations of Earth's climate at 2050 to suggest that "...negative effects of increasing ozone will outweigh any possible benefits triggered by warming" (Giles, 2005, p7), this is if farmers fail to consider methods of adaptation to deal with the changing environmental conditions. Urban pollutants are expected to increase levels of near-surface ozone by at least 25%, causing crop yields to drop by up to 10% around the year 2050 (Giles, 2005).

Farmers face not only a changing climate, but must also examine the impacts of these projected changes on their environment against rapidly changing socio-economic and political backgrounds. In this study a crudely modified SLEMSA shows that soil erosion is likely to increase under all the simulated scenarios of projected climate change. In order to completely verify this result, field trials would be best conducted at a number of sites within the Swartland to examine the full impacts of climate on soil erosion. As the region is primarily dry-land irrigation farming, soil erosion, and water availability, storage and use are critical components of farming management practices.

The key to improving water-use efficiency is to implement strategies to store rainfall and to reduce the wasteful pathways, chiefly soil evaporation (Sadras and Angus, 2005). Climate change is a concern for farmers and hence the importance of studies pertaining to water-use efficiency (Hart and Ashton, 2004). Some more recent research has identified that reduced row spacing

between crops, early vigour and a sufficient supply of nutrients can favour rapid groundcover growth and reduce soil evaporation (Sadras and Angus, 2005). Sowing as early as possible following the first rainfall also contributes to greater water-use efficiency; however this would need to be explored in more detail in conjunction with the climate change projections, e.g. increased dry spell duration within the rainfall season could prove detrimental if crops are planted too soon. Improved wheat varieties suitable to dry environments can also help to increase water-use efficiency (Sadras and Angus, 2005), which would be a possible adaptation for the Swartland.

Where climate change is concerned, government policy responses should include maintaining a vigorous agricultural research community able to identify emerging problems in time to develop adaptive solutions. Flexibility in approach is a key rather than attempting to maintain the current geographical distribution of agricultural practices through subsidies when the climate becomes unsuitable (DEAT, 1998). Thus scientists and researchers within the climate change sphere need to interact with end users and conduct more studies relating to impacts of the projected climate changes, in order to assist decision makers.

Further research must also deal with mitigation options when dealing with climate change. These could include promoting, through education, demonstration and the removal of entry-cost barriers: decreasing of the stocking rate and promoting a more productive herd composition in order to reduce methane emissions; reduced-tillage crop agriculture can save energy while building up soil carbon and reducing soil erosion (DEAT, 1998).

It is necessary for society to be forewarned in order to prepare for the future challenges of climate change. Soil erosion has been shown from three different climate models to increase under future climate change in the Swartland, and this will have gross impacts in a region that is largely a crop farming community. Thus it is necessary to take this initial study forward to examine the agricultural responses available to farmers and explore further

adaptation strategies that could be implemented over time in order to equip the farmer and other end users for the future.

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# ***APPENDICES***

University of Cape Town

## **APPENDICES**

**Appendix A: Recent newspaper clippings concerning climate change in southern Africa (A3-15).**

**Appendix B: Tree clustering results from GCM data (A16-20).**

**Appendix C: Comparison of erosion models for the Swartland (A21-30).**

**Appendix D: SLEMSA calculation tables (A31-34).**

**Appendix E: Table of historical wheat yields for the Swartland for 1947 – 1987 (A35-36).**

**Appendix F: Monthly rainfall at Boshof farm in Malmesbury, Swartland (A37-38).**

**Appendix G: Downscaled climate change anomalies (A39-72).**

University of Cape Town

# SA faces spread of malaria

CAPE TIMES FRIDAY, MAY 8, 2009

MELANIE GOSLING  
Environment Writer

CLIMATE change could mean malaria would spread to regions like Gauteng and increase the number of South Africans at high risk by four, Environmental Minister Marthinus van Schalkwyk said yesterday.

Speaking at a media briefing at Klipfontein on the release of a climate change report by the SA National Biodiversity Institute, Van Schalkwyk said that by 2050, the increased number of people at risk from malaria could cost the country between 0.1% and 0.2% of GDP.

Because of the higher temperatures, malaria mosquitoes would be likely to spread to Mpumalanga, Limpopo, the North West, KwaZulu-Natal and even Gauteng by 2050.

Van Schalkwyk said until recently, the issue of climate change had been the realm of "only a few mad scientists".

"It is a mainstream issue now. More people understand it is becoming a reality. Quite dramatic climate changes will be taking place in the next 10 to 15 years," he said.

Van Schalkwyk said the cabinet had been briefed on climate change and had approved a "process of scenario-planning" to examine the different international models being proposed to reduce greenhouse gas emissions.

"We will continue to press at the international level for all nations to take responsibility for dealing with climate change, both by reducing levels of greenhouse gas emissions and assisting developing nations in adapting to the effects of climate change," Van Schalkwyk said.

He was asked at the briefing



**CHANGES DUE:** Marthinus van Schalkwyk, speaking about climate change yesterday. Picture: ANDREW INGRAM

about the apparent contradiction of the government saying they would make climate change a national priority on the one hand and on the other, Eskom's coal-fired power stations pumping millions of tons of CO<sub>2</sub> into the atmosphere annually. This amount was set to increase when Eskom took three power stations out of mothballs.

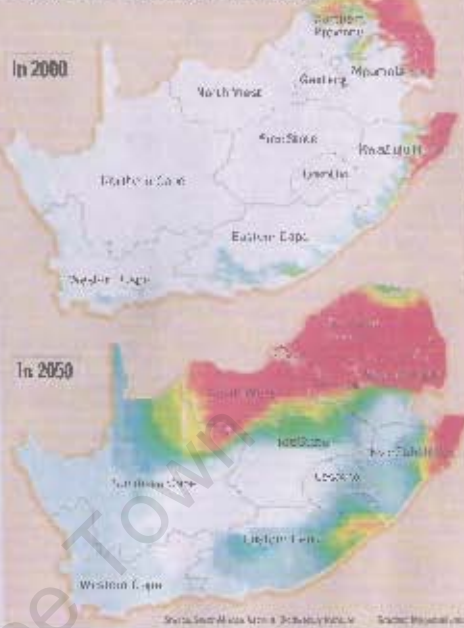
Van Schalkwyk agreed there was a contradiction, adding that

South Africa did not have a comprehensive policy on climate change.

"The reality is we have a coal-based economy," he said.

However, South Africa was not taking cognisance of cleaner coal technology, which the country must begin to do. While it would be difficult to move away from coal, the government was looking at wind, solar and gas options. Nuclear power was "part and parcel" of our energy.

## POSSIBLE FUTURE SPREAD OF MALARIA THROUGH CLIMATE CHANGE



Among the startling predictions in the climate change report were that, in less than 100 years, thousands of plant species may be extinct, with massive areas of fynbos and succulent karoo vegetation wiped out. Bird and mammal populations may be reduced, with high rates of extinction in the Highveld and Lowveld.

This would have serious effects on tourism based on wildlife.

Projections were that the Western Cape would become hotter and drier, while rainfall would increase in the east. Both projections would have a profound impact on agriculture, particularly on emerging farmers on marginal land.

"Clean water will become scarce, small-scale agriculture is likely to be hard hit. Regional migration will accelerate, placing burdens on urban centres," he said.

**Devastating danger:** climate change conference warned of alarming new threat from CO<sub>2</sub> emissions

# Oceans turn acid, endangering all marine life

**CLIMATE CHANGE**

THE CO<sub>2</sub> changes to the world's oceans, making it toxic to many marine life, are being discussed in a report released by the Intergovernmental Panel on Climate Change (IPCC) on Monday. The report says that the oceans are becoming more acidic, a process that could have devastating effects on marine life. The report also says that the oceans are warming, which could lead to more frequent and severe weather events. The report is the first of a series of reports that will be released over the next few years.

Climate change is expected to have a significant impact on the world's oceans. The oceans are becoming more acidic, a process that could have devastating effects on marine life. The report also says that the oceans are warming, which could lead to more frequent and severe weather events. The report is the first of a series of reports that will be released over the next few years.

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# Good weather boosts local SABMiller beer volumes

ANN CROTTY

Johannesburg - Good weather and continuing robust consumer spending helped to maintain growth in beer volumes at 4 percent for SABMiller's local beer operation, Beer South Africa, in the three months to end-December.

In a trading update issued yesterday SABMiller said the group's global beer interests had "continued the momentum of organic growth achieved in the first half of its financial year, and the financial performance has been in line with our expectations as outlined at the time of our interim results announcement".

The overall growth for the third quarter to end-December was strong, with organic growth of about 5 percent in total lager beer volumes.

In the US, Miller's domestic sales in retail units were 9.1 percent below the comparative quarter the previous year.

However, because the market was weak, this slight decrease was sufficient to increase Miller's market share. Sales of the all-innocent Miller Lite brand continued to grow in line with management's expectations and were 1.2 percent ahead of the previous year.

In Europe, organic lager volume growth for the third quarter was 6 percent, and 6 percent for the year to date. This was influenced by continuing strong performance from Poland,

Russia and Romania, which more than offset weakness in Italy, Hungary and Slovakia.

Again in Africa, outside South Africa, reported a 10 percent increase.

The strong volume growth in South Africa that has been reported for the first nine months of financial 2005 is a return to the type of performance achieved by SAB until the 1990s.

Ahead of the interim results announcement last November, SABMiller chief executive Graham Mackay said that during the 1990s and in the first few years of this decade beer had underperformed the general economy reflecting the fact that the benefits of economic growth had largely been restricted to the higher-income groups.

Mackay said at the time that "on average, for the foreseeable future, we would expect to see growth of between 2 percent and 3 percent in the South African beer market".

Meanwhile, stock market first Lehmann is forecasting that SABMiller and Heineken will take the lead in an active acquisition period for the global beer industry in 2006.

Lehmann said in a report that it expected SABMiller to focus on acquisitions in developed markets where it had comparatively less exposure. Heineken would try to beef up its exposure in developing markets.

Weekend Argus, Jan 15, 2005

Recurring droughts: non-heating cold fronts will pass by

# Cape 'will become progressively drier'

WILEN STRICKLAND

THE weather in Cape Town is expected to be generally drier and milder in the coming months, according to the latest long-range weather forecast.

Climate scientists predict that the winter rainfall will be below normal, but that the spring and summer months will see above-normal rainfall. This is due to a combination of factors, including a shift in the position of the South Atlantic high pressure system.

The Cape region is expected to receive about 100mm of rain in the next three months, which is below the long-term average of 120mm.

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# Iceberg harvesting is viable solution to drought crisis

THE January 1 report, "Anti-dam lobby partly to blame for water crisis" raises important issues.

Man and his ingenuity have

always come up with novel solutions:

the humble bucket, the aqueduct, the

reservoir, the piping of water, the

laying of water systems, the damming

(and on the Witwatersrand, the diversion)

of rivers, the sinking of bore

holes, purvey that became more

sophisticated as technology

advanced, seeding of clouds, recycling

of waste water and desalination

of sea water - to name some of the

techniques employed since time

immemorial - or which are at present

the subject of experimentation.

The fact that iceberg harvesting is

the Cinderella of the piece is evident

from your report and from the

announcement that the Ministry of

Forestry and Water Affairs and the

City of Cape Town have held talks and

are considering measures such as tap-

ping squatters, recycling waste water, desalinating sea water and filling swimming pools with sea water.

Clearly some imaginative thinking, but too little too late perhaps. The possibility of iceberg harvesting is

contemplated by its absence. It is a

great pity that more than 20 years ago the City of Cape Town squandered a

rare opportunity of playing a pivotal role in the development of an experimental iceberg-harvesting scheme

that would have been a neatly funded by a European country provided there was interest in the project, more particularly if Cape Town had

expressed any need for water. In the event, the opportunity went begging because the city engineer at the time ridiculed the idea that Cape Town would ever suffer a water shortage. So he cut the head of Department of Forestry Research at a well-known

university. The ice sheet overlying the



Supply: the Slenbras dam provides much of Cape Town's water.

Antarctic continent contains about 30,000,000 cubic kilometres of ice and represents about 90% of the world's glacial ice.

Antarctica possesses just over two-thirds of the world's freshwater. At the South Pole the ice is 3.8km thick; at the North Pole a mere 4.5m. Antarctica's ice is constantly replenished by

huge quantities of snow. Historically

the reason d'icy of Cape Town has been its ability to supply an abundance of practical, potable water for its inhabitants.

There is every reason why the Cape can again become a halfway house, this time on the Aqua-Antarctica Route.

Agua Antarctica Newlands

Weekend Argus, Jan 15, 2005

# Real 'waterwise' behaviour our only hope

**WEEKEND Argus (January 8)** reported that "senior city water experts" claim the anti-dam lobby is partly responsible for the water shortage in Cape Town.

However, according to research by the Centre for Southern African Studies in the School of Government at the University of the Western Cape, which involved extensive interviews with key officials in the water sector of the City of Cape Town and Department of Water Affairs, the direct reason for the current shortage is that water restrictions should have been put in place after the 2000 dry winter but were not because they were deemed "politically sensitive" before the elections.

In 2001 damns at the catchment areas serving Cape Town were 99% full showing just how much water was wasted between now and then. Senior officials in the department and the council admit that the lack of attention to a comprehensive water demand strategy and a formal record of recycling water are contributing to

the city's water problem. KwaZulu Natal delayed any dam-building (favoured by the previous parliament government) because so little emphasis had been placed on water demand strategies. In the early 1990s the city council did not even have one, a point that was underlined by environmentalists at the time. But the environmental movement had relatively little impact on the (notable) participation process around water supply options to the city by the 1990s.

It is unfortunate that less emphasis has been placed on water demand strategies in practice. During the 2000-2001 water restriction years, and again now, municipalities in high-income areas pay a water excess tariff if the household consumption goes over certain levels per month. The punitive measures - water restrictions - are distinguished from water demand strategies which are seen to emphasise "a responsible authoritative and water users" (City of Cape Town Water Services Development Plan). Environmentalists point out that

We should all use less water and that strict restrictions to reduce wastage should be in place all the time. However, the council has not wanted to restrict consumption because it is financing the dam - the high cost of the water consumption. The more money the city makes to pay back the loans.

Now that we are facing the crunch, the restrictions are draconian and have been made without encouraging much public input, which usually leads to non-compliance. Current restrictions do not place heavy emphasis on compliance or water-saving indoors, nor the potential that businesses have to save water. More affluent domestic consumers are "punished" and others are not encouraged sufficiently to save water.

Right now everyone should be allowed to help decide how they use limited allocations of water, to encourage genuine "waterwise" behaviour.

**Vina Thomsson**  
Director, Centre for Southern African Studies

*Weekend Argus, Jan 15, 2005*

CAPE TIMES THURSDAY, JANUARY 13, 2005

# Drought: province seeks R26m

**MELAVE GOING**

THE Western Cape cabinet has called on central government to fund the province through a drought relief fund to help it cope with the current drought.

Provincial Agriculture Minister Melave Goings yesterday said that the province, which has received no financial aid from the national government, is facing a dire situation.

The money will be used to help alleviate drought and provide relief to farmers and stockers in the region.

The province is also facing a drought relief fund which is already exhausted. The province is also facing a drought relief fund which is already exhausted.

In some areas, farmers are forced to cut the throats of their own herds.

Goings said that the province is facing a dire situation. The province is also facing a drought relief fund which is already exhausted.

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given that it "falls outside their own" drought relief.

According to the Western Cape drought relief fund, the province is facing a dire situation.

"We are making a request to the national government to help us cope with the current drought," Goings said.

He appealed to farmers to "remain calm and not to panic" and not to drive workers off their farms.

"Where there are many farmers who are not able to continue to pay workers, we will encourage them to sell on farms to maintain their cash while we develop a process," he said.

In the case of large-scale drought relief, the province is facing a dire situation.

The province is also facing a drought relief fund which is already exhausted.

"We can't ignore the impact of global warming and the fact that we are facing a dire situation," Goings said.

The province is also facing a drought relief fund which is already exhausted.

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as the solution to what is called a drought.

There is a drought relief fund which is already exhausted.

While the R26 million will help stock farmers survive the drought, it will not help the province's water demand strategy.

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South African Wholesaler India 19 2004



**SWEET SQUEEZE** South African businessmen from left: Dreyer Coetzee, Peter van der Merwe and Alan Grey pay a visit to a sugarcane plantation in the Western Cape. The province is facing a drought relief fund which is already exhausted.

# Indian drought may push global sugar prices to four-year highs

**JASON DALE**

**Dumplings** International sugar prices may rise to a four-year high by June as a drought reduces the harvest in India, forcing the world's biggest consumers to import more of the sweetener, according to analysts. Sugar prices are expected to rise to a four-year high by June as a drought reduces the harvest in India, forcing the world's biggest consumers to import more of the sweetener, according to analysts.

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Wholesale prices of US cent sucrose are the highest in 30 years. Last year, when the world's largest sugar producer, India, was hit by a drought, prices rose to a four-year high. Analysts expect prices to rise to a four-year high by June as a drought reduces the harvest in India, forcing the world's biggest consumers to import more of the sweetener, according to analysts.

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India's drought may push global sugar prices to four-year highs. The price of sugar in India is expected to rise to a four-year high by June as a drought reduces the harvest in India, forcing the world's biggest consumers to import more of the sweetener, according to analysts.

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# Britain begs US to limit greenhouse gas emissions

REUTERS, SABA-APF

**BREXIT** - England's Britain appealed to the United States yesterday to sign up to climate-saving cuts in greenhouse gas emissions as environmentalists warned of approaching Asian monsoons.

Opening a three-day scientific meeting to assess the threat of global warming, Environment Minister Margaret Beckett said it was vital Washington became more involved.

"A significant impact is already inevitable - we need to act now to limit the scale of warming in the future and avoid even worse effects," she said.

America is one of the lowest emitters of greenhouse gases like carbon dioxide (CO<sub>2</sub>), but needs what is now majority scientific opinion that mankind is largely to blame for climate warming and has refused to join the Kyoto Protocol in making pledges.

Kyoto, which comes into force on February 16, aims to cut CO<sub>2</sub> emissions by developed states by 5.2% below 1990 levels by 2008 to 2012.

US President George Bush is seeking a less stringent goal.

Evidence is growing that global warming is already starting to alter the world's delicately balanced climate system and that the damage will reverse itself for generations, leading scientists now hold true.

Conference chairman Dennis Timpane said "Global warming of the past 16 years have been the warmest since records began in 1850. Rising greenhouse gases are affecting rain fall patterns and the global water cycle."

Threats stung out the heat wave that gripped western Europe in 2003 as an example. Europe's worst natural disaster

in 50 years killed as many as 30,000 people and inflicted an estimated \$80 billion in damage.

"Since the 1950s, climatic warming has increased the extent and frequency of droughts over land," he said.

In two parts of Asia, "worsening land-use of floods and droughts is already apparent," said Rajendra Pachauri, chairman of the Intergovernmental Panel on Climate Change, the UN's principal scientific authority on global warming.

British scientist Chris Rapley said anything from an Arctic this size could be at least 15% of the ocean surface, just as the global sea level due to melting.

In the Antarctic peninsula, which juts north over the continent, there had been three ice shelf breakups in the last decade, including the creation of the Larsen B iceberg, a 1,200-hour signal beacon, the world's biggest floating object.

When those ice shelves break off, that speeds up the flow of ice into the sea from coastal glaciers, he said.

The ice melted, adding to global sea levels, he said.

If Antarctica melted, that would boost global sea levels by 100m.

However, most of Antarctica's ice is locked up in the West and East Antarctic ice sheet, and temperatures there are colder than before, said Rapley.

The conference is riddled with cutting up with a state-of-the-art assessment about man-made global warming.

But, said Jason Lowe of Britain's Hadley Centre for Climate Prediction and Research, "Even if atmospheric CO<sub>2</sub> levels are eventually stabilised at quite modest concentrations, sea levels will continue to rise for more than 1,000 years, degradation of the land surface will be irreversible."

# Food crisis looms for SA

MELINDA GRIFFITHS  
The Cape Press

**SOUTH AFRICA'S** wheat and maize industry faces a crisis, with the industry predicting a 20% drop in production next year.

The industry predicts a 20% drop in production next year, with the industry predicting a 20% drop in production next year. The industry predicts a 20% drop in production next year, with the industry predicting a 20% drop in production next year.

and for the year when it is 20% of what it was in 2004, says the industry. The industry predicts a 20% drop in production next year, with the industry predicting a 20% drop in production next year.

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75% import for the wheat and 90% for maize, leading to a 20% drop in production next year, with the industry predicting a 20% drop in production next year.

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**DIRE STRAITS:** More than 1,000 Western Cape farmers attended a crisis meeting in Bakhofen yesterday at which they called for the government to provide high-quality maize and agricultural products to help reduce the competition in the massive wheat and maize industry.

## Raise import tariffs on wheat, maize -- farmers

**From Page 1**  
FTI, "the only responsible government must protect and maintain the infrastructure in its rural areas," he said.

Steve Shute, chief executive officer of Grain SA, said the drought in the Western Cape had added to the crisis facing wheat farmers.

"But the fact that it's had such a significant impact is symptomatic of the more serious underlying problem of international protectionism and farm subsidies."

"In the past, farmers might have been able to build in a buffer to absorb the losses associated with a drought, but no longer. Farmers are now producing grain at a loss."

Grain SA had tried unsuccessfully for three years to get the Department of Trade and Industry's Trade & Commission Commission to investigate wheat tariffs. Last week, it secured a meeting with the commission for February 9.

"It's the floor, a wheat farmer from Nottersburg, said: "It costs me R1,000 to produce a ton of wheat. The cash I get is my pocket money. I'd rather not produce wheat at all. I need at least R2,000 a month for salaries and petrol and so on. Where am I going to get that if I'm making a 50% loss on my produce?"

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## Council beats targets, but residents must save more water – mayor

### QUINTON MTYALA

THE city has exceeded its own water saving targets for the past month although residents still have to come to the party.

At a press conference yesterday, Mayor Noma India Mfeketo, flanked by her official, said it was

essential that the message of saving water was brought home.

Member of the Mayoral Committee for Trading Services, Saleem Mowzer, said council departments had saved 53%, more than the targeted 50%.

"The shortage of water in Cape Town won't stop tomorrow, if we

look at global warming trends, things will get worse before they get better," she said, adding that longer term solutions needed to be looked at.

One of these would be education, with the city embarking on a campaign to change the outlook of users.

## Province on flood alert

### KAREN BREYTENBACH

PARTS of the province have been put on high alert for more flash flooding today and tomorrow after three people died flooding in similar conditions in the Kaaimans River gorge recently.

Water in the river rose from ankle to thigh depth in less than five minutes and washed a party of five over three waterfalls and down the river. Two survived.

The Cape Town weather bureau yesterday issued flood warnings to the South West Cape, Namagualand, Boesmansland, the Karoo, Overberg and Garden Route.

Rian Smit of the weather office at the airport said flash floods were caused when 45mm of rain or more fell within an hour or two.

INCREASED levels of greenhouse gases will have a much greater impact on climate change than previously thought and will lead to a "dramatically different" future, according to the latest climate change experiment to be carried out today.

If the predicted levels of greenhouse gases are reached, the oceans are likely to have melted and Britain will be an average 10°C warmer.

The verdict published on Thursday in the journal *Nature*, shows that recent warnings have been caused by man and that a doubling of greenhouse gas from pre-industrial levels could cause more than double the maximum temperature rise so far envisaged likely by the Intergovernmental Panel on Climate Change.

The first results from climate production not show that average temperatures could eventually rise by up to 11°C – albeit after a new global climate pattern has been established over several hundred or even thousands of years – even if carbon dioxide levels in the atmosphere

are limited to twice those found before the industrial revolution.

Such levels of greenhouse gases are expected to be reached around the middle of this century unless drastic cuts are made to their emissions.

The experiment's chief scientist, David Stainforth of Oxford University, said: "Increased levels of greenhouse gases could have a much greater impact on climate than previously thought. We are facing a world in the future which is dramatically different."

The 11°C warning, almost double that seen so far in the geological record, would have a greater impact at higher latitudes, such as Britain.

"At high latitudes the average warming could be 20°C," said Stainforth. "The UK could be well into the tundra."

The model, like any computer forecast, has many uncertainties. The team is not able to work out which of the range of temperature rises is the most likely, save to say that rises under 1°C are highly unlikely – so they can rule out advice

causes for recent warming.

"Having found that extreme responses are a realistic possibility, we need people's support more than ever to put down the risk of such strong warming and understand its regional impact," said Stainforth.

Project co-ordinator David Frame said: "The possibility of such high responses has far-reaching implications."

"If the real world response were anywhere near the upper end of our range, even today's levels of greenhouse gases could already be dangerously high."

And Myke Allen of Oxford University, who helped to set up the experiment, said the project could see a shift in the discussions about greenhouse gas emissions from stabilising atmospheric levels to cutting them.

"Our results confirm what the Pambans found in 2001 (when thousands were killed by a heat wave). The danger zone is not something we are going to reach in the middle of the century. We are in it now," he said. © The Telegraph, London

January 30 2005

Sunday Times 13

## Study predicts huge temperature rises

Cape Times, Thurs  
Jan 20, 2005.



## THE SUNDAY INDEPENDENT

SOUTH AFRICA'S QUALITY SUNDAY NEWSPAPER

# Saving Earth requires more than hot air

**E**yes used to glaze over when talk turned to climate change. Not any more. Worldwide there seems a growing recognition of this danger to life on Earth.

It is because the signs that some have been warning about for decades are increasingly there for all to see. The starkest evidence is the melting glaciers and shrinking polar ice caps. Less specific signs include rising average temperatures and changing weather patterns. In the past these used to be easily dismissed from some quarters as being part of the Earth's age-old cyclical changes. But people generally are taking these warning signs more seriously. With the regrettable exception of the Bush administration, governments and important institutions the world over are showing a sense of common purpose against practices causing climate changes that were not there a few years back.

The most significant landmark in this progression will be Wednesday's coming into force of the Kyoto Protocol. The product of international negotiations going back to 1992, it sets in place a system whereby signatories are in a sense contractually bound to limit the human factors causing climate change.

What a disgrace, then, that the United States, as the most powerful nation, has chosen not to be party to this vital initiative. Whatever its reasoning, for a nation considered to be the leader of the world it remains a most peculiar position to take on a literally burning global issue.

In Europe, by contrast, all nations have signed the treaty. And how well Britain's Tony Blair put it at last month's World Economic Forum in Davos: "I support the Kyoto Protocol. Others will not and that position is understood. But business and the global economy need to know this is not an issue that is going away. My clear view, for what it is worth, is that the debate will be how and on what time scale it is confronted, not whether."

As for South Africa, so engrossed were we in our troubled domestic situation that we lagged behind for a while. This has changed. As marked particularly by our hosting of the 2002 World Summit on Sustainable Development, we have become an important international voice in this field. On the domestic front, the government last year produced a strategy document on climate change. It has also been introducing important environmental legislation, including an air-quality law that aims to reduce greenhouse gas emissions.

These mounting activities at the international and national government level are reassuring. Ultimately, however, it cannot stop at agreements and laws. To make any difference at all to this global threat will require adaptations to our lifestyle that are hard to imagine. In fact, it is said that whatever we do, we cannot change the atmospheric heating and the consequent environmental changes already happening as a result of the carbon dioxide our machines have over decades been pumping into the air.

Still, there is much we as individuals and as a society can do to help avert a longer-term and even bigger catastrophe for our world. We can start by teaching ourselves and our children as much as possible about the causes and effects of climate change. We can use our votes and consumer money to bolster political and business action. We can encourage research and investment in alternative energies and better technologies.

The things we can do as individuals may seem puny, but put together on a global scale they could make a significant contribution. We could, for instance, start using fresh water and electricity more sparingly and treat our waste disposal more intelligently. Even the simple act of planting an indigenous tree could help; it will play its small part in absorbing harmful gases. And the public care demonstrated in this way may just help to expose those greedy destroyers of the world's remaining forests and other natural habitats for the selfish creatures they are.

# On the brink of disaster

JO ANNE BARTHELEME

FARMERS and workers in rural parts of the Western Cape are on the brink of a dire crisis, judged at a meeting last week. The provincial treasurer is so alarmed that he has taken emergency steps to help them.

Large numbers of farmers will have to leave their farms unless government - which has not been successful - lifts its financial support.

The National Treasury has already ordered the banks to stop lending to struggling farmers and other small businesses. It has also asked that they stop lending to small businesses, such as food stores, says the CEO of the Western Cape Farmers Union, Willem van der Merwe.

In the West Coast, the drought has spread from Plettenberg Bay and Swartkops to the southern coast. In all these areas, crops have failed. In the West Coast, the rains have melted old dams, but have not brought new water. In some areas, farmers have stopped irrigating parts of their farms to save water. Water rationing in Plettenberg and Swartkops has started.

Across the province, farmers are using the water in their dams to irrigate crops. But existing levels are being used up and water tables are dropping. Farmers are finding it increasingly hard to drill for more water.

Thousands of small farmers are believed to have been ruined because the banks they usually work with have refused to supply them this season.

Farmers who still have water in their dams are being told to use it for drinking water and for their own use, but not for irrigation. "Government should do more to help them," says the Western Cape Farmers Union. "We're just hoping that there will be enough rain in the next winter to help us through."

The Western Cape is the only region in South Africa not to receive rain in recent years and it is expected to receive only a small amount this winter.



**HARD HIT** Willem van der Merwe says the drought in the western Cape has hit his farm in

Allican, a severely drought-stricken area. Van der Merwe says the provincial treasurer should lift the ban on short-term residential mortgages for farmers and workers.

There is a danger of a mass exodus of farmers from the region, the minister

said last week. The department of agriculture, animal services and forestry, West Virginia, is considering a drought relief fund. Van der Merwe said.

The provincial government has a fund of 10 million available for drought relief in December, but

some farmers have said the Cape Times. They did not say how much they would need.

The Cape Times visited the West Coast near Plettenberg Bay and the southern coast, two of the regions badly hit by drought.

The state of Plettenberg Bay is a small town. It is one of the

most severely drought-stricken areas in the province. The drought has hit the town since the start of the year, and two weeks ago farmers filled the silos to store the first crop of wheat. Now the silos are empty.

Van der Merwe says the drought has hit his farm in Allican, a severely drought-stricken area. He says the provincial treasurer should lift the ban on short-term residential mortgages for farmers and workers.

There is a danger of a mass exodus of farmers from the region, the minister said last week.

Two years running he has been unable to get his crops in. The drought has hit his farm in Allican, a severely drought-stricken area. He says the provincial treasurer should lift the ban on short-term residential mortgages for farmers and workers.

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Picture: ANDREW MORGAN

far the drought. "The shortage of water is even bigger than the shortage of the drought."

"The current prices are not sustainable," says Van der Merwe, provincial treasurer for Western Cape.

See Page 4

University of Cape Town

# Fynbos project aims to save our national flower

Grassroots involvement in collecting data has been a coup, writes **Luon Marshall**

**S**OUTH AFRICAN flowering plants are among the most diverse species of the Cape Floristic Region that are under threat from climate change, habitat spread and, in the species' National Red Data Book, the threat of extinction in the wild.

Since 2002, plant life in the fynbos region has been under attack, with the loss of several species to poachers and the loss of habitat.

During the last few years, the fynbos has been under attack from poachers and the loss of habitat. The loss of habitat is a major threat to the survival of many species.

It is also a major threat to the survival of many species. The loss of habitat is a major threat to the survival of many species.

South African plants are under threat from climate change, habitat spread and, in the species' National Red Data Book, the threat of extinction in the wild.

To save these plants from extinction and to protect their unique genetic diversity, it is necessary to take action now. This is the message of the report.

Keynote & featured addresses

## Saving the Cape's endangered flora has profound economic implications

participated in the first phase of the Project. The first phase of the Project was to identify the most endangered species and to develop a conservation plan for them.

The project, which began in 2002, is being led by the Department of Environmental Affairs and Forestry. It is a major initiative to protect the Cape's unique flora.

"Climate change poses a serious threat to the survival of many species. The loss of habitat is a major threat to the survival of many species.

Findings from the first phase of the project are being used to develop a conservation plan for the most endangered species. This is a major initiative to protect the Cape's unique flora.

The first phase of the project is being led by the Department of Environmental Affairs and Forestry. It is a major initiative to protect the Cape's unique flora.

ago at a conference in Stuttgart by Bill Harms of Germany's Institute for Climate Impact Research.

The Cape Floristic Region supports the highest known concentrations of plant species in the world. It is also the southern tip of Africa, the region's main vegetation zone.

By 2002, 1,400 plant species were under threat from climate change, habitat spread and, in the species' National Red Data Book, the threat of extinction in the wild.

In a report, the Cape Floristic Region's main vegetation zone is under threat from climate change, habitat spread and, in the species' National Red Data Book, the threat of extinction in the wild.

"However, it is not clear if plants diversified from about 10 million to 100 million years ago. It is not clear if plants diversified from about 10 million to 100 million years ago.

Plants were chosen as the species to be studied for several reasons. They are easy to study and they are under threat from climate change, habitat spread and, in the species' National Red Data Book, the threat of extinction in the wild.

Under the main heading of 'Endangered species', the report lists the most endangered species and the reasons for their endangerment.

The report also lists the most endangered species and the reasons for their endangerment. This is a major initiative to protect the Cape's unique flora.

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WS

Thursday, Feb 10<sup>th</sup>, 2005

CAPE TIMES

CLEANING UP AIR COULD BACKFIRE

# Climate change may turn Kalahari dunes into shifting sand

**RICHARD INGHAM**  
Sapa-AP

PARIS: Scientists publish two new studies today that shed light on hidden aspects of global warming.

In a paper in the British journal *Nature*, researchers warn that a patch of southern Africa could be transformed into a roasting, Sahara-like desert as the dunes of the Kalahari become eroded and destabilized by global warming.

For thousands of years, these dunes - extending from Angola to northern South Africa - have been used for pastoral or agricultural farming.

The scientists assembled knowledge about the micro-dynamics of dunes, such as moisture and the percentage of vegetation that are needed to hold the sandy soil together.

They combined this data with powerful computer simulations about the expected rise in temperatures over this century and its likely impact on rainfall.

The news was bad. Within decades, higher temperatures and less moisture are likely to destroy vegetation and erode the dunes, exposing them to wind shift.

In the southern dunes, in eastern Namibia and northern

South Africa, the dunes began to move "significantly" by 2050, a phenomenon likely to be followed in the eastern dunes fields, in eastern Botswana and western Zimbabwe, by 2070.

By 2090, all dunes fields are highly dynamic, from northern South Africa to Angola and Zambia, write the authors, led by David Thomas of the Centre for the Environment at Oxford University.

"Our results suggest that dunes fields are likely to be reactivated (the sand will become significantly exposed and move) as a consequence of 21st-century warming."

The other paper focuses on aerosols - another term for dust, soot, particulates from industrial discharge, road traffic and volcanic eruptions that linger in the atmosphere.

Aerosols block the sunlight, helping to prevent Earth's surface from warming, but they also have a big effect on cloud and rainfall patterns. One of the big unknowns is what happens when this "aerosols" shield is removed by anti-pollution measures.

German and British scientists, led by Meinert Andreas of the Max Planck Institute for Chemistry in Mainz, Germany, estimate that as aerosols are cleaned up, Earth's mean global

temperature could rise by more than 6°C by 2100. A rise of this magnitude is in the doomsday range, they acknowledge.

"Soon a degree of climate change is so far outside the range covered by our experience and scientific understanding that we cannot with any confidence predict the consequences for the Earth as a whole."

The report even exceeds the most pessimistic estimate suggested in 2001 by the top UN scientific authority on global warming, the Intergovernmental Panel on Climate Change.

In its landmark report, the panel said the planet's temperature was rising as carbon dioxide, stored up heat from the sun.

These estimates ranged from 1.4°C to 6.4°C, according to carbon dioxide levels that ranged from 560 to 960 parts in a million. These compare with 380 parts in a million before industrial times and around 300 parts today.

The greater the increase, the more dramatic the effect on Earth's climate, with the higher ranges predicting shrinkage of the polar ice cap, greater water stress, more frequent and more violent storms, and mean sea levels that would rise by up to 66 centimetres.

■ A version of this article has appeared in the *Star*. Contact: 021-462-1000 or [luon@star.com](mailto:luon@star.com)

# Neighbours light up from exodus of Zimbabwe tobacco farmers

ANNIE SWANZEN  
and JENNIFER MUMFORD

IT'S THE EARLY MORNING in the small town of Mberema, Zimbabwe, and the sun is just rising over the hills. The air is still and the ground is damp from the night's rain. A group of about 10 people, mostly men, are gathered in a small, open-sided structure that looks like a makeshift market stall. They are dressed in simple, practical clothing, and some are wearing hats. One man in the foreground is looking towards the camera, while the others are engaged in conversation or looking around. The scene is a typical day in a rural Zimbabwean town, capturing the daily life of the community.



**UP IN**  
The farmers' exodus from tobacco has led to a surge in other agricultural activities in the region. Many former tobacco farmers have turned to other crops like maize and beans, which are less capital-intensive and have shorter growing cycles. This diversification is seen as a way to reduce risk and ensure a more stable income for the rural population.

It is a common sight to see people carrying bundles of tobacco leaves on their heads or backs, heading towards the processing plants. The landscape is a mix of cultivated fields and natural vegetation, reflecting the agricultural nature of the area.

The exodus of tobacco farmers has had a significant impact on the local economy. The tobacco industry was once a major source of revenue for the government and a primary livelihood for many rural households. As farmers leave, the local market for tobacco-related goods and services has shrunk, leading to a decline in income for many people. However, some argue that this could be an opportunity for the region to diversify its economy and become less dependent on a single commodity.

The government has implemented various policies to support the remaining tobacco farmers and those who have left. These include providing subsidies, improving infrastructure, and promoting alternative agricultural practices. The goal is to ensure that the rural population remains viable and that the country's agricultural sector continues to contribute to the national economy.

The impact of the tobacco exodus is a complex one, with both challenges and opportunities. While the loss of a major industry is a significant setback, it also presents a chance for the region to develop more sustainable and diversified agricultural practices. The future of Zimbabwe's rural areas will depend on the effectiveness of government policies and the resilience of the farming community.

# Peninsula carbon emissions up despite aim to cut them

ENVIRONMENT WRITER

CARBON emissions, the major greenhouse gas causing climate change, have increased in the Cape Peninsula by 30% in the last 10 years.

Yet the global aim was to have reduced carbon emissions by 60% by 2050.

Jonathan Hanks, of the SA Centre on Climate Change, said at the Western Cape Sustainable Development Conference yesterday that there was a lack of understanding about the problem of climate change, and a lack of incentives to tackle the problem.

One of the major reasons was that South Africa provided cheap electricity from the burning of coal, and externalised the costs to the environment and to society of burning fossil fuel.

"We need to start paying the right price for electricity because it is not factoring in what it is doing to our natural resources and to society. We all have comfort zones. What we need is a major rethink of how we do things," Hanks said.

He said the financial sector in South Africa was not seeing the risks or opportunities which climate change presented.

"Fifteen years after sustainable development was brought

on to the international agenda, only now is it coming on to boardroom agendas. They talk about sustainable development glibly, but it is not well understood."

Most of the discussion in the financial and other media was about financial capital, GDP and growth. It was understood that human capital was needed for economic growth, but business failed to understand that financial and human capital was totally dependent on natural resources.

"They are failing to assign sufficient value to natural capital," Hanks said.

If the Western Cape were to develop an integrated energy strategy, it was essential to set long-term goals and targets for carbon emissions, as had been done in the Netherlands.

It was also critical to internalise the cost of energy production, and to eliminate inconsistencies in policies.

Hanks said a problem was that many municipalities relied on income from electricity charges. When business and industry reduced their electricity costs through energy saving, municipalities raised their electricity tariffs in response.

There was therefore no incentive to cut energy use.

40% FACE EXTINCTION BY 2050

# Cape proteas under threat from global warming

MELANIE GOSLING  
Environment Writer

CLIMATE change caused mainly by the burning of coal and oil will have a massive impact on the Western Cape, where hotter temperatures are expected to wipe out between 30% and 40% of protea species by 2050.

Global warming will also have a significant impact on Western Cape agriculture, leading to a reduction in production, employment and economic welfare.

These sobering facts are given in a report in the journal *Nature* this week on the most comprehensive analysis to date of the effects of climate change on land plants and animals.

In the largest collaboration yet in assessing the problem, scientists from eight countries studied six regions rich in biodiversity, representing 20% of the planet's land area, and found that between 15% and 37% of their species could become extinct by 2050.

The Kruger National Park, for instance, could lose up to 60% of its species.

Lead author Chris Thomas, a conservation biologist at the University of Leeds, said: "If the projections can be extrapolated globally, our analyses suggest well over a million species could be threatened with extinction as a result of climate change."

This meant climate change was the biggest new extinction threat.

Guy Midgley, of the National Botanical Institute, who contributed to the research, said yesterday there had been a steady increase in temperatures in the Western Cape in the past 20 years.

"We seem to be at the leading edge of climate change here and that's worrying."

"Climate change is one of the most fundamental problems yet faced in modern society. It will take the best minds on the planet to deal with the problem."

Midgley said hotter temperatures would affect the Western Cape's fruit industry.

Some fruit trees need temperatures to drop low enough in winter to ensure that they become properly dormant. This is necessary to initiate proper fruit production in the summer.

"If they don't go into dormancy properly, the fruit quality is a mess," Midgley said.

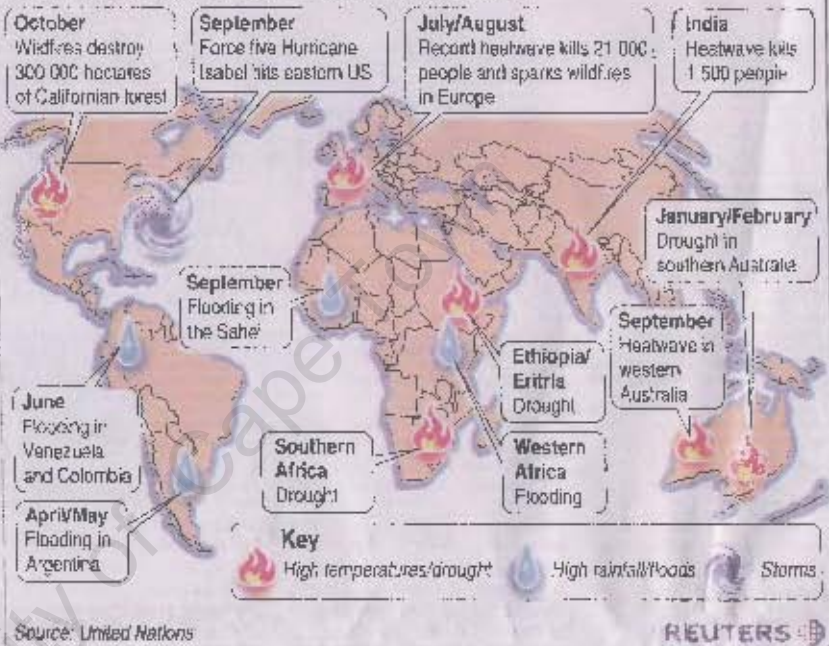
Researchers from the University of Stellenbosch and the University of Pretoria have found that the Western Cape's agricultural economy would be particularly susceptible to the lower rainfall that would accompany climate change.

Lower rainfall would lead to "reduced producer and consumer economic welfare and lower levels of farm-sector

## EXTREME WEATHER IN 2003 A RESULT OF GREENHOUSE GAS BUILD-UP



Climate change will wipe out between 30 to 40% of South African proteas between now and 2050 and have a negative impact on Western Cape agriculture.



employment", the study says, adding that the "reduction in economic welfare is expected to disproportionately affect the poor".

The study found that the arid western regions of South Africa were particularly vulnerable to extinctions by climate change, while the Kruger National Park could lose up to 60% of its species.

The Western Cape floral kingdom was home to more than

8 000 species, more than 60% of which were endemic. Most would not be able to survive throughout the areas in which they grew, Midgley said.

"These species have originated and persisted here for many millions of years. Their potential loss is devastating for the complex ecosystems that have evolved here."

To reduce the impact of cli-

mate change, the world would have to change now to technologies other than those based on the burning of fossil fuels.

"An immediate switch to technologies that produce little or no greenhouse gases, combined with the active removal of carbon dioxide from the atmosphere, could save a million or more species from extinction," Thomas said.

BOREHOLES STAVE OFF DROUGHT, BUT WATCH TABLE'S FALLING

# Koue Bokkeveld's harvest of despair

BY ANDREW WINGRAM

THE 2004-2005 drought in the Koue Bokkeveld region of the Western Cape has been the worst in 100 years. It is expected that the region will lose 100,000 head of sheep and 100,000 head of cattle.

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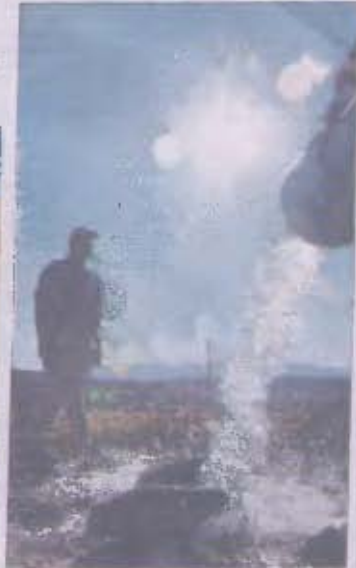
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WASTE LAND: Pieter Roussouw has not had a wheelbarrow for two years on two of his 1000-hectare farms. Pictures: ANDREW WINGRAM



LIMELINE: Koue Bokkeveld farms are mostly in the Western Cape. The region is the poorest in the country.



BITTER FRUIT: Berries in the Tint's pulled out an orchard of apples in 2004 because the orchard was too dry.



DAMNED IF WE DO, DAMNED IF WE DON'T: Damned if you do, damned if you don't is one of many that farmers in the Koue Bokkeveld who have had their dams empty since 2004 are saying.



10 DEEP TROUBLE: Apple farmer's orchard in the Koue Bokkeveld region. It has had been empty since 2004.

## Use water sparingly, minister urges parched SA

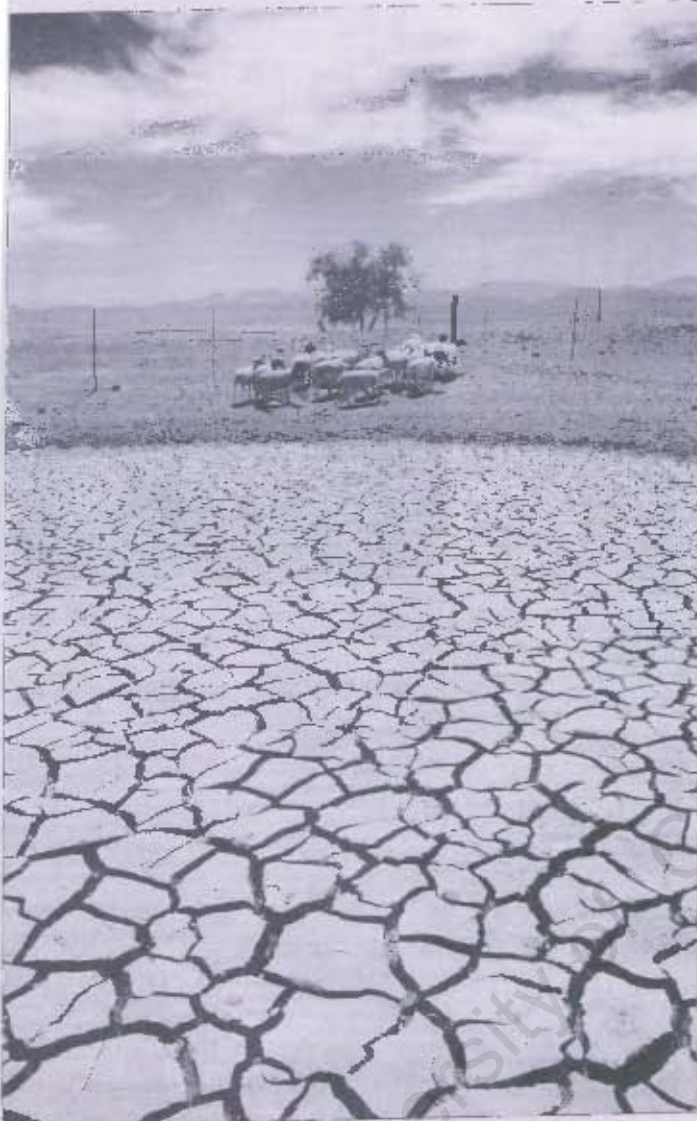
PRETORIA: South Africans should be using water sparingly as overall reserves have not improved, despite good rains in some parts of the country, says Minister of Water Affairs and Forestry Buyelwa Sonjica.

Some areas seemed green and crops were growing, but these did not reflect the true picture, which was "serious".

Dam levels in Gauteng, Limpopo,

KwaZulu-Natal and Mpumalanga had increased on average by only 1%, while those in the Free State remained virtually unchanged. In the Eastern Cape, dam levels had risen by 3%.

"South Africa is water-scarce ... and all water users should exercise discipline ... Farmers and other large water users should review their commitments and use water with utmost care." - Sapa



**PARCHED EARTH.** As the drought tightens its grip in the Western Cape, dams and boreholes have dried up. Sheep wander aimlessly alongside the cracks of mud that was once a dam on a Ronerville farm.  
Picture: ERIC MILLER

## Namaqualand farmers give up as drought bites

STAFF WRITER

SEVEN farmers in drought-stricken Namaqualand have packed up and left their farms and have taken jobs as care bands on farms in the Olifants River valley and elsewhere.

Near Vanrhynsdorp, 11 farmers have to truck in water daily as their boreholes have run dry. Jan van Zyl, a wife and grape farmer in the Olifants River, said yesterday he would be travelling around the region this week to assess the worst-hit areas.

The seven that had left their farms to work elsewhere were from the Bitterfontein district.

"Some of the farmers are working with us in the Olifants River helping to bring in the grape harvest. I know that one of those farmers has gone to work in Cape Town and another has taken a job in Springbok."

"They do this so that at least they get some sort of income. I suppose they will go back when things come right again," Van Zyl said.

"Normally they bring their families with them and live with the farmer where they are work-

ing. Sometimes it's the son who leaves the farm, but then the father stays on behind," Van Zyl said.

Near Vanrhynsdorp the local municipality has initially had donated R5 000 to help the farmers pay for the cost of trucking water to their farm.

"Only one of the farmers in that area still has water from his borehole and the others are taking water from him. Each day they have to drive the water in to their farms. Most are sheep farmers but some are coolboer or farmers and they need water at this stage to spray on the tea-plants," Van Zyl said.

He said his own harvest of wine grapes was between 15% and 18% lower than last year, which had also not been a big harvest.

"We each get a quota of water for irrigation, and when that's used up, that's it," he said.

Two weeks ago the Bitterfontein area had had between 20mm and 40mm of rain.

"It will help with grazing pastures in the grassy areas, but it won't help the winter-sold grazing which grows only in winter, even if it gets warmer in summer."

## Leon urges higher tariffs to give SA farmers a fair chance

THE government is not doing enough to protect South Africa's agriculture and marine sectors from cheap imports and unfair foreign competition, Democratic Alliance leader Tony Leon said yesterday.

In a speech prepared for delivery at Durban he called for a "cautious and judicious" raising of import tariffs to protect these industries.

"The government is not doing enough to help farming communities survive through one of the most difficult periods the agricultural sector has ever experienced."

"Grain farmers, for example, are struggling to deal with the

impact of cheap imports flooding the market.

"The DA is in favour of free trade, but we also insist on fair trade."

"The rules of the World Trade Organisation (WTO) and the Agreement on Agriculture at the Uruguay Round allow for higher tariffs in special circumstances."

"Currently, import tariffs are only about 1% on wheat and 1.5% on maize."

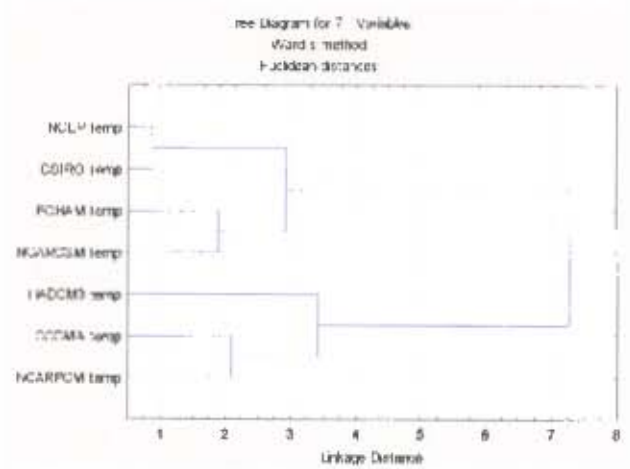
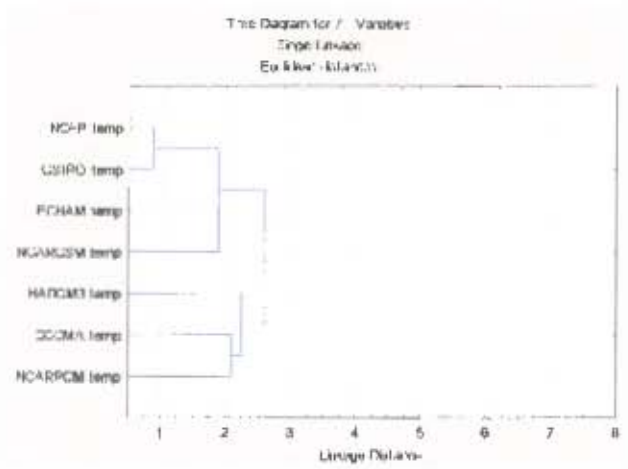
"These tariffs could theoretically be raised to levels of 20% for wheat and 30% for maize, accord- ing to Grain SA, though we would have to be cautious and judicious in doing so." - Sapa

**APPENDIX B:**

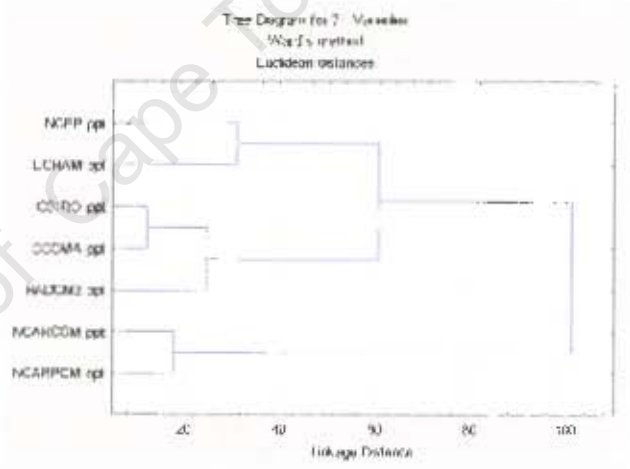
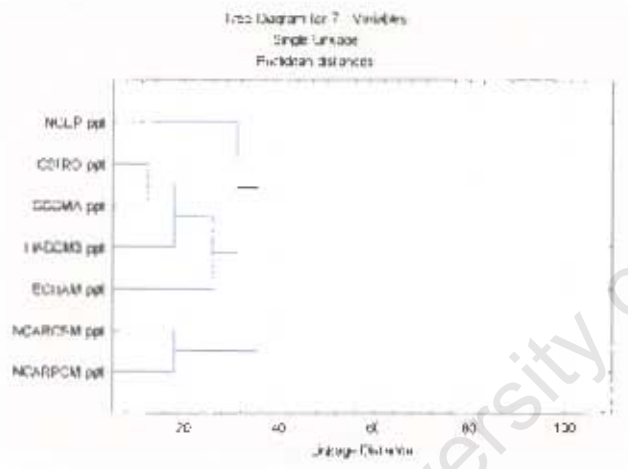
Tree-clustering results for GCM data, where Single Linkages identifies outliers and Ward's Method identifies cohesive groups.

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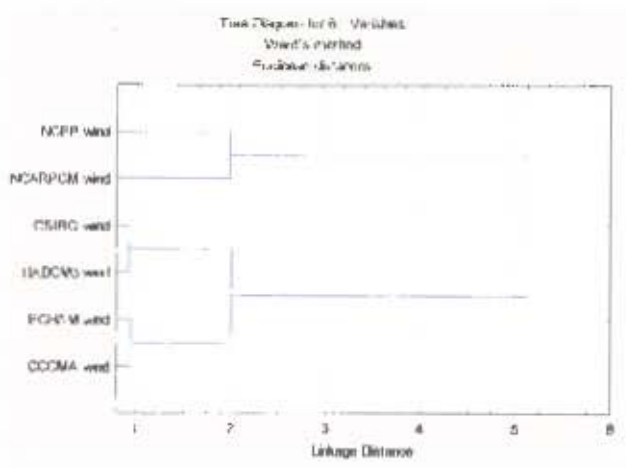
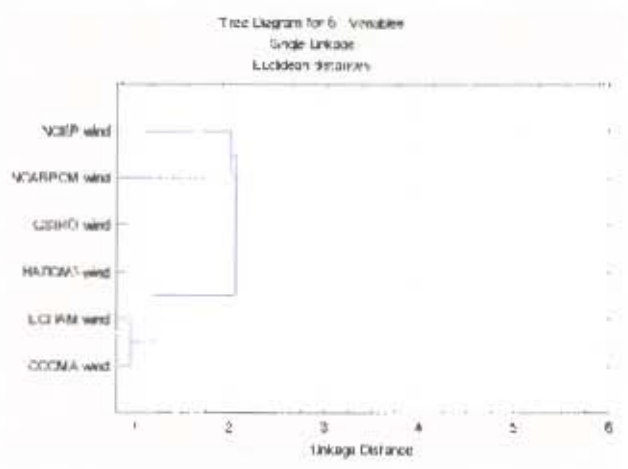
Average SRES A2 emission scenario control temperature clusters with NCEP:



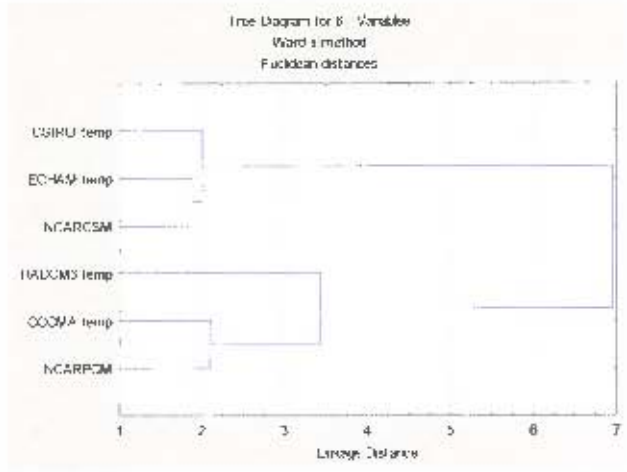
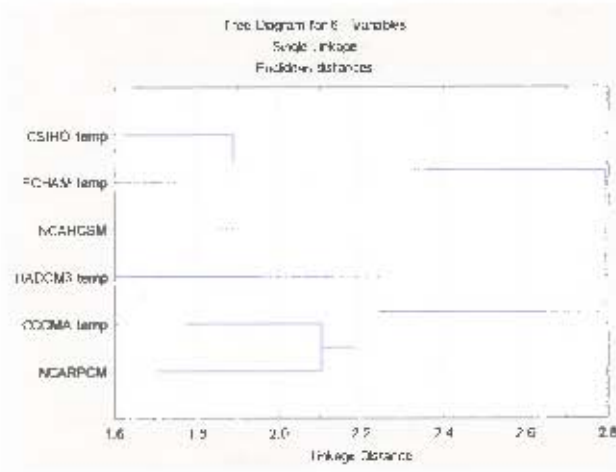
Average SRES A2 emission scenario control precipitation clusters with NCEP:



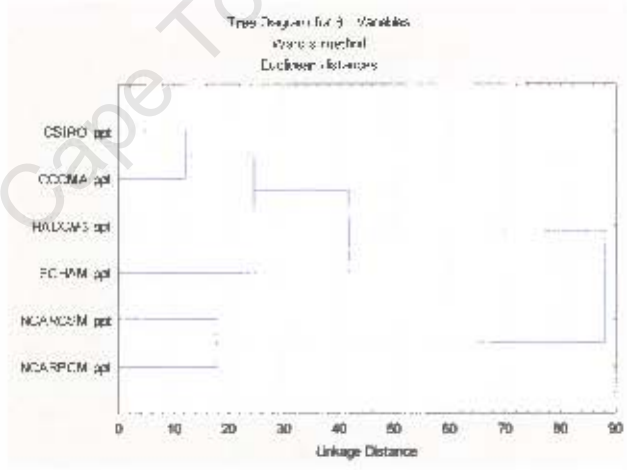
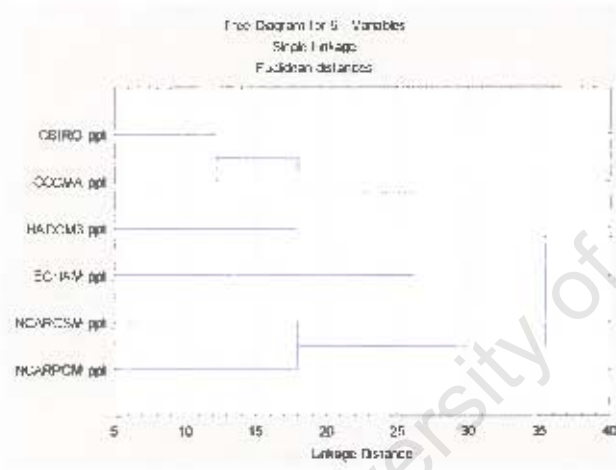
Average SRES A2 emission scenario control wind speed clusters with NCEP:



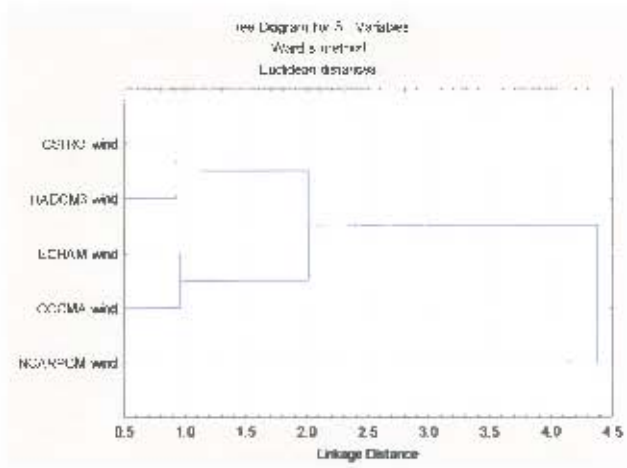
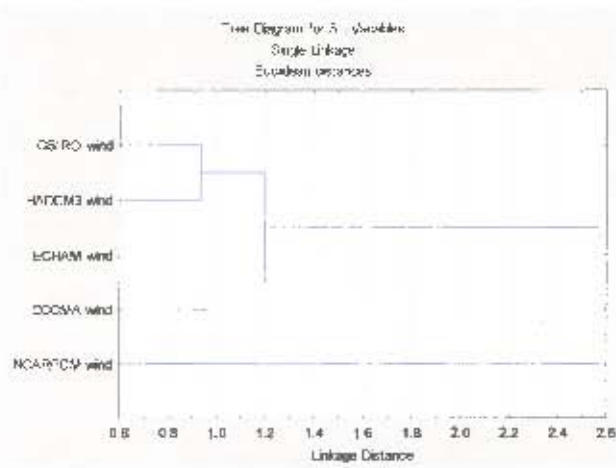
Average SRES A2 emission scenario control temperature clusters:



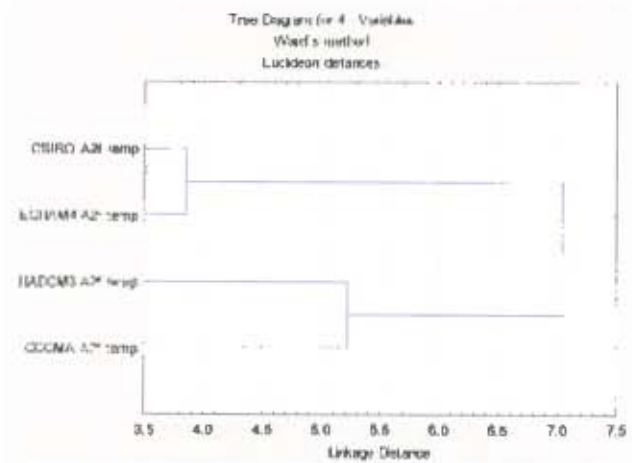
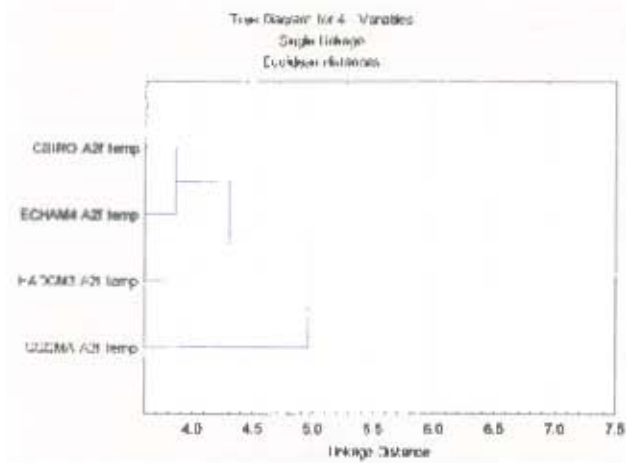
Average SRES A2 emission scenario control precipitation clusters:



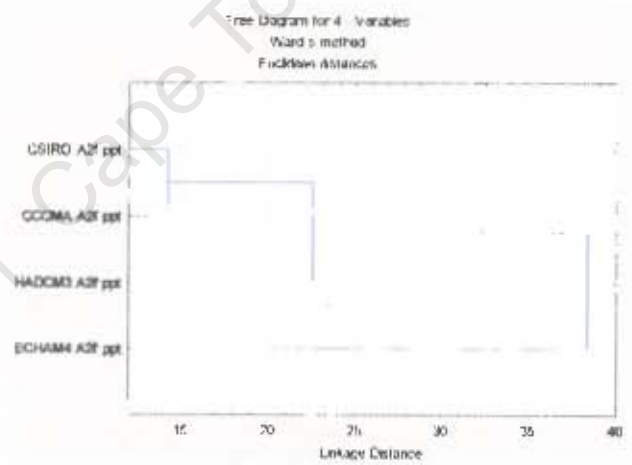
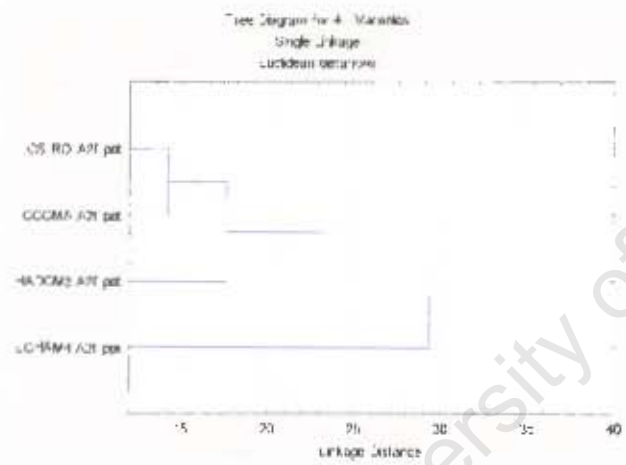
Average SRES A2 emission scenario control wind speed clusters:



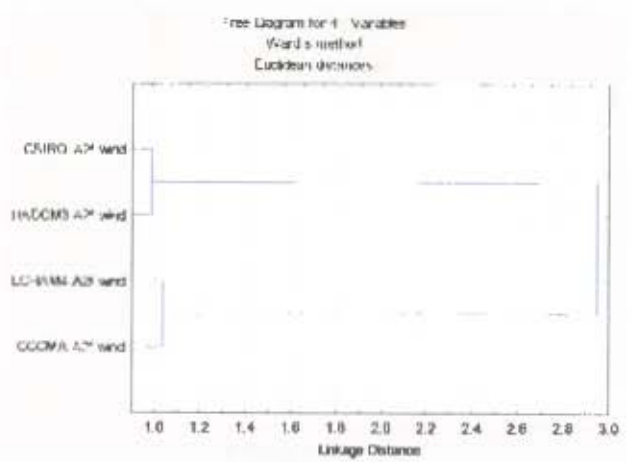
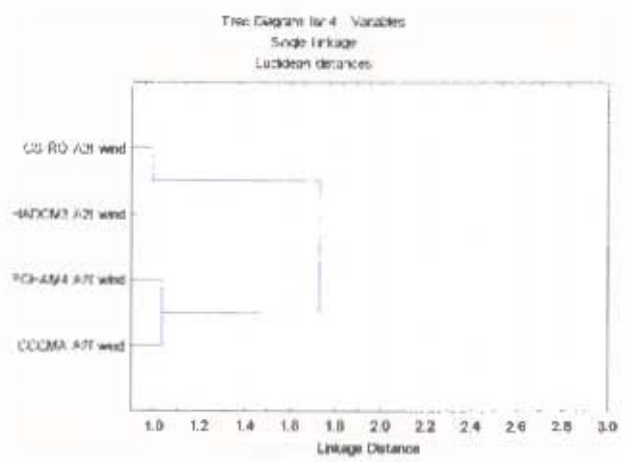
Average SRES A2 emission scenario future temperature clusters:



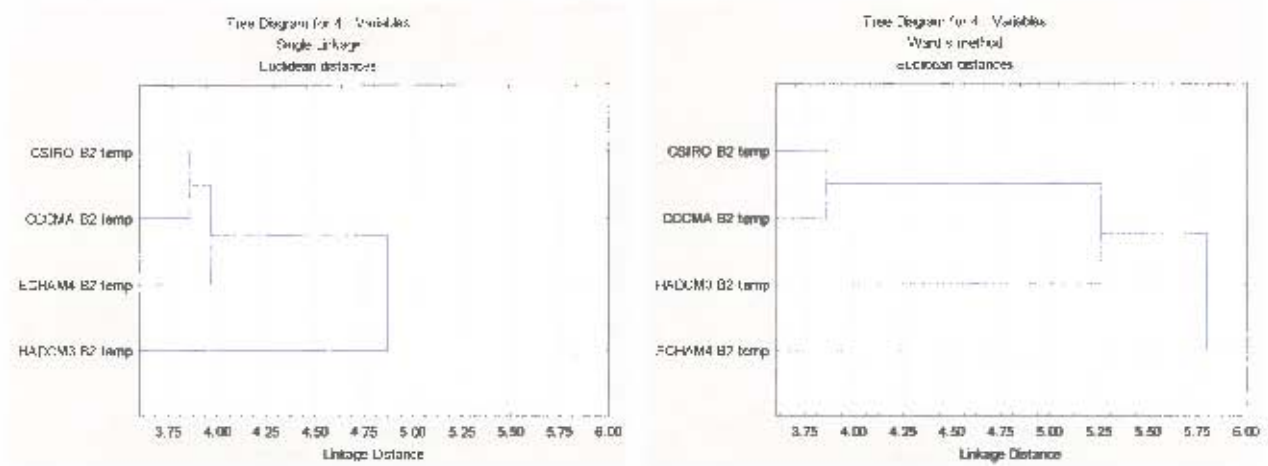
Average SRES A2 emission scenario future precipitation clusters:



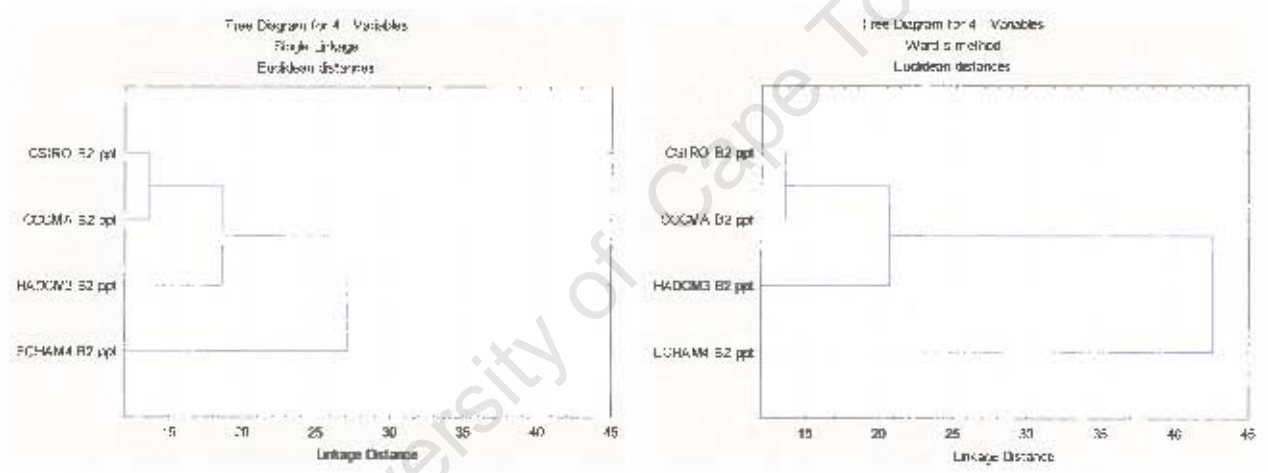
Average SRES A2 emission scenario future wind speed clusters:



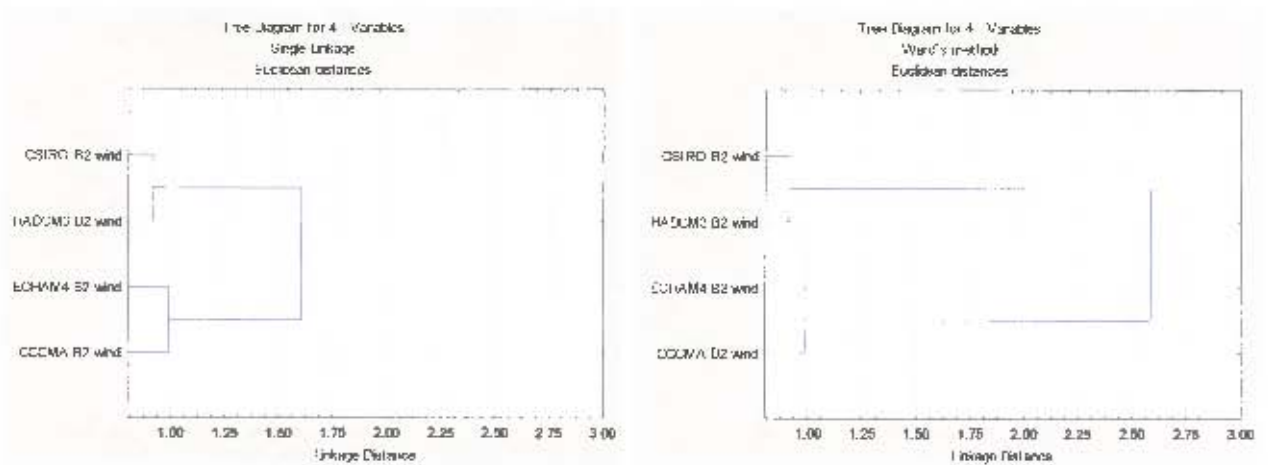
Average SRES B2 emission scenario future temperature clusters:



Average SRES B2 emission scenario future precipitation clusters:



Average SRES B2 emission scenario future wind speed clusters:



## **APPENDIX C:**

Some commonly recognised soil erosion models were examined for use in the Swartland region. They are compared here under the following headings:

- 1) Description
- 2) Appropriate Use
- 3) Scope
- 4) Key Output
- 5) Key Input
- 6) Ease of Use
- 7) Training Required
- 8) Computer Requirements
- 9) Cost
- 10) Summary for the Swartland

A list of references, which pertain directly to the contents of this appendix, appears at the end and is also included in the main reference list. The models compared are listed alphabetically:

- 1) ACRU
- 2) APSIM
- 3) EPIC
- 4) SLEMSA
- 5) USLE
- 6) WEPP

## **1) ACRU Agricultural Catchments Research Unit) for the Swartland**

**Description:** The ACRU model has its origins in a catchment evapotranspiration based study carried out in KwaZulu-Natal in the early 1970s. The agrohydrological component of ACRU first came to the fore during research on an agrohydrological and agroclimatological atlas for KwaZulu-Natal. ACRU is a multipurpose model that integrates water budgeting and runoff components of the terrestrial hydrological system with risk analysis, and can be applied in crop yield modelling, irrigation water demand/supply, climate change, land use and management impacts, and resolving conflicting demands on water resources, to list a few. The ACRU model uses a daily multiplayer soil water budgeting and has been developed essentially into a versatile total evaporation model. It has therefore been structured to be highly sensitive to climate and land use/cover changes on the soil water and runoff regimes, and its water budget is responsive to supplementary watering by irrigation, to changes in tillage practices, or to the onset and degree of plant stress. ACRU was designed for easy expansion as new objects can be created and linked into the existing structure without major revision.

**Appropriate Use:** ACRU can be used at the catchment or subcatchment level to study impact of climate change and enhanced CO<sub>2</sub> conditions on crop yield and water balances.

**Scope:** ACRU can operate as site-specific or as a lumped small catchments model. However, for large catchments or in areas of complex land uses and soils, ACRU can operate as a distributed celltype model.

**Key Output:** Crop Yield and water balances (including irrigation needs, runoff, etc.) for different climate change scenarios.

**Key Input:** Weather data: maximum and minimum temperatures, rainfall. Catchment: location, area, configuration, altitude. Other data: land cover, soil properties (texture, depth).

**Ease of Use:** For trained hydrologists and agronomists.

**Training Required:** No formal training, but advanced knowledge of plant and soil processes as well as hydrology is needed.

**Computer Requirements:** Windows-based or Unix-based PC.

**Cost:** not available.

**Summary for the Swartland:** Hydrological model, not a soil erosion model. X

## **2) APSIM (Agricultural Production Systems sIMulator) for the Swartland**

**Description:** APSIM is a modelling framework with the ability to integrate models derived in fragmented research efforts. This enables research from one discipline or domain to be transported to the benefit of some other discipline or domain. It also facilitates comparison of models or submodels on a common platform. This functionality uses a “plug-in-pull-out” approach to APSIM design. The user can configure a model by choosing a set of submodels from a suite of crop, soil, and utility modules. Any logical combination of modules can be simply specified by the user “plugging in” required modules and “pulling out” any modules no longer required. Its crop simulation models share the same modules for the simulation of the soil, water, and nitrogen balances. APSIM can simulate more than 20 crops and forests, and its outputs can be used for spatial studies by linking with geographic information systems (GIS).

**Appropriate Use:** The APSIM environment is an effective tool for analysing whole-farm systems, including crop and pasture sequences and rotations, and for considering strategic and tactical planning. APSIM allows users to improve understanding of the impact of climate, soil types, and management on crop and pasture production. It is a powerful tool for exploring agronomic adaptations such as changes in planting dates, cultivar types, fertilizer/irrigation management, etc.

**Scope:** Site-specific but can be extrapolated to national and regional levels using GIS.

**Key Output:** Changes in crop and pasture yields, yield components, soil erosion losses, for different climate change scenarios.

**Key Input:** Soil properties, daily climate data, cultivar characteristics, and agronomic management.

**Ease of Use:** For trained agronomists as it requires advanced knowledge of plant growth and soil processes. Programming knowledge of FORTRAN 77 is required.

**Training Required:** APSIM training takes approximately one week to acquire minimum skills to conduct simple simulations.

**Computer Requirements:** Windows-based PC Pentium.

**Cost:** Not identified, restricted for approved collaborators through Agricultural Production Systems Research Unit (APSRU) in Australia.

**Summary for the Swartland:** Advanced agronomic knowledge required as well as training to use the model. ✕

### 3) EPIC (Erosion Productivity Impact Calculator) for the Swartland

**Description:** EPIC is an IBM, Macintosh, or Sun based generalised crop model that simulates daily crop growth on a hectare scale. Like most process plant growth models, it predicts plant biomass by simulating carbon fixation by photosynthesis, maintenance respiration and growth respiration. Several different crops may be grown in rotation within one model execution. It uses the concept of light-use efficiency as a function of photosynthetically available radiation (PAR) to predict biomass. EPIC has been modified to simulate the direct effects of atmospheric carbon dioxide on plant growth and water use. Crop management is explicitly incorporated into the model.

**Appropriate Use:** This approach is useful for evaluating a limited number of agronomic adaptations to climate change, such as changes in planting dates, modifying rotations (i.e. switching cultivars and crop species), changing irrigation practices, and changing tillage operations. The parameter files are extremely sensitive to local conditions and EPIC can give grossly misleading results when relying on default settings as it is being tailored to different locations and cropping systems.

**Scope:** All locations; agricultural; site-specific.

**Key Output:** Response of crop yields; yield components; and irrigation requirements to climate change adaptations.

**Key Input:** Quantitative data on climate, soils, and crop management.

**Ease of Use:** Data intensive and difficult to use without sufficient qualifications. A person trained in general crop systems science with moderate programming skills should be able to use EPIC reliably with 3-4 days of intensive training.

**Training Required:** Requires technical modelling skills and a basic knowledge of agronomic principles.

**Computer Requirements:** IBM-compatible PC 486 with 4k of RAM and 80MB.

**Cost:** Model freely available.

**Summary for the Swartland:** Technically complex and data intensive. X

#### **4) SLEMSA (Soil Loss EstiMator for Southern Africa) for the Swartland**

**Description:** Originally developed in the late 1960s in Zimbabwe to provide estimates of annual soil losses through sheet erosion on arable lands. SLEMSA has a framework for the development of local soil loss models that takes into account the specific conditions of major agro-ecological zones, their soils and environments. It proves reasonable accuracy with the ability to extrapolate to unmeasured conditions and to the complex farming systems of a developing country.

**Appropriate Use:** A rapid method for mapping ground layer vegetation cover. Estimate gross field rates of soil loss and sediment yields. Adaptable to a number of environmental conditions with modest data demands.

**Scope:** Plot-sized farming areas, not good for large generalisations.

**Key Output:** Estimated soil loss, as the 'field rate of soil loss' or 'gross erosion'.

**Key Input:** Mean annual rainfall, soil erodibility, vegetation cover, slope steepness, slope length.

**Ease of Use:** Easy to use. Its simplicity and cheapness with reasonable accuracy makes it ideal in developing countries. "It has the advantages of reasonable accuracy, simplicity, flexibility and suitability for less developed countries with a limited amount of data" (Lu and Stocking, 1994).

**Training Required:** No basic training required, just an understanding of climate and soil parameters.

**Computer Requirements:** Windows-based PC.

**Cost:** Inexpensive.

**Summary for the Swartland:** Simple, cheap and easily adaptable in the southern African region. ✓

## 5) USLE (Universal Soil Loss Equation) for the Swartland

**Description:** Released in the early 1960s USLE was originally developed for croplands in the eastern USA. It is an index-based, empirically derived model that allows one to estimate the average annual soil loss for a given region under natural and anthropogenic conditions. The USLE was originally derived from experimental data collected over a period of 20 years and so calculates soil loss over the long term.

**Appropriate Use:** Modellers need to validate the model prior to use, thus it has the disadvantage of being data demanding. Has been known to overestimate soil loss as it neglects the process of deposition.

**Scope:** At a field scale, the USLE is strictly valid only to cropland east of the Rocky Mountains in the United States. USLE has shown problems when applied to environments for which it was not originally designed, thus results need independent verification if used elsewhere.

**Key Output:** Soil loss from an area, simply as the product of empirical coefficients, which must be accurately evaluated. This soil loss has sometimes been referred to as "soil movement" (Clark, 1996) as the USLE does not account for the deposition of sediment.

**Key Input:** Rainfall erosivity, soil erodibility, slope length and steepness, land-use type, erosion-control practice factor.

**Ease of Use:** Attention must be paid to the reliability of the results when an application is made outside the range of experimental and calibrated conditions. Thus, it is easy to use, but requires validation within new areas of application.

**Training Required:** No basic training required, just an understanding of climate and soil parameters.

**Computer Requirements:** Windows PC. Data downloads as Excel or Text files.

**Cost:** Free downloads, other costs not identified.

**Summary for the Swartland:** USLE experienced difficulty of estimating and interpreting vegetation cover. X

## 6) WEPP (Water Erosion Prediction Project) for the Swartland

**Description:** A continuous simulation model, being physically process-based and therefore able to predict soil loss and deposition. These are done using a spatially and temporally distributed approach of soil loss and deposition for a wide range of time periods and spatial scales. Three different versions exist: the Hillslope version computes erosion along a single slope profile, while the Watershed version can be used to assess soil loss at the catchment scale. The Grid version divides a watershed into square grid cells, allowing easier linkages with GIS. WEPP takes into account climate, hydrology, water balance, plant growth, soil composition and consolidation.

**Appropriate Use:** Used for conservation planning. Not appropriate for areas with gullies and perennial streams.

**Scope:** Field-sized areas or conservation units.

**Key Output:** WEPP models net soil loss and deposition over a wide range of spatial and temporal scales. Other outputs include detailed soil, plant, water balance, crop yield, winter and rangeland values.

**Key Input:** The data files needed for input consist of climate, slope, soil, and cropping/management data. The Climate data is read from CLIGEN or BCDG (Amore *et al.*, 2004), while other key values comprise infiltration, runoff, erosion rate.

**Ease of Use:** Large data requirements when compared to the simple response functions of many other erosion modes (USLE and SLEMSA). These large quantities of data can be simplified through GIS technology.

**Training Required:** Training recommended in hillslope applications and hillslope interface.

**Computer Requirements:** Windows-based IBM PC with Geographic User Interface, possibly also ArcView GIS application software if simplifying the data.

**Cost:** Free downloads make this an inexpensive and rapid method for evaluating soil conservation options, but data intensive.

**Summary for the Swartland:** Data demanding when compared with other models. X

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## **APPENDIX D:**

SLEMSA calculation tables:

- 1) Correction factors for soil management techniques
- 2) Soil erodibility factors
- 3) Values of rainfall energy interception proportion

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1) Correction factors for soil management techniques (Elwell, 1980). The factors are to be added algebraically to the soil erodibility factor,  $F$ , to determine the equation  $F_m = F_b + \text{correction factor}$ .

Practice		Factor		
A	Soil loss in previous year	<10 t/ha	0	
		10 to 20 t/ha	-0.5	
		>20 t/ha	-1.0	
B	Ridging practices	Normal tilth	0	
		Fine powdery	-0.25	
B1	Crops on large ridges (>200mm)	Slope < 1%	1.5	
		Ridges without tie-ridges	Slope < 1%	1.0
			Slope 1 to 2%	0
			Slope > 2%	-1.0
B2	Crops on small ridges (<200mm)	Slope < 1%	-1.0	
			Slope 1 to 2%	0
			Slope > 2%	-1.0
C1	Annual crops planting direction	On contours	0	
			Angle to contours	-0.25
			At right angle	-0.5
C2	Tillage techniques	Fine powdery tilth	-0.5	
			Zero tillage	-0.5
			Disced fine tilth	0
			Ripped and disced	0
			Plowed and rolled	0.5
			Plowed only	1.0
D	Fallows and leys	First year	0	
			Second year	1.0
			Third year and more	2.0
			Good pasture	2.0
E	Perennial crops and orchards	Mechanical cultivation	-0.5	
			Herbicide weed control	0
			Mulch soil cover	2.0
F	Irrigated lands	Sands and loams	-0.5	
			Good pastures	3.0

2) Soil erodibility factors,  $F_b$ , for various soil types (Elwell, 1980).

Soil group	Soil family	Texture of topsoil		
		Sands	Loams	Clays
Regosol	Kalahari sand	4.0		
Lithosol	Lithosol	2.0	2.5	4.0
Vertisol	Basic rocks			5.0
	Sediments			4.5
Siallitic	Basic rocks		3.5	4.0
	Ultra basic			4.0
	Sediments			3.5
Fersiallitic	Sandstones	3.5	4.0	
	Granites			
	Basic rocks		5.5	6.0
	Ultra basic			6.0
Paraferrallitic	Sediments		4.5	4.5
	Granites	4.0	4.5	
	Arenaceous	3.5	4.0	
Orthoferrallitic	Granites	4.5	5.0	
Sodic	Basic rocks			7.0
	Sediments			5.5
	Granites	5.5	6.5	6.5
	Sandstones	5.0	6.0	
Sodic	Strongly sodic	1.0	1.5	1.5
	Weakly sodic/saline	1.0	1.5	2.0

3) The values of rainfall energy interception proportion,  $i\%$ , for various crops and emergence times before (-) or after the start of the rainy season (Eiwell, 1980). As wheat was not one of the crops presented below, sorghum was taken as representative as it is also grown in the Swartland and has shown similar yields under the same climatic conditions as winter wheat.

Crop	Yield (t/ha)	Emergence time after start of rainy season				
		-1 mth	0	1 mth	2 mth	3 mth
Cotton	1.0	62	55	41	24	9
	2.5	84	75	56	32	13
	4.5	95	84	63	36	14
Cowpeas hay	1.5	54	62	67	55	35
	2.5	65	76	81	67	43
Cowpeas silage	2.0	26	29	32	29	20
	6.0	43	50	54	49	34
	10.0	61	70	83	69	48
Ground nuts	0.8	50	57	49	32	16
	1.5	64	73	62	41	20
	3.0	71	80	69	45	22
Maize	2.0	24	29	28	21	12
	6.0	43	52	51	37	21
	10.0	55	68	66	48	27
Rice	1.5	54	56	53	40	24
	2.5	69	72	67	51	31
	4.5	84	88	82	62	37
Sorghum	1.0	39	40	35	25	12
	2.0	47	49	43	30	15
	6.0	81	84	73	52	26
Soybeans	0.8	34	38	36	27	14
	1.5	51	57	54	39	20
	2.5	69	77	73	53	28
	4.0	80	90	85	62	32
Sunflowers	0.1	5	8	11	9	5
	0.4	11	19	24	21	12
	1.3	28	50	62	55	30

**APPENDIX E:**

Table of historical wheat yields for the Swartland for 1947 – 1987.

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Wheat yield in the Swartland from government historical records.

Date	Millions of bags produced	Area (ha)	Yield (t/ha)
1947			0.616703
1948			0.685225
1949			0.625268
1950	1.4		0.625268
1951	1.4		0.693791
1952	1.4		0.693791
1953	1.4		0.719487
1954	1.4		0.685225
1955	1.5	160.6585716	0.933657
1956	1.4	155.6444458	0.899486
1957	1.7	173.2824902	0.981057
1958	1.6	150.570096	1.062628
1959	1.8	171.3466514	1.050502
1960	1.5	154.8097852	0.968931
1961	2.1	179.8950955	1.167347
1962	1.6	198.5631474	0.805789
1963	2	178.4041747	1.12105
1964	2.6	184.1147233	1.412163
1965	1.7	175.4510899	0.968931
1966	1.9	169.4839659	1.12105
1967	2.5	179.9970048	1.388912
1968	2.7	195.9519236	1.377889
1969	1.6	185.1397574	0.864212
1970	3	213.121008	1.407651
1971	2.5	203.9534334	1.22577
1972	2.8	216.3644133	1.294113
1973	2.9	214.937568	1.349229
1974	2.5	174.6019984	1.444027
1975	3	164.7396919	1.576305
1976	2.2	170.7898737	1.300727
1977	2	174.5415879	1.146403
1978	0.8	117.7449971	0.655875
1979	2.4	171.9572522	1.380093
1980	2.7	181.7110957	1.506859
1981	3.1	169.0136642	1.843064
1982	3.4	194.4934	1.770312
1983	3.6	216.355588	1.683229
1984			1.77913
1985			1.709684
1986			1.729526
1987			2.188087

**APPENDIX F:**

Monthly rainfall at Boshof farm in Malmesbury, Swartland, from January 1966 –  
May 2005.

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Boshoff monthly rainfall statistics (mm) with May to September being the dominant rainfall period for the region. Blue indicates good farming years, and orange indicates bad farming years. No data was available for 1983.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	yrly total	May-Sept total
1966	0	0	47	21	15	47	74	35	36	2	6	4	287	207
1967	4	1	1	63	23	97	26	42	19	35	30	0	341	207
1968	16	0	0	56	56	54	100	37	6	67	8	10	410	253
1969	15	5	4	39	5	44	21	70	44	45	5	0	297	184
1970	7	7	0	0	46	100	56	55	38	19	0	0	328	295
1971	0	2	27	2	23	65	53	71	11	9	4	0	267	223
1972	6	6	5	51	42	48	45	27	21	6	0	30	287	183
1973	0	0	25	5	34	13	121	65	49	15	0	38	365	282
1974	0	0	7	0	117	139	77	267	58	52	0	1	718	658
1975	14	1	3	45	102	58	69	48	4	22	24	0	390	281
1976	0	0	19	72	29	101	38	29	34	0	86	49	457	231
1977	25	19	0	57	131	108	110	46	40	23	13	0	572	435
1978	0	0	14	18	31	8	9	7	47	11	10	18	173	102
1979	0	29	0	22	64	44	30	59	29	43	5	0	325	226
1980	0	0	0	32	60	65	24	52	23	10	122	0	388	224
1981	24	0	18	22	11	58	83	82	73	12	10	0	393	307
1982	31	3	61	59	48	73	94	47	7	56	0	0	479	269
1983														
1984	8	0	60	14	118	36	39	29	88	47	0	35	474	310
1985	14	10	78	57	26	71	72	54	35	9	3	0	429	258
1986	5	0	17	14	33	58	59	99	32	0	0	0	317	281
1987	15	0	4	45	70	79	109	77	71	7	3	15	495	406
1988	0	0	13	113	12	60	51	66	31	7	6	0	359	220
1989	6	15	54	52	47	37	64	84	47	47	0	0	453	279
1990	8	20	0	105	67	79	86	20	17	0	11	0	413	269
1991	7	8	3	20	40	40	75	11	62	37	9	0	312	228
1992	0	20	12	36	45	76	60	29	35	57	12	0	382	245
1993	0	15	0	95	105	43	89	38	13	2	4	16	420	288
1994	0	0	9	28	22	152	29	10	49	13	0	0	312	262
1995	0	0	16	9	24	70	64	55	12	42	0	77	369	225
1996	0	47	12	31	45	69	77	69	69	37	30	13	499	329
1997	8	0	0	36	51	99	9	55	4	6	27	6	301	218
1998	0	0	0	14	131	38	39	41	19	23	35	0	340	268
1999	0	0	0	31	41	39	52	60	88	0	8	0	319	280
2000	0	0	9	6	22	37	61	53	52	3	34	0	277	225
2001	14	15	0	27	83	37	205	110	55	44	32	0	622	490
2002	60	31	5	37	99	64	95	87	40	31	12	0	561	385
2003	19	0	33	33	27	8	27	127	36	22	0	44	376	225
2004	6	0	11	45	8	80	40	64	23	75	0	0	352	215
2005	0	0	0	72	74									
Ave													391	276

## APPENDIX G:

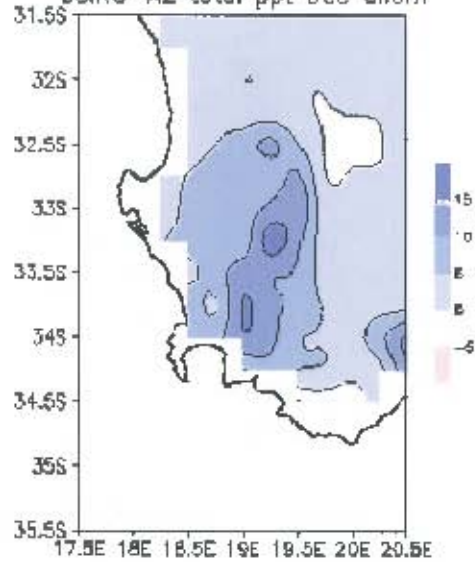
Downscaled climate change anomalies of the variables of the regionally downscaled monthly precipitation examined in *Chapter Five*. They include the following:

- 1) CSIRO-A2 total precipitation djf and mam
- 2) CSIRO-A2 total precipitation jja and son
- 3) CSIRO-B2 total precipitation djf and mam
- 4) CSIRO-B2 total precipitation jja and son
- 5) ECHAM total precipitation djf and mam
- 6) ECHAM total precipitation jja and son
- 7) HADAM total precipitation djf and mam
- 8) HADAM total precipitation jja and son
  
- 9) CSIRO-A2 raindays > 20.00mm djf and mam
- 10) CSIRO-A2 raindays > 20.00mm jja and son
- 11) CSIRO-B2 raindays > 20.00mm djf and mam
- 12) CSIRO-B2 raindays > 20.00mm jja and son
- 13) ECHAM raindays > 20.00mm djf and mam
- 14) ECHAM raindays > 20.00mm jja and son
- 15) HADAM raindays > 20.00mm djf and mam
- 16) HADAM raindays > 20.00mm jja and son
  
- 17) CSIRO-A2 dry spell duration djf and mam
- 18) CSIRO-A2 dry spell duration jja and son
- 19) CSIRO-B2 dry spell duration djf and mam
- 20) CSIRO-B2 dry spell duration jja and son
- 21) ECHAM dry spell duration djf and mam
- 22) ECHAM dry spell duration jja and son
- 23) HADAM dry spell duration djf and mam
- 24) HADAM dry spell duration jja and son
  
- 25) CSIRO-A2 90<sup>th</sup> percentile djf and mam

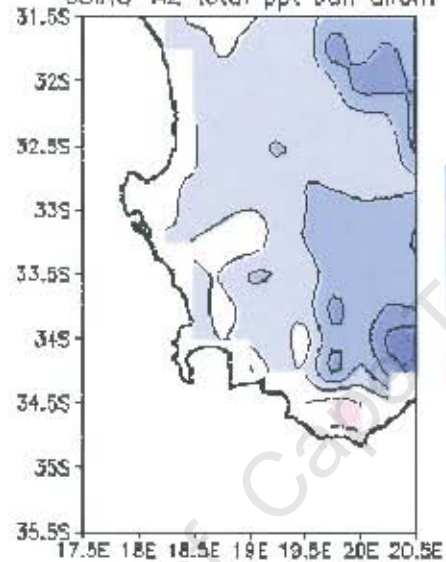
- 26)CSIRO-A2 90<sup>th</sup> percentile jja and son
- 27)CSIRO-B2 90<sup>th</sup> percentile djf and mam
- 28)CSIRO-B2 90<sup>th</sup> percentile jja and son
- 29)ECHAM 90<sup>th</sup> percentile djf and mam
- 30)ECHAM 90<sup>th</sup> percentile jja and son
- 31)HADAM 90<sup>th</sup> percentile djf and mam
- 32)HADAM 90<sup>th</sup> percentile jja and son

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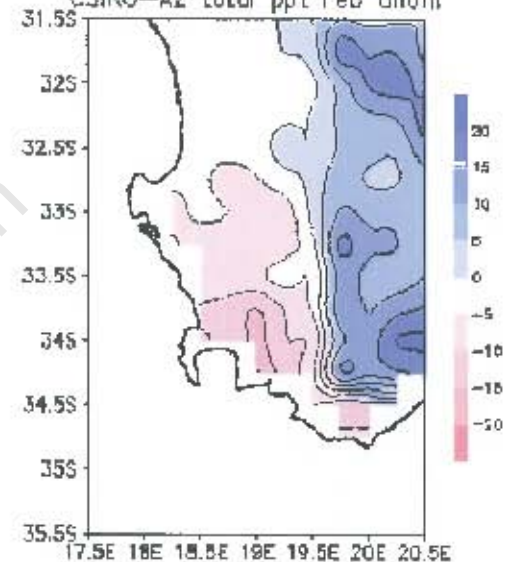
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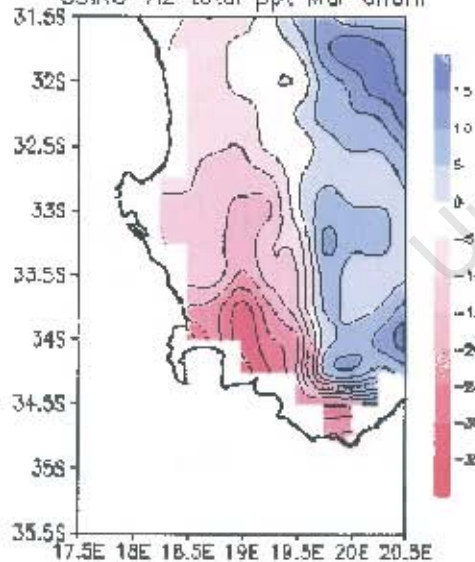
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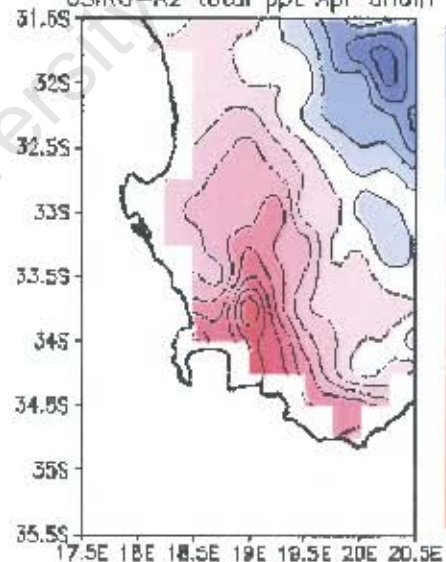
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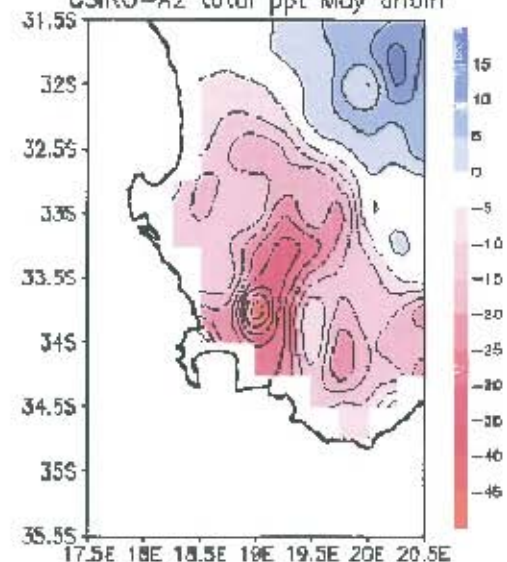
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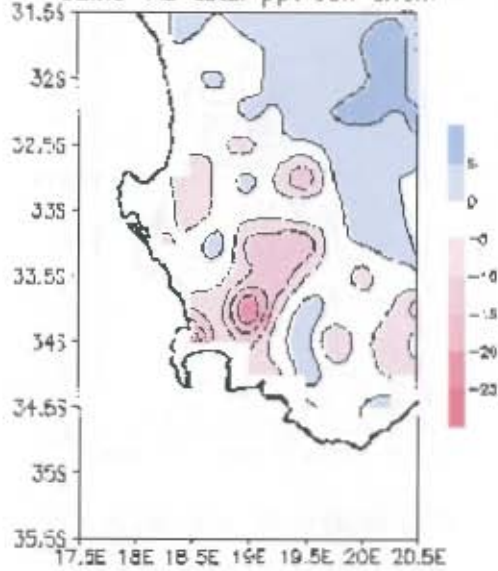
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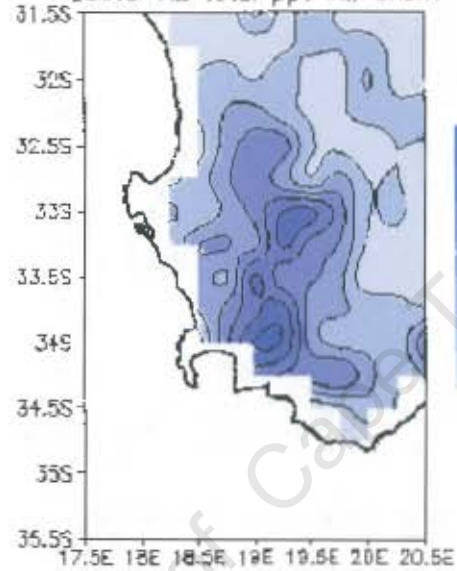
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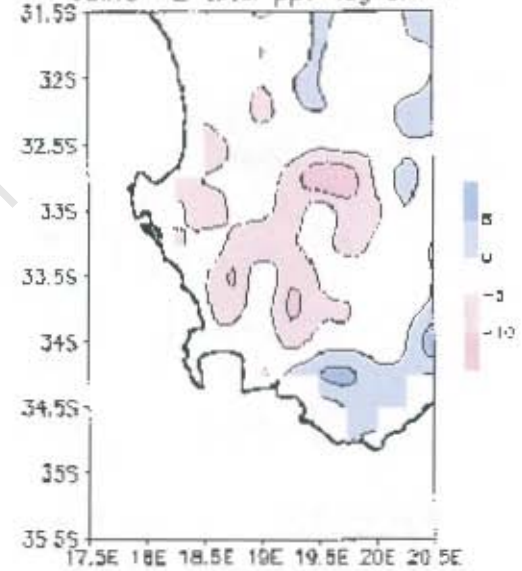
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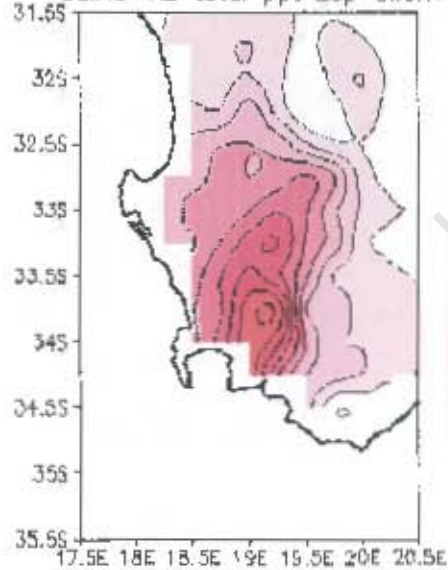
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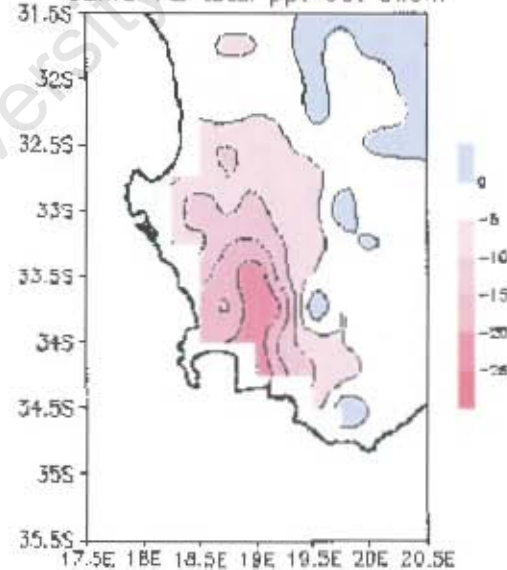
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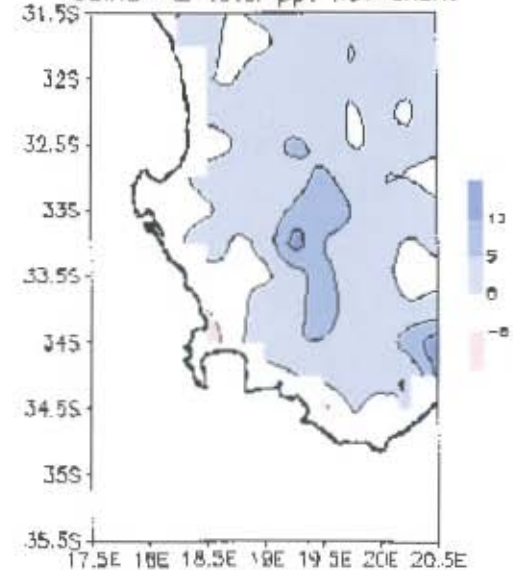
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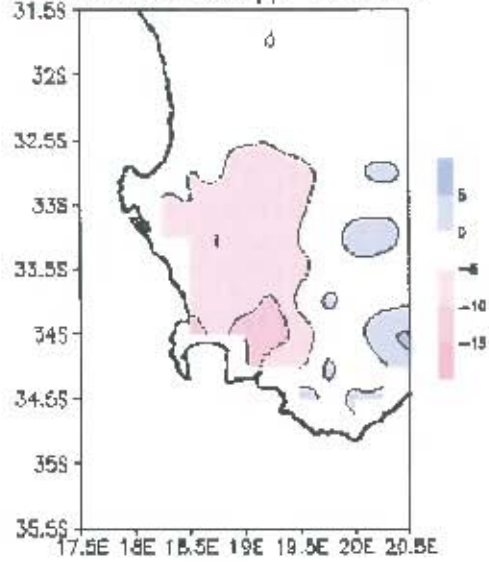
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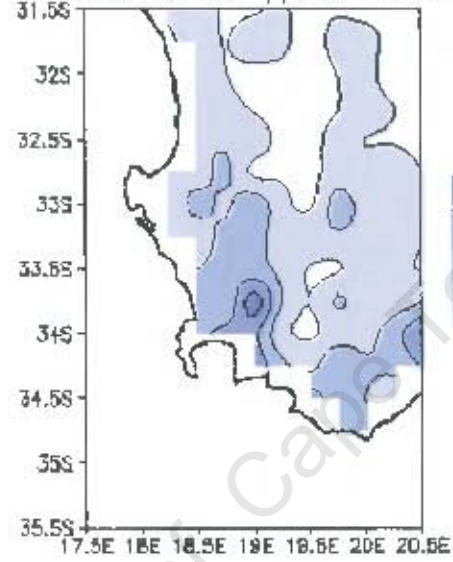
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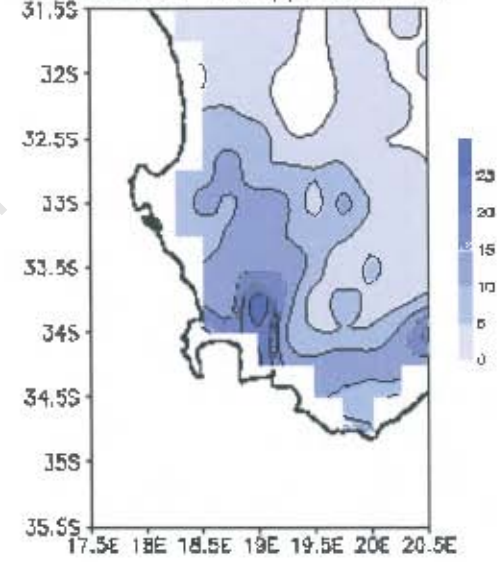
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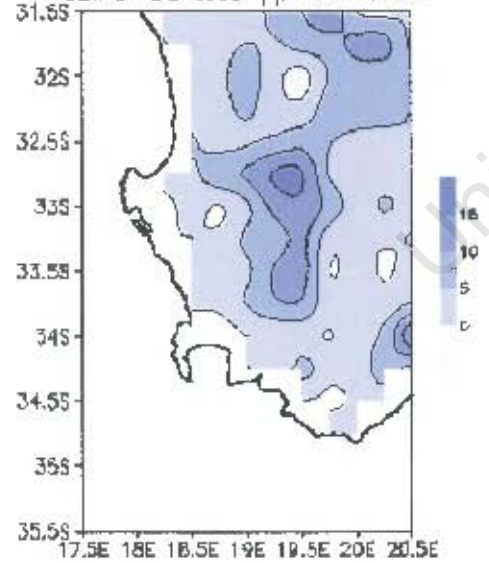
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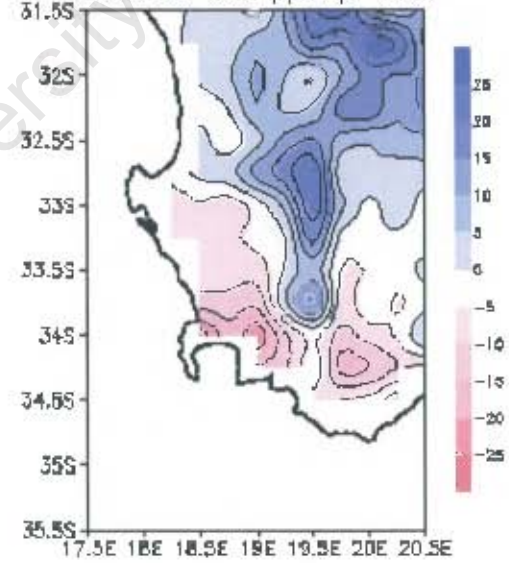
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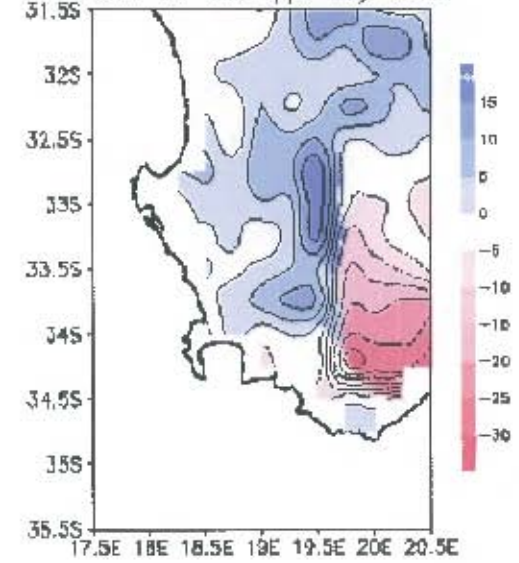
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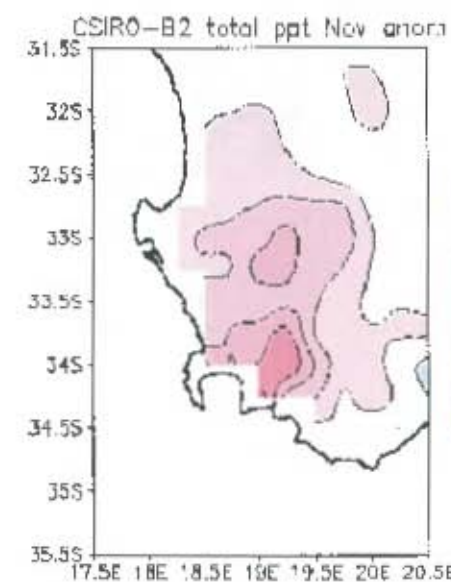
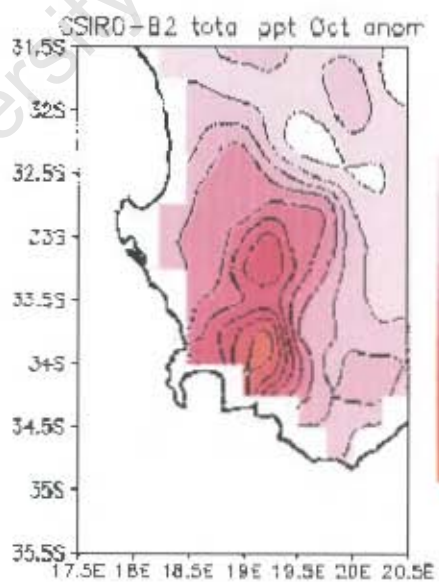
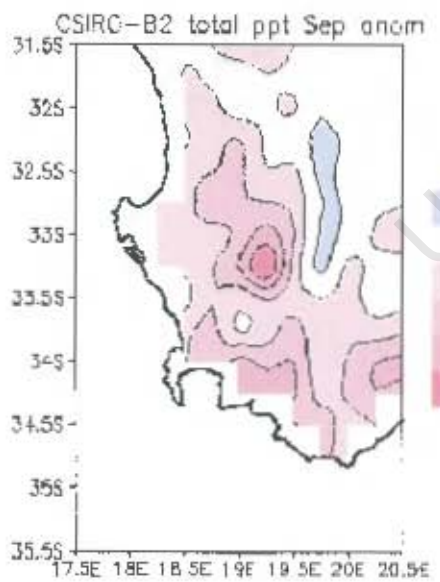
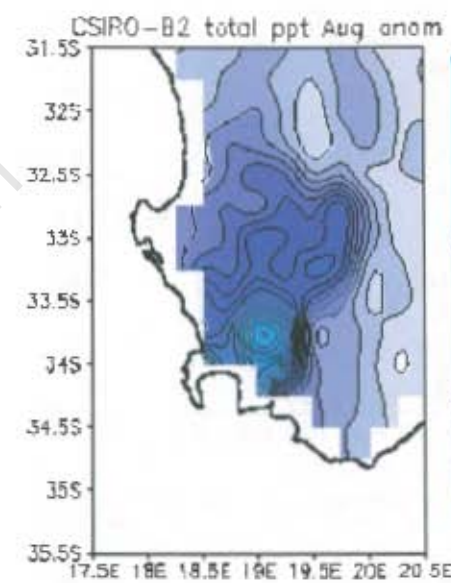
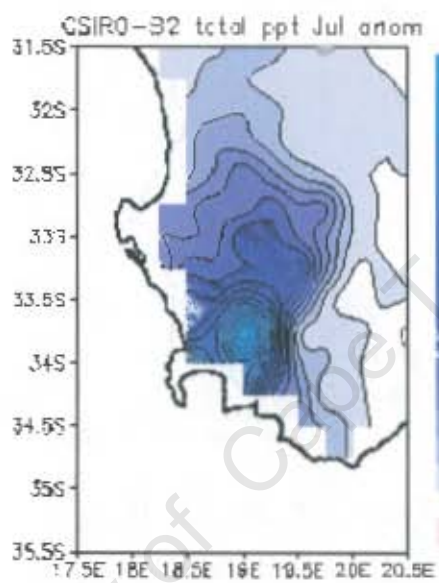
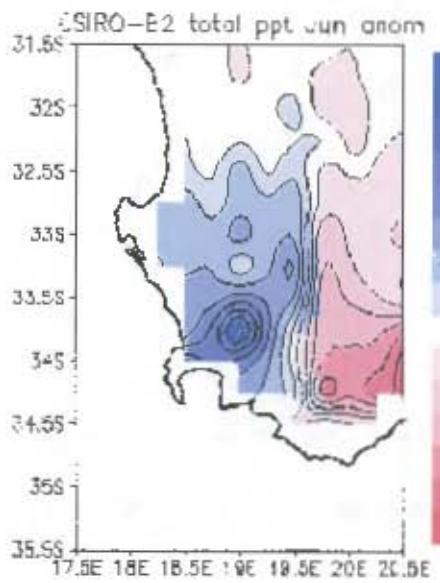


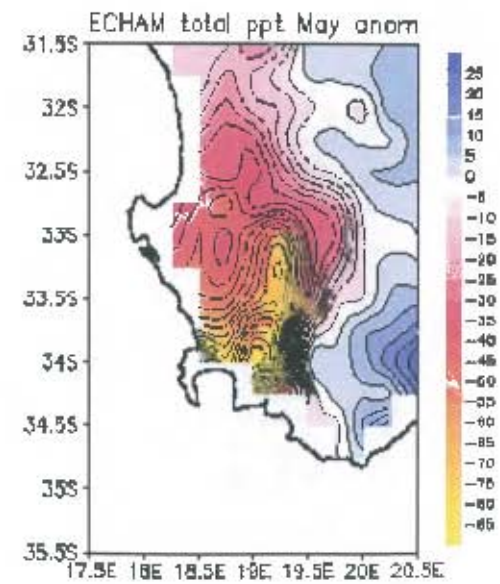
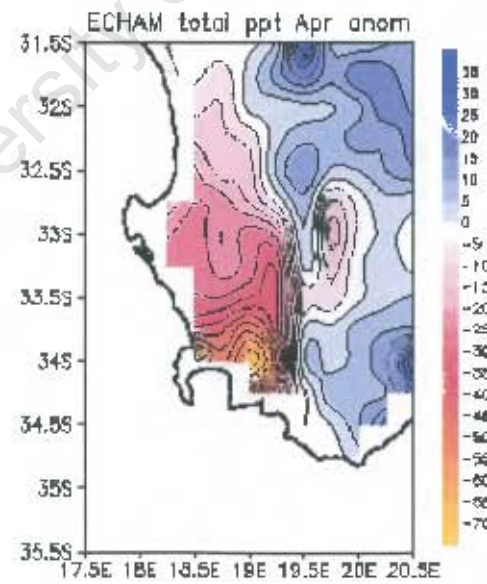
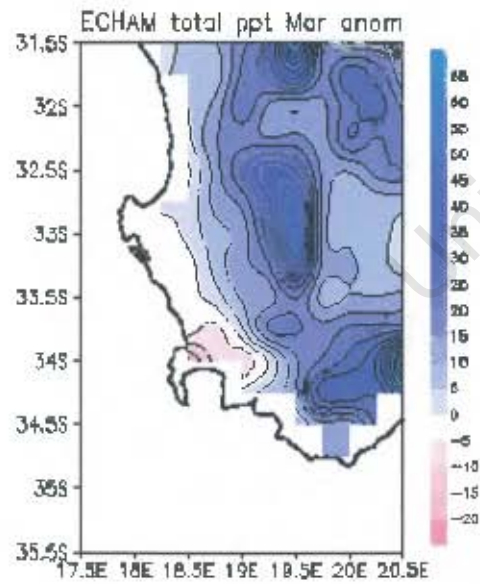
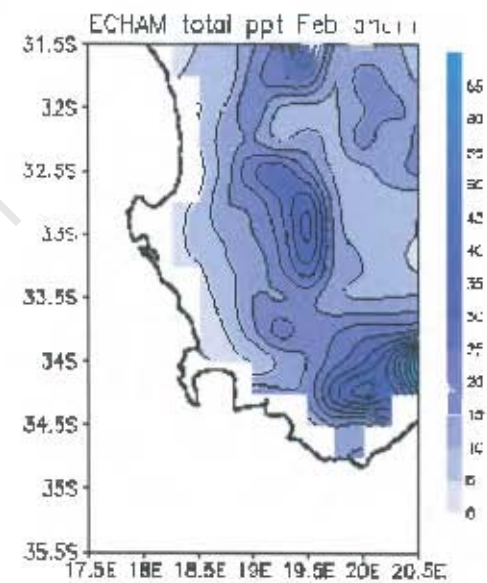
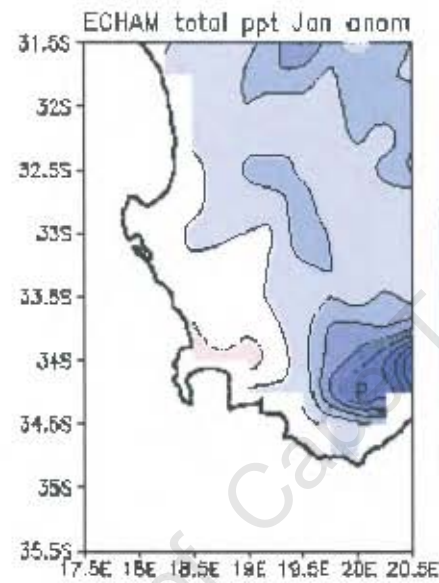
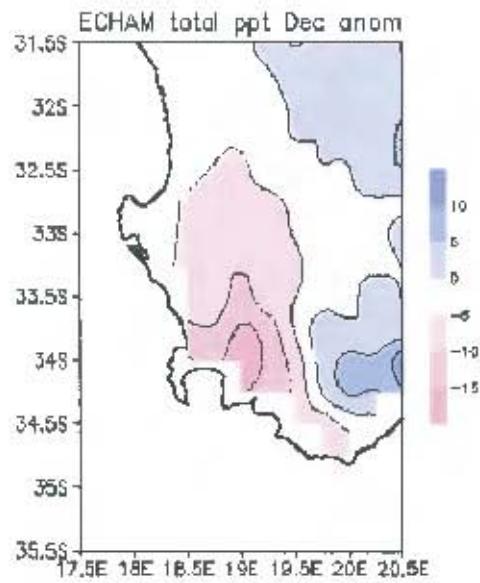
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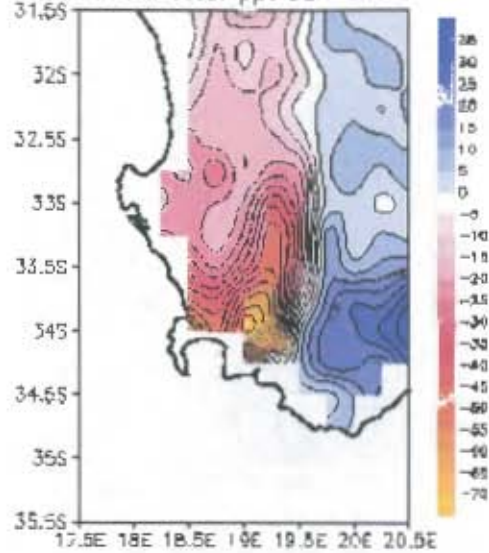
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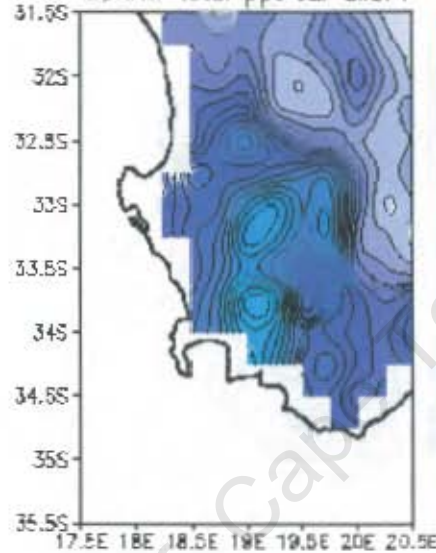




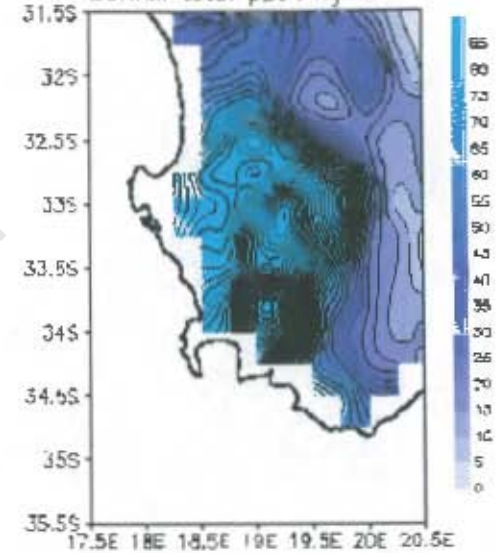
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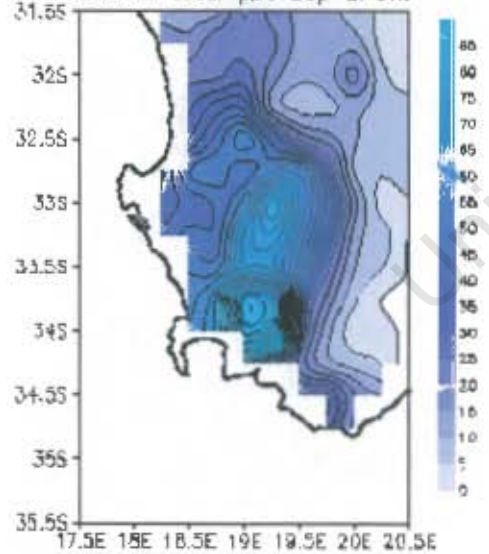
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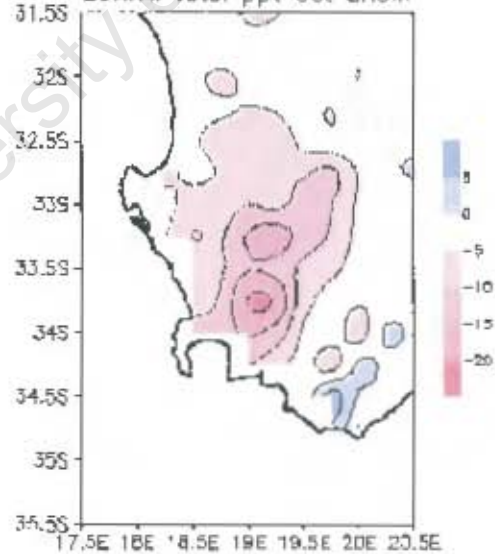
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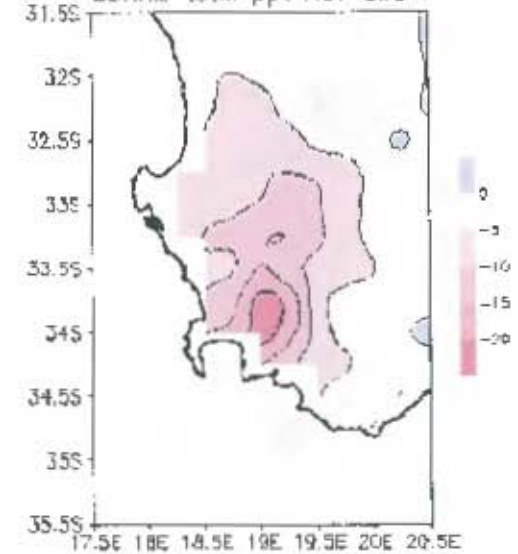
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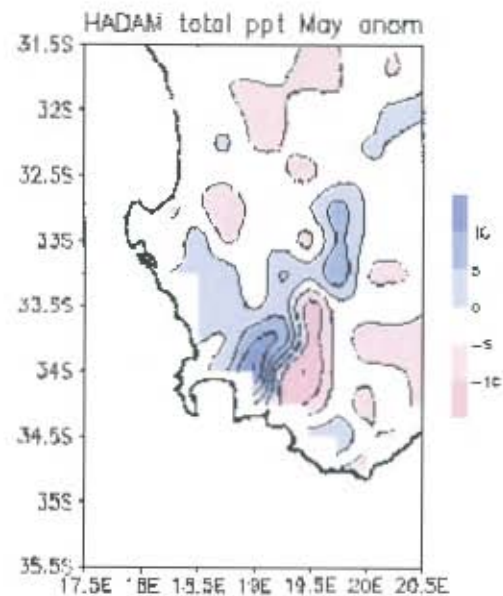
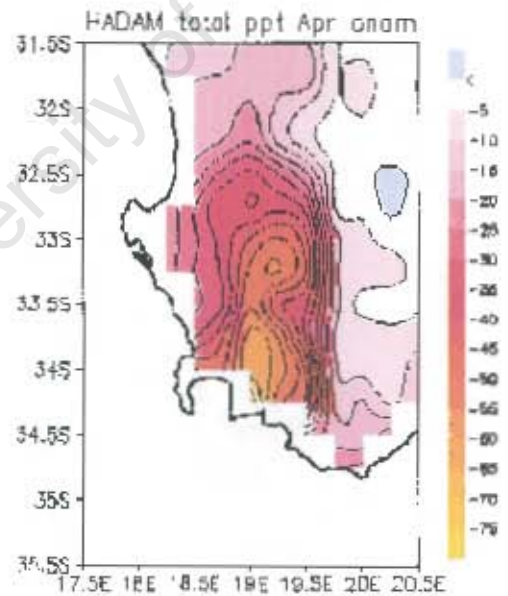
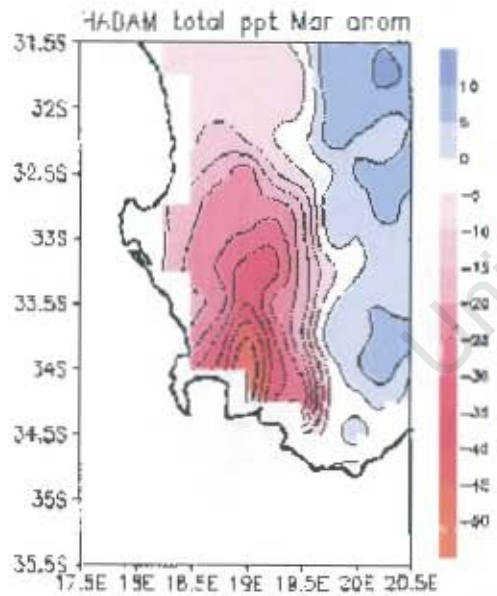
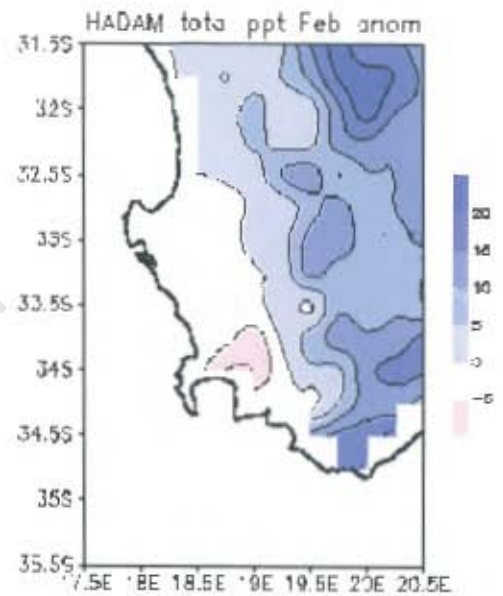
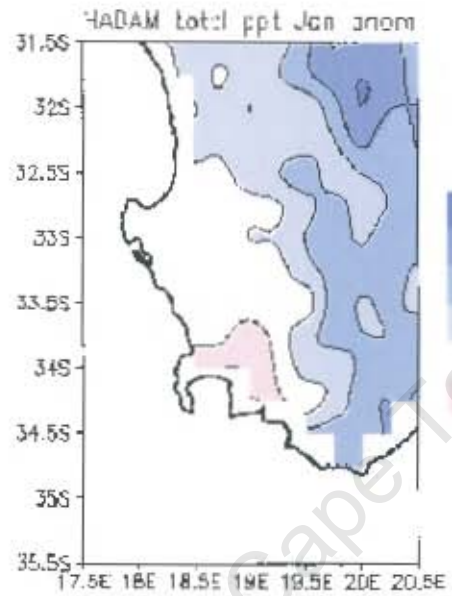
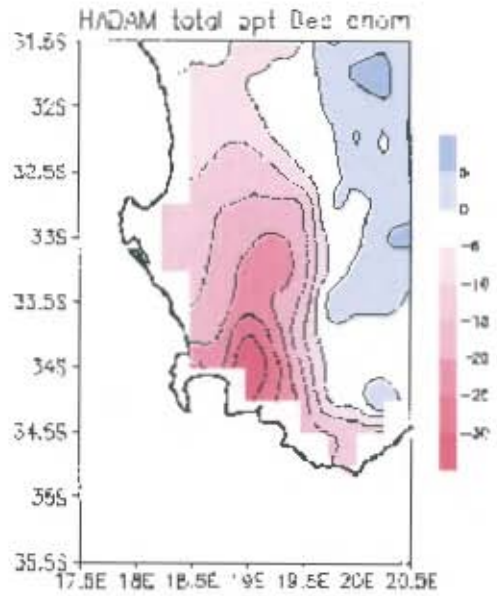


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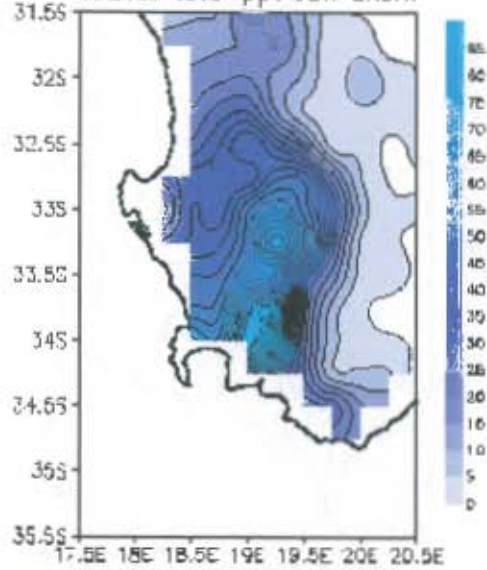


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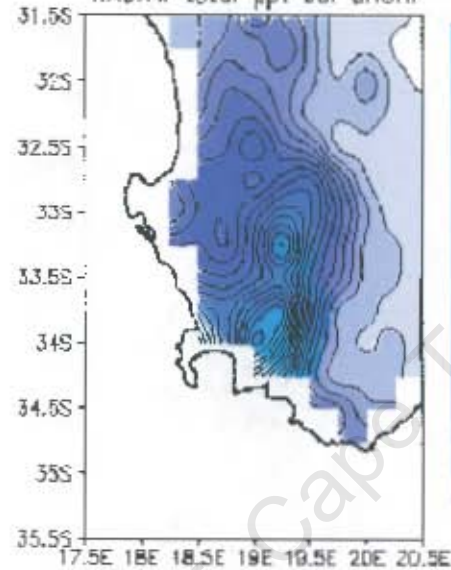




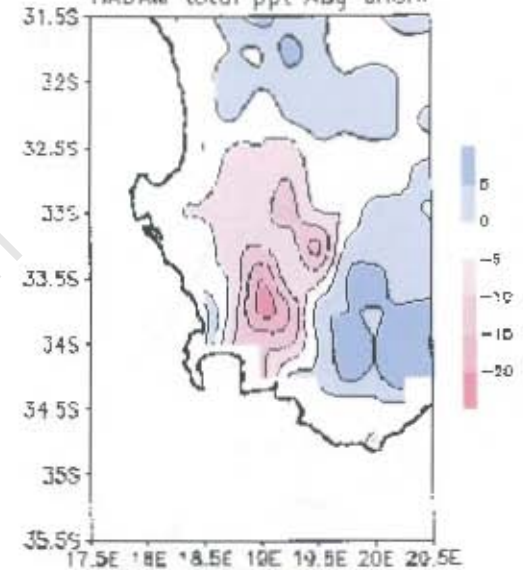
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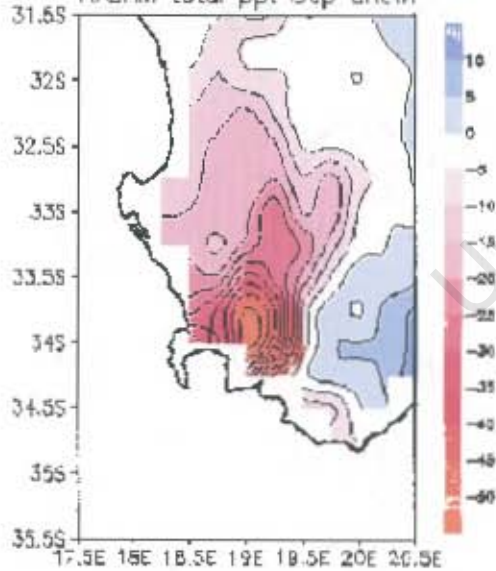
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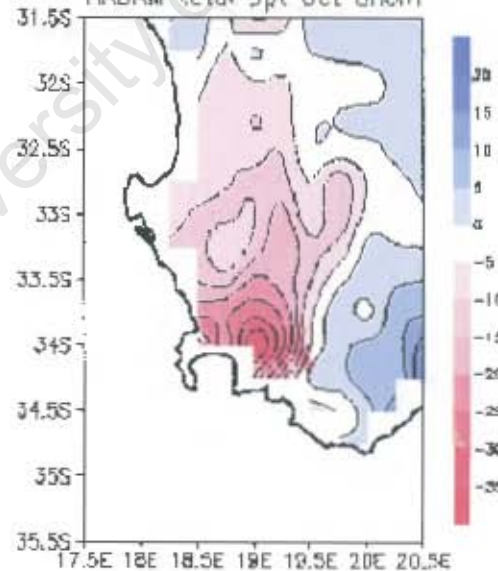
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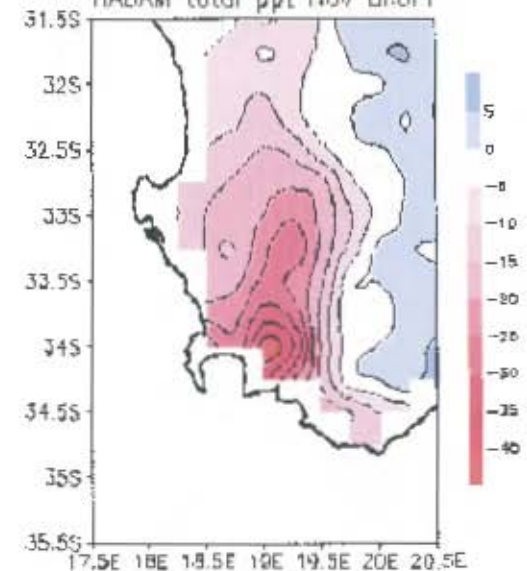
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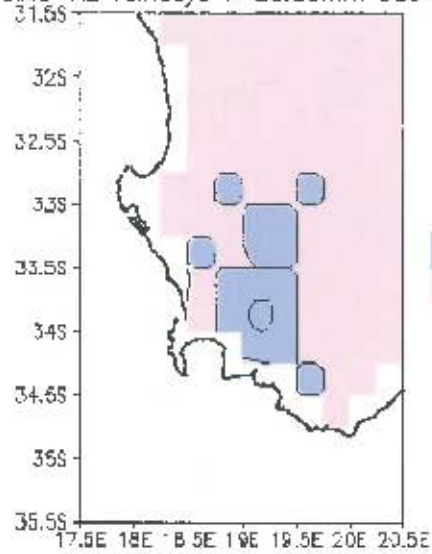
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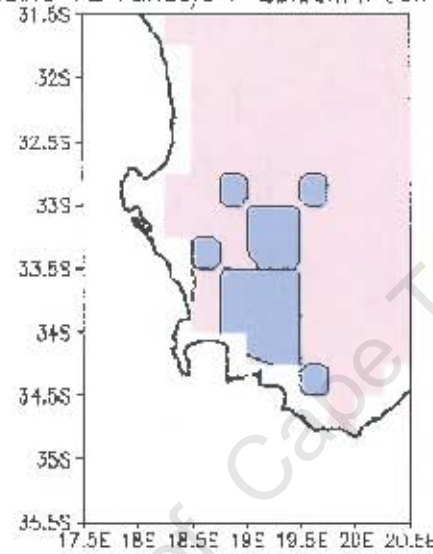
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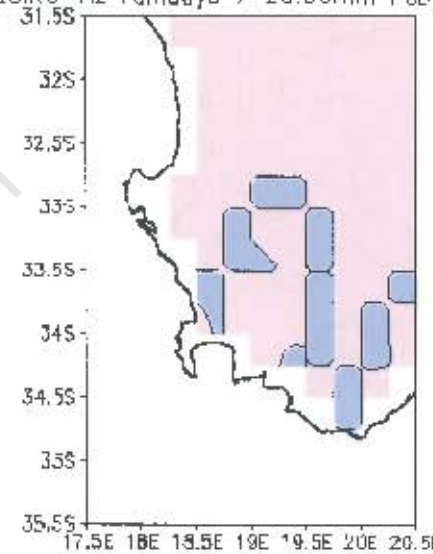
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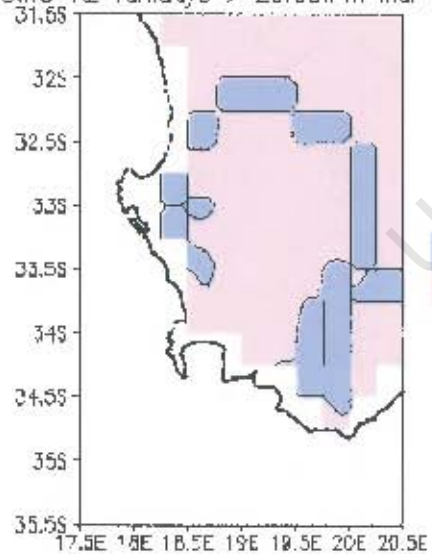
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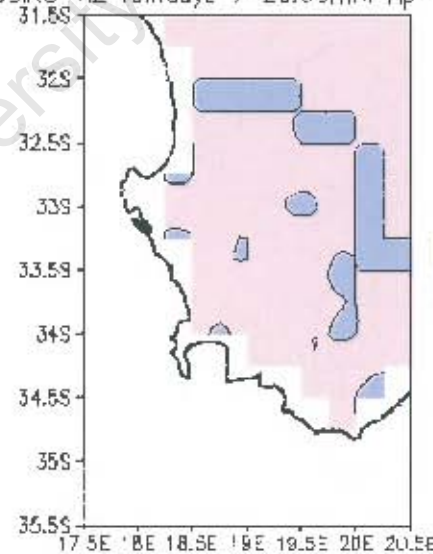
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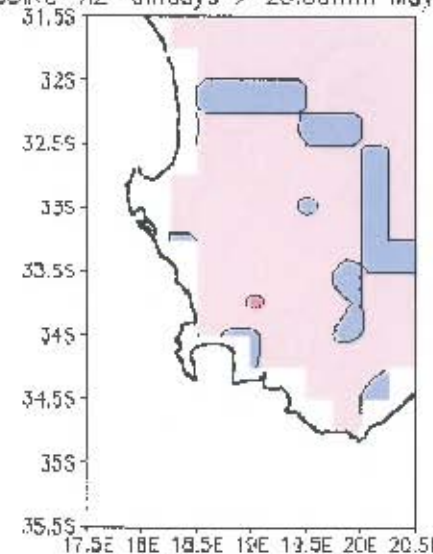
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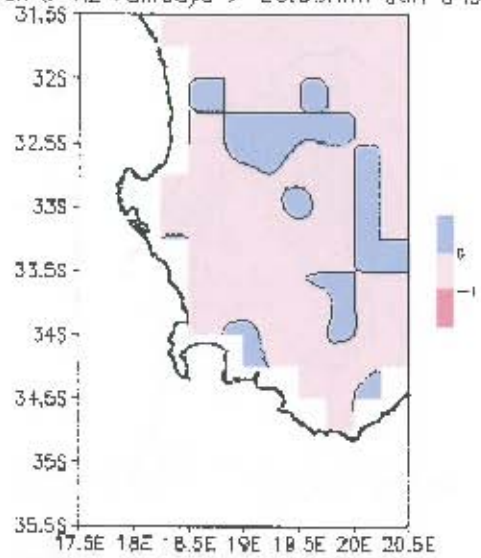
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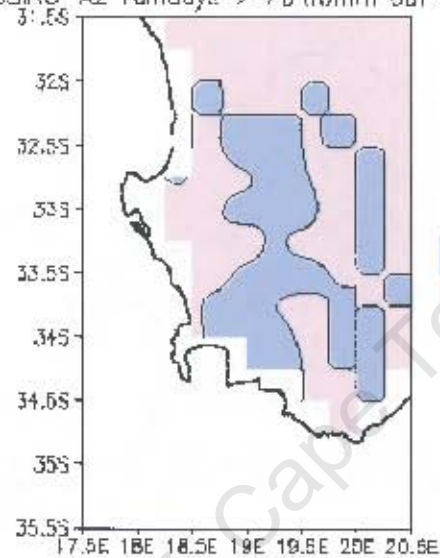
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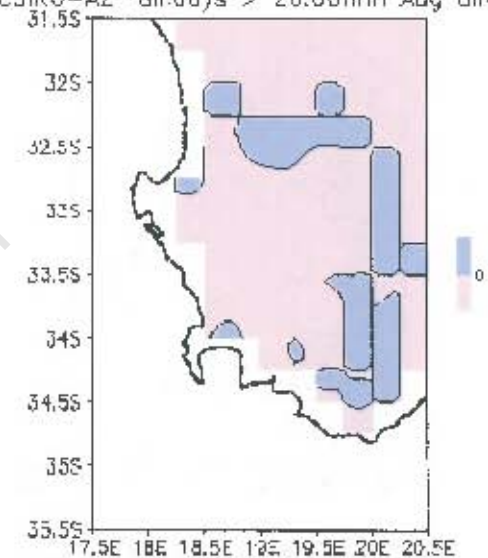
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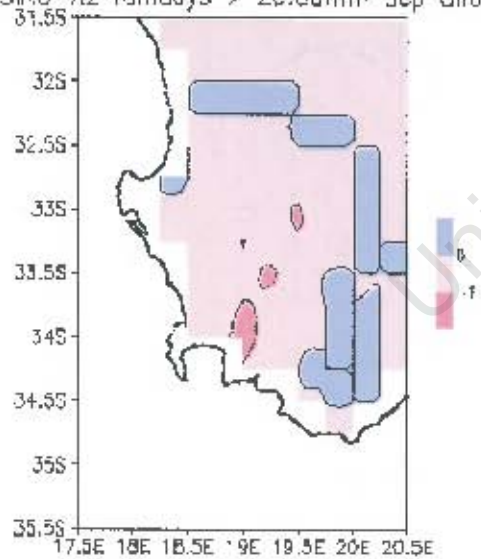
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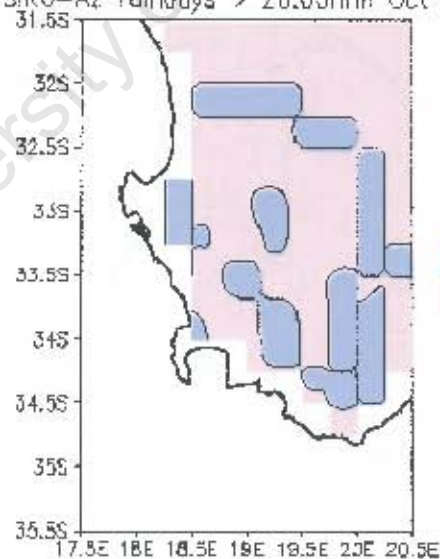
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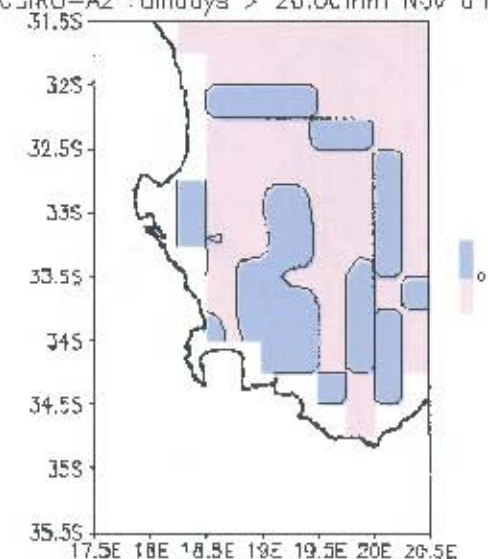
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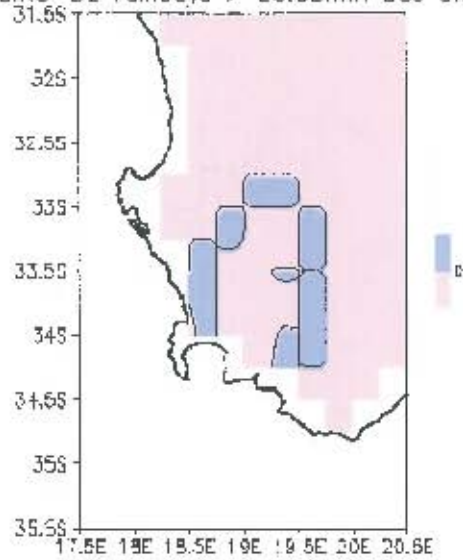
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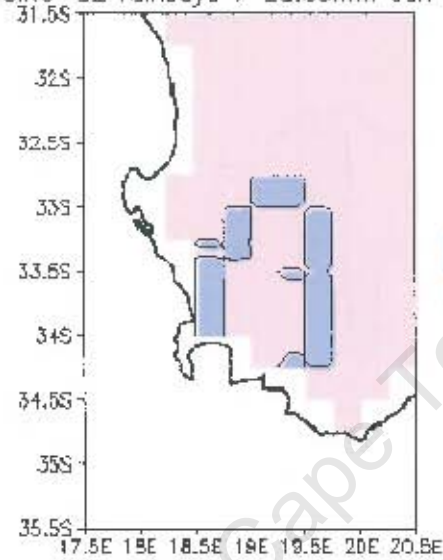
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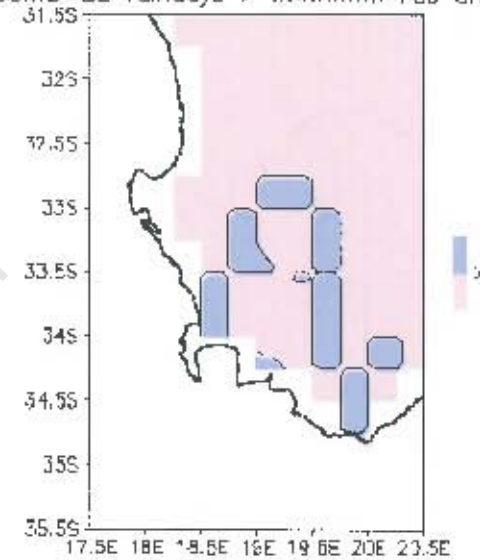
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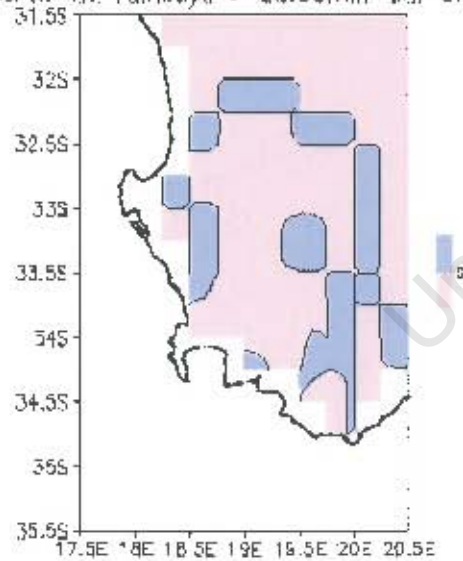
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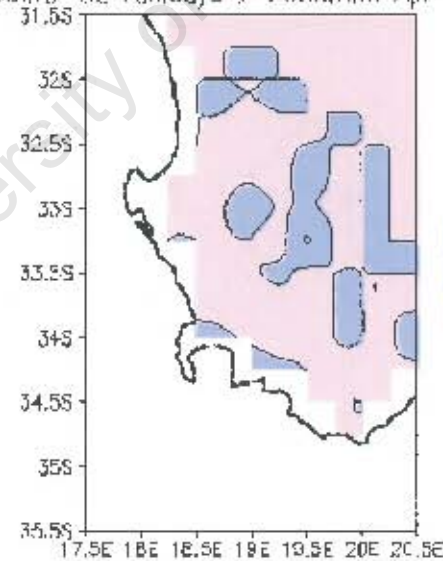
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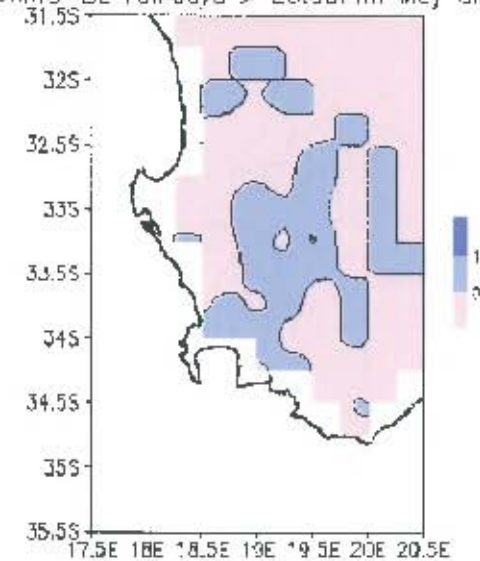
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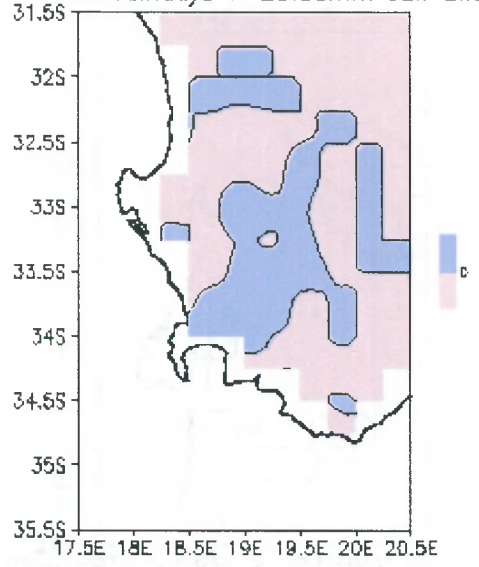
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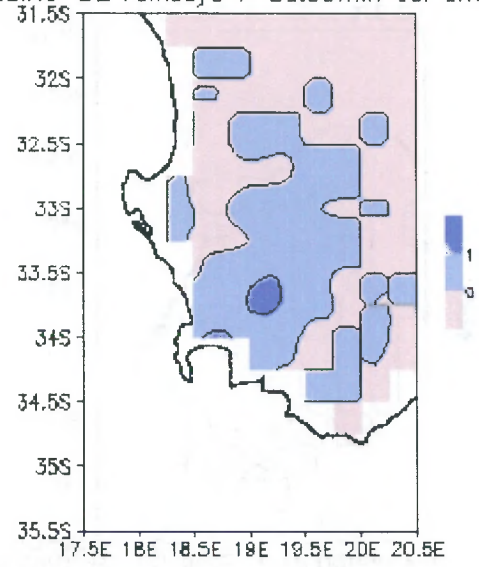
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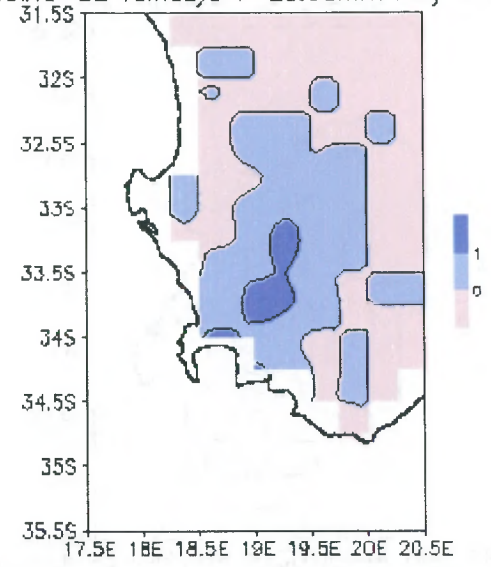
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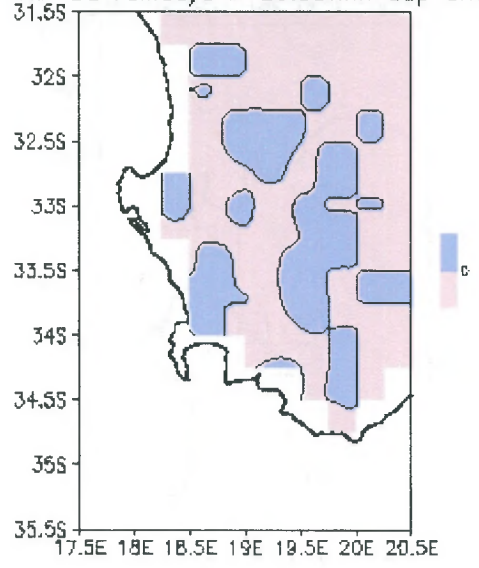
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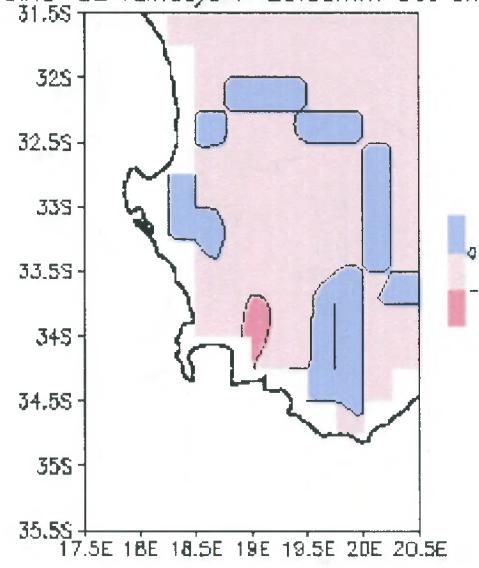
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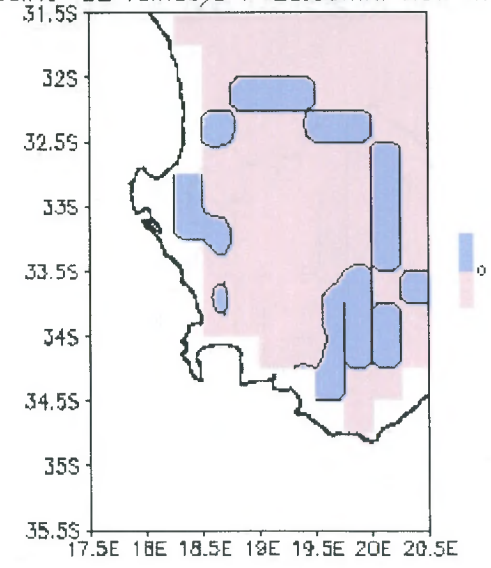
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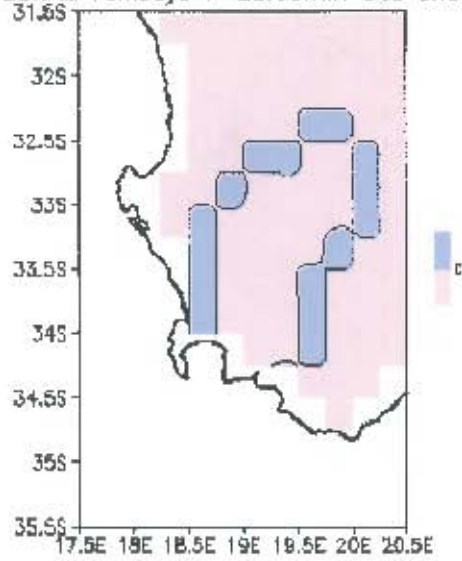
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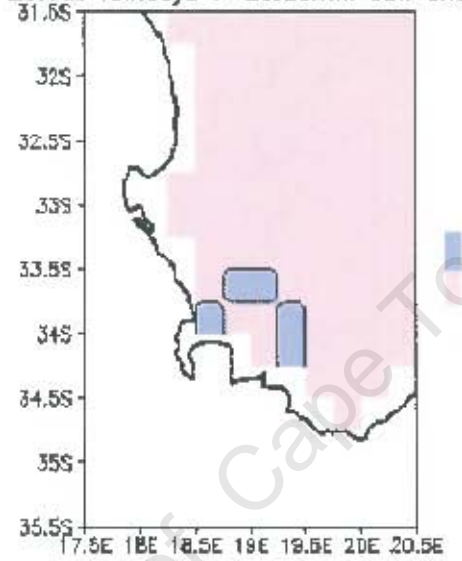
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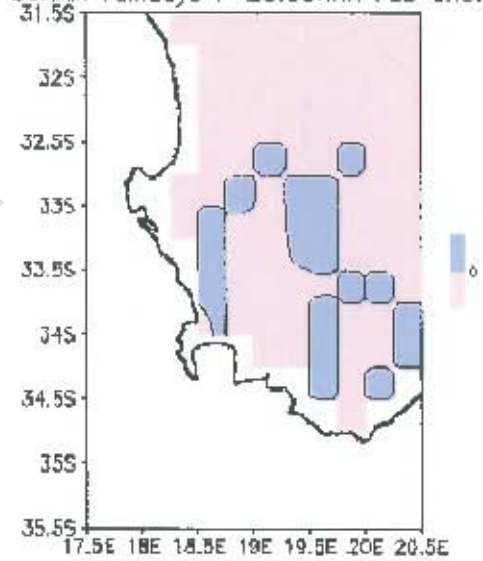
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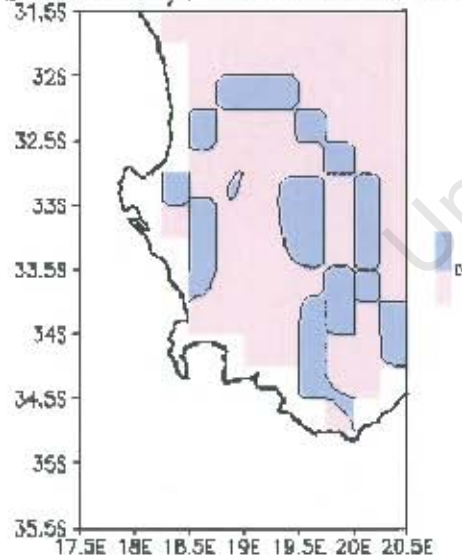
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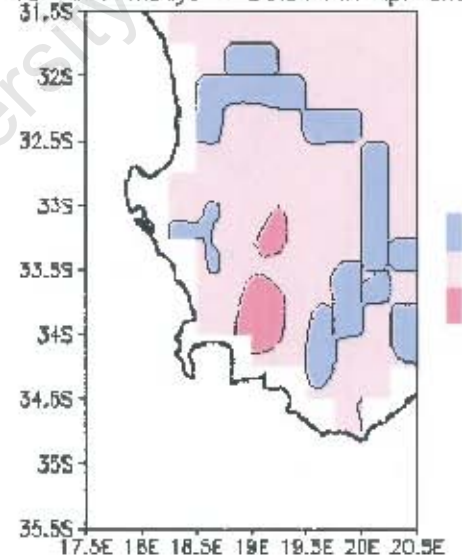
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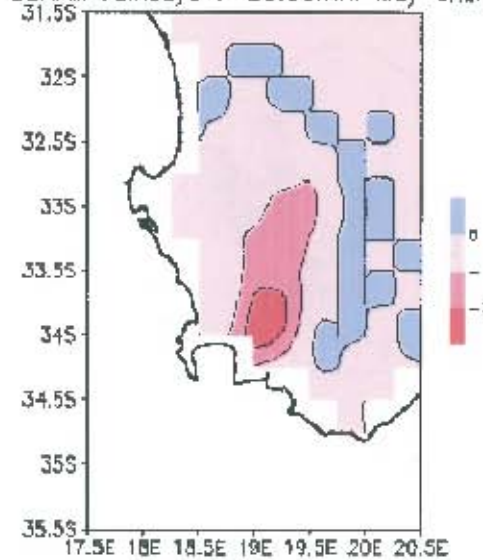
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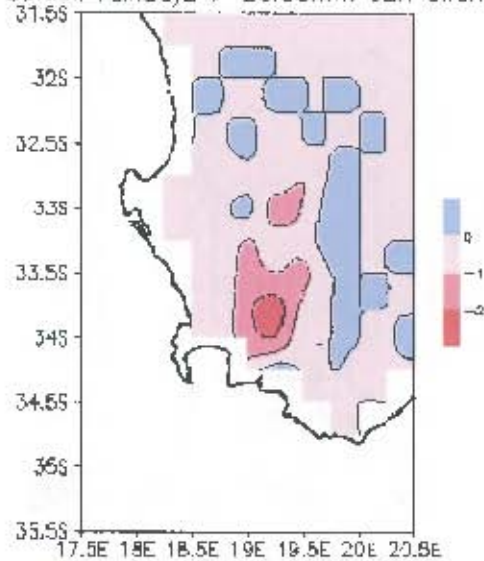
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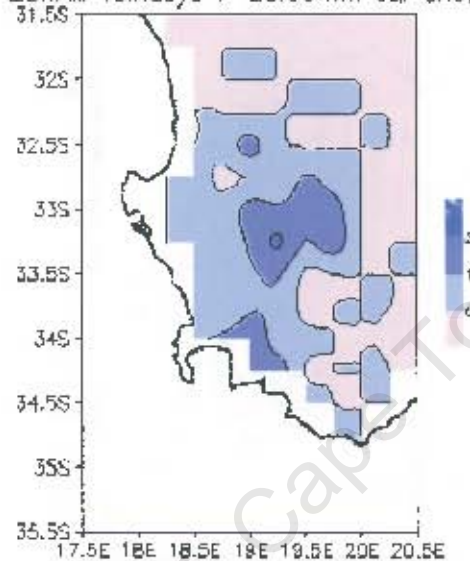
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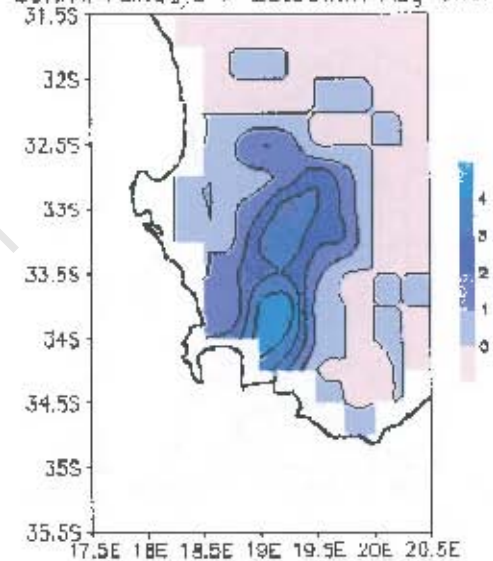
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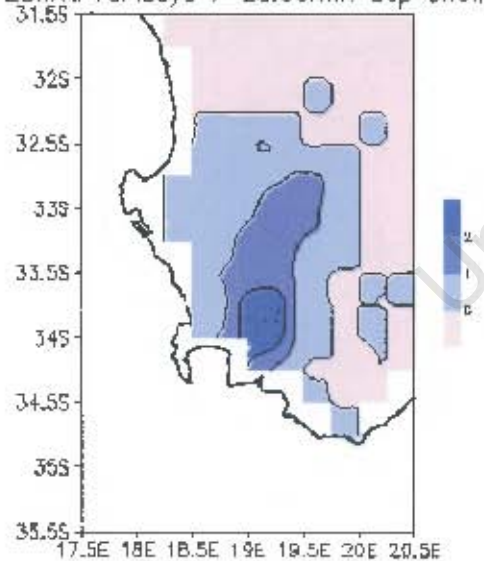
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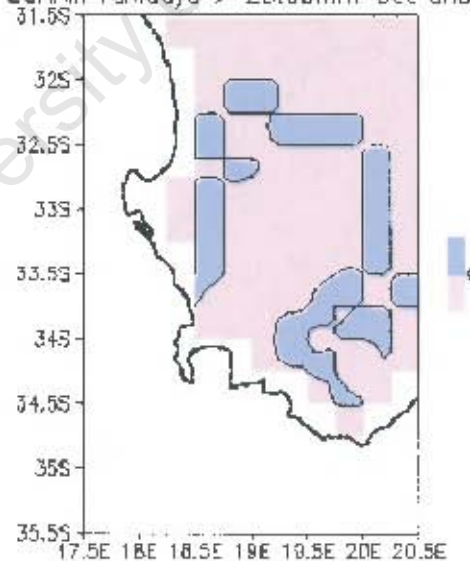
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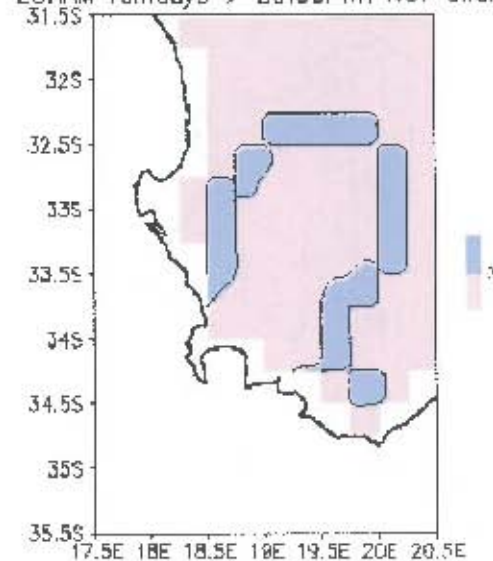
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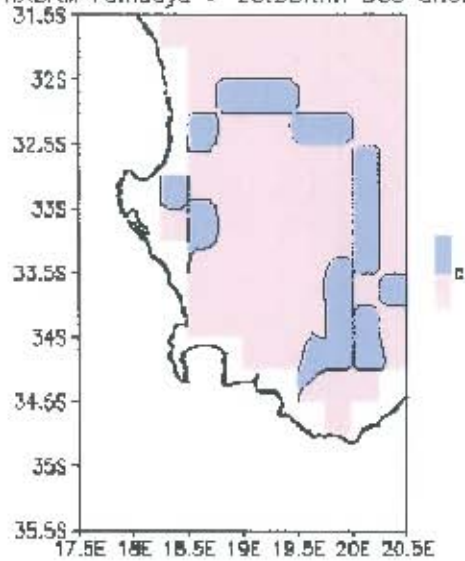
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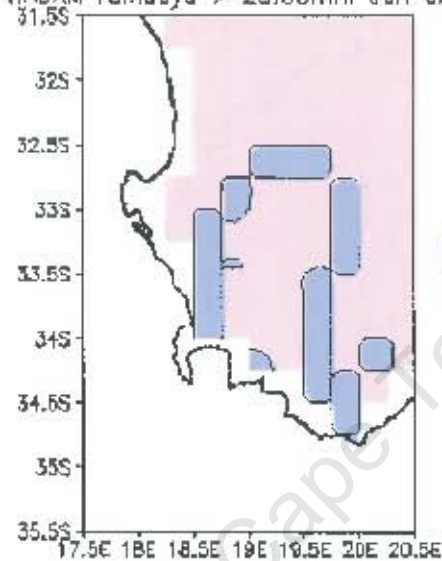
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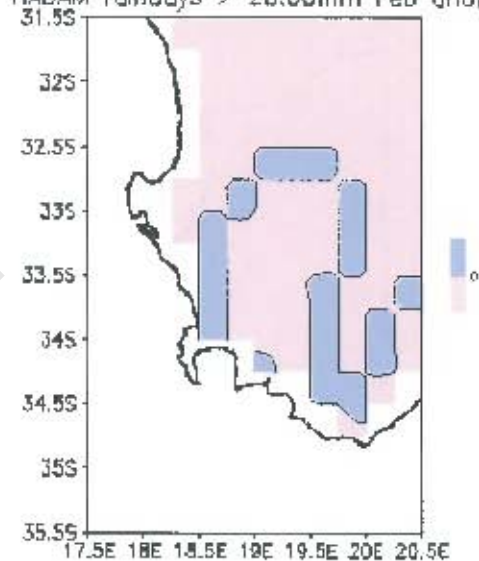
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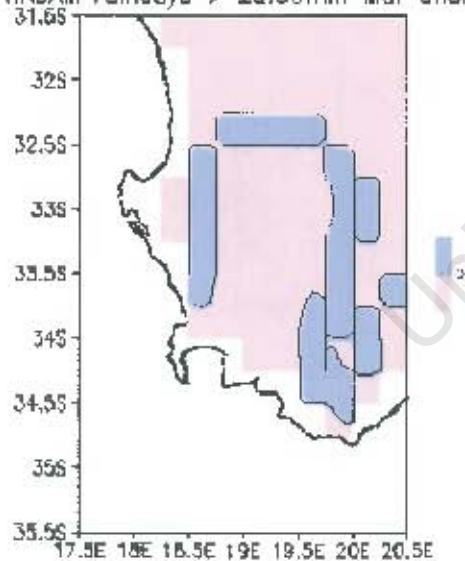
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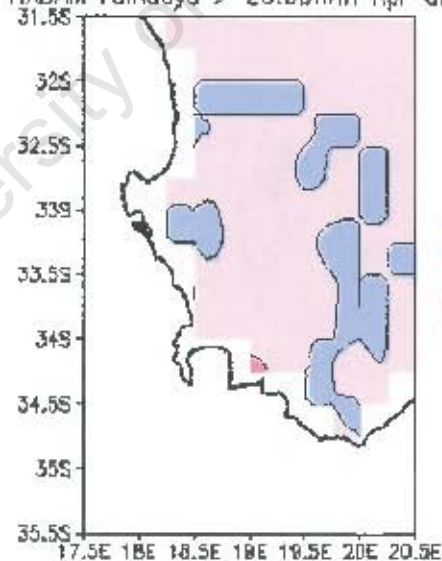
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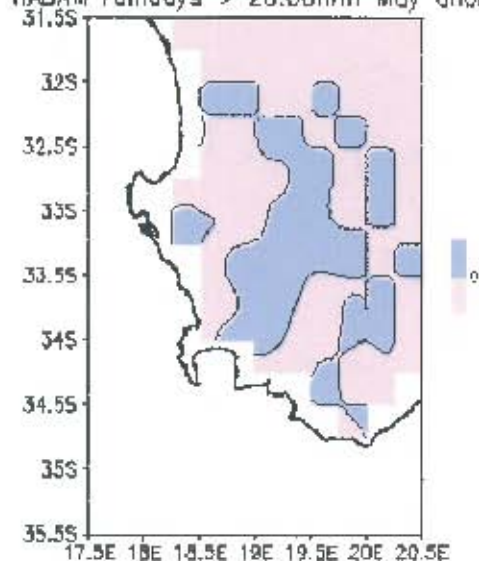
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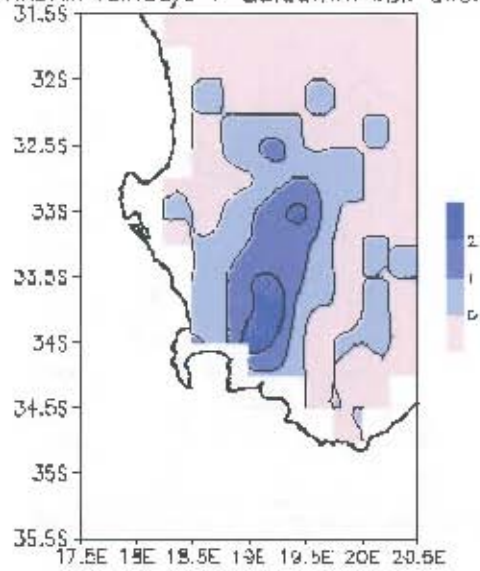
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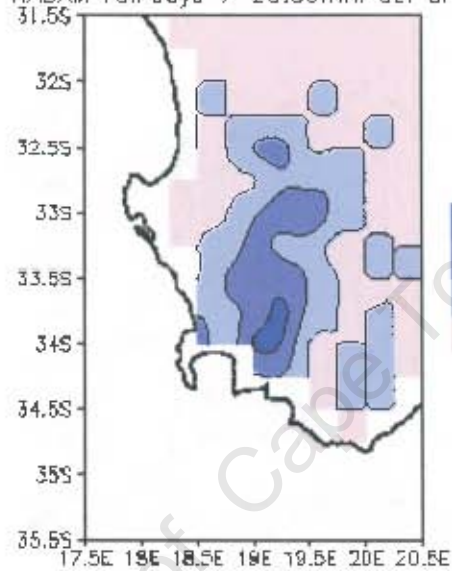
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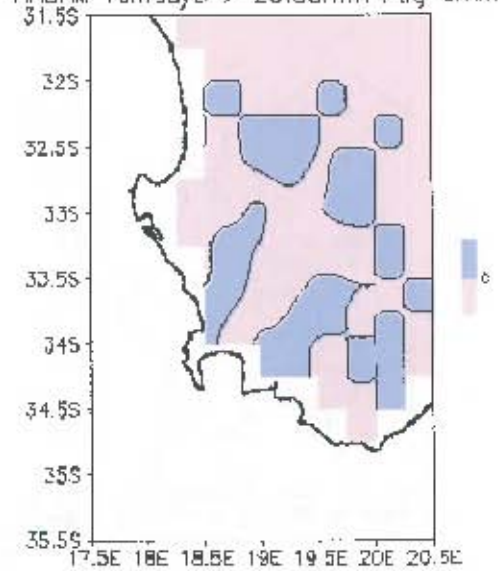
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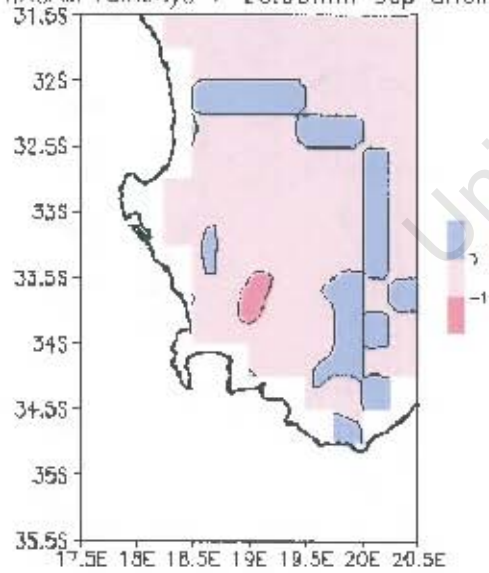
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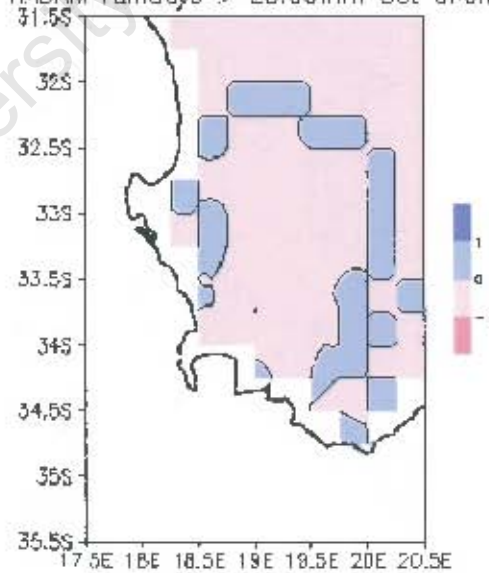
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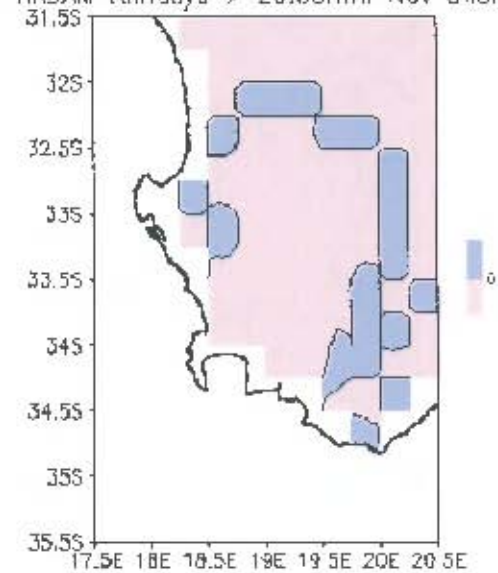
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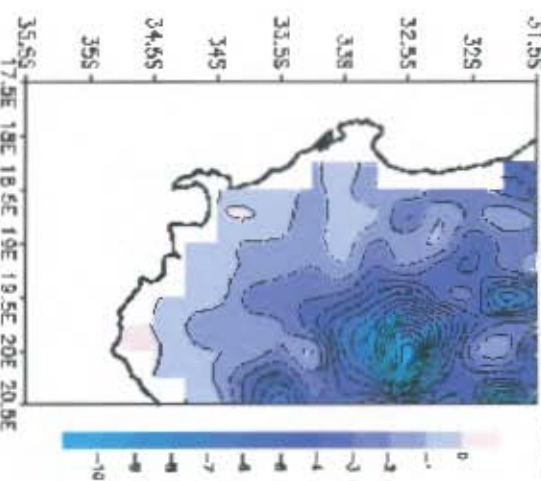
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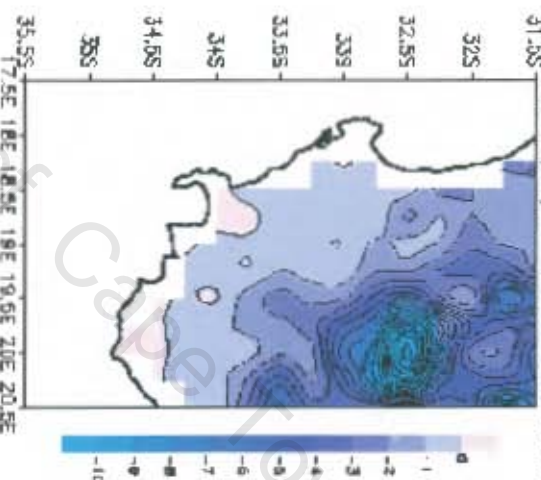
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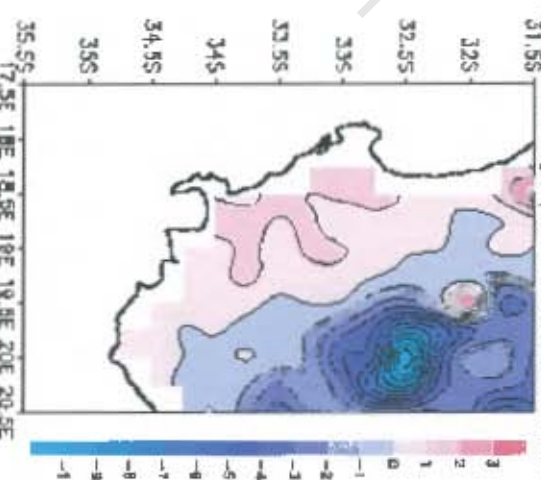
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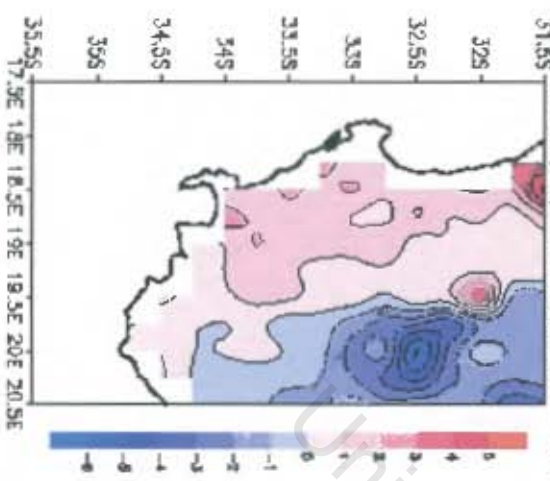
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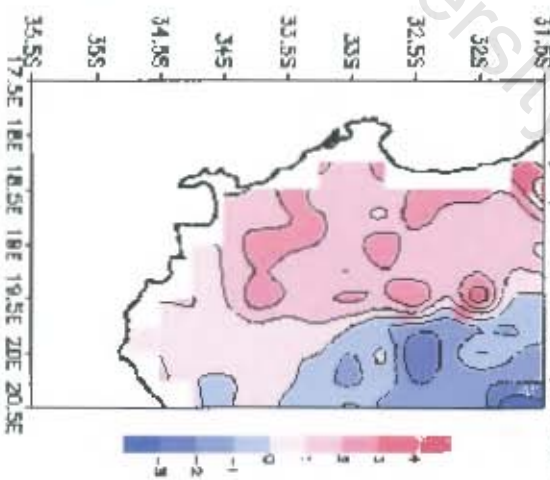
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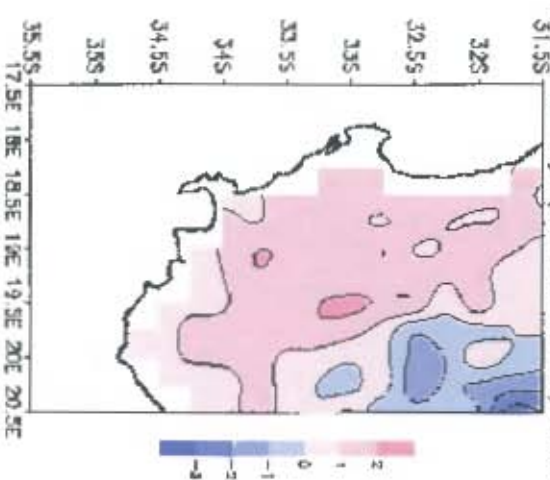
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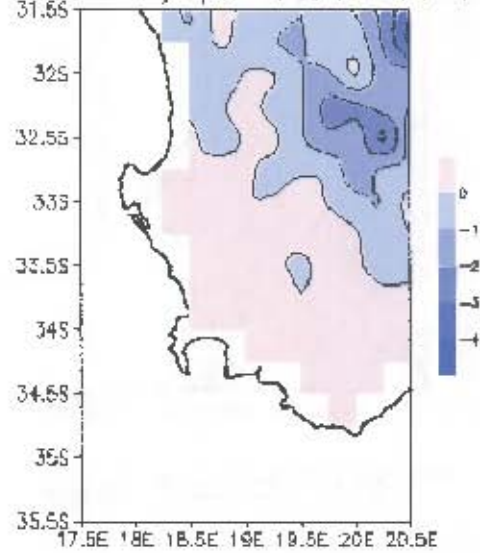
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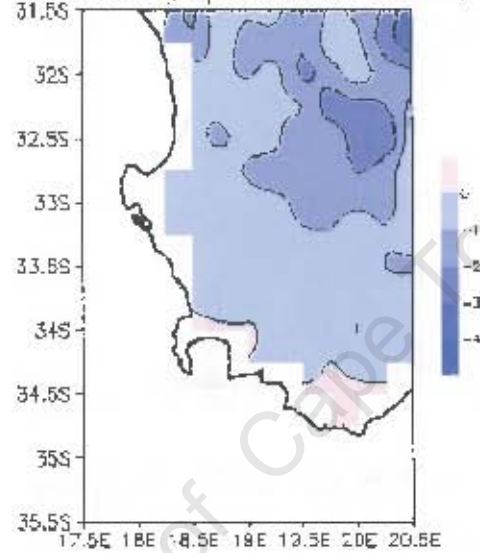
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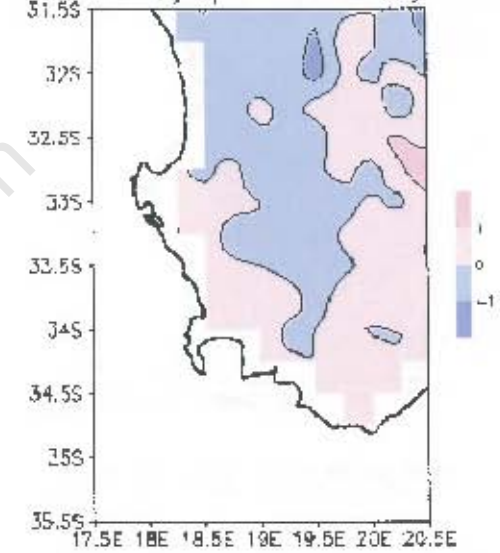
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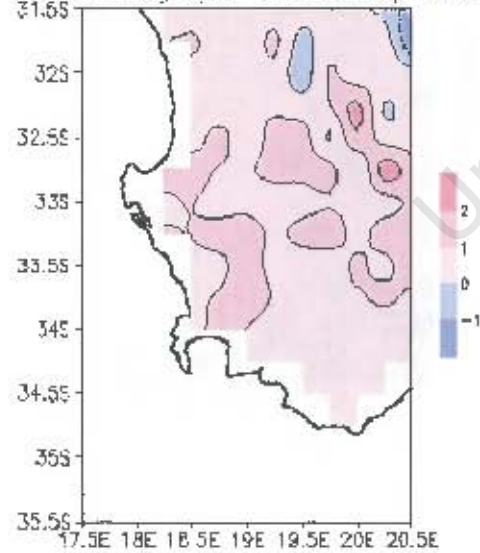
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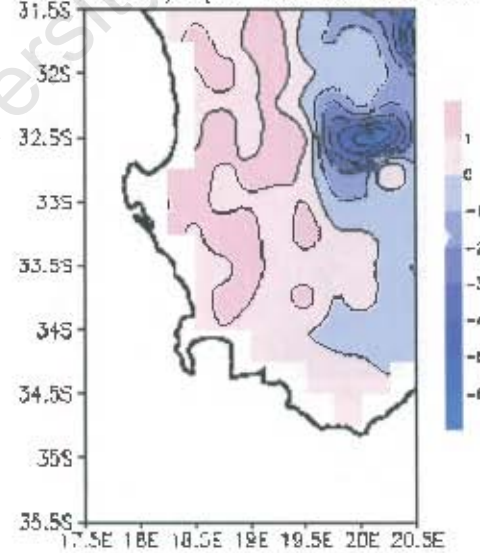
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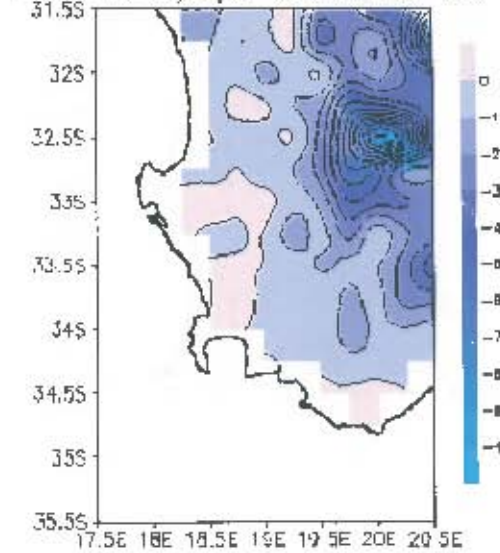
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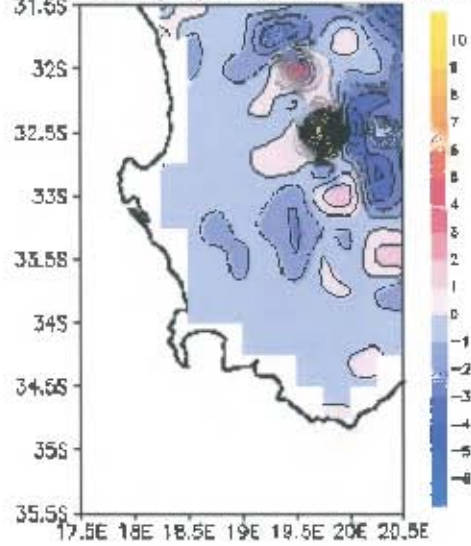
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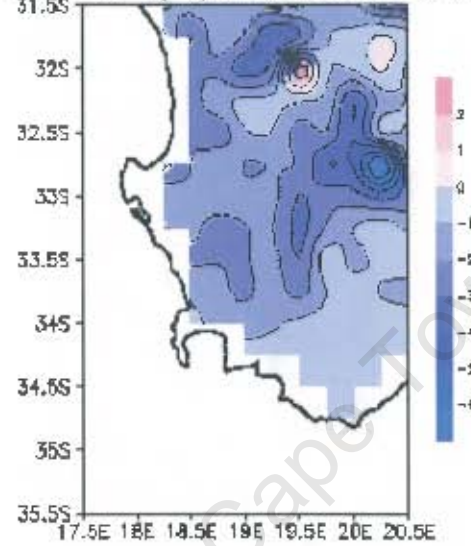
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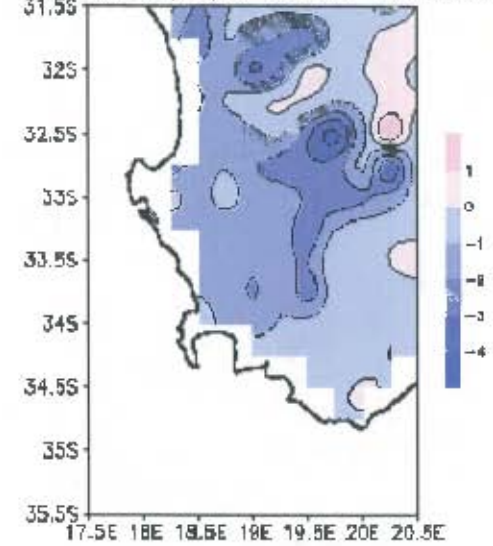
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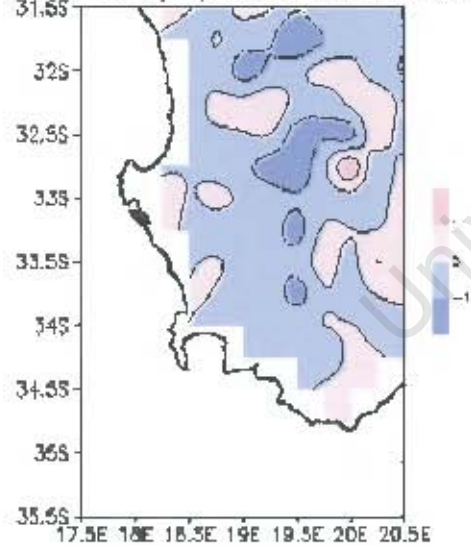
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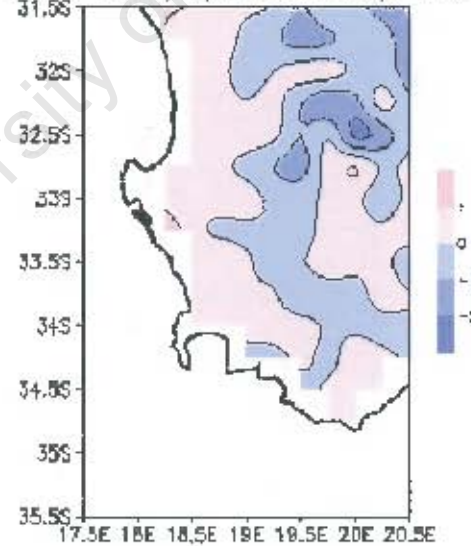
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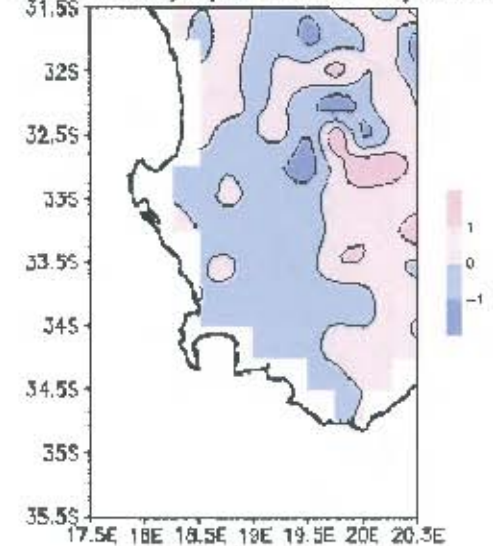
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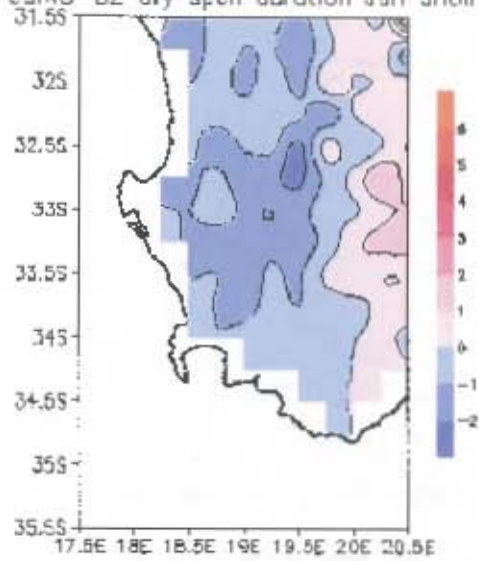
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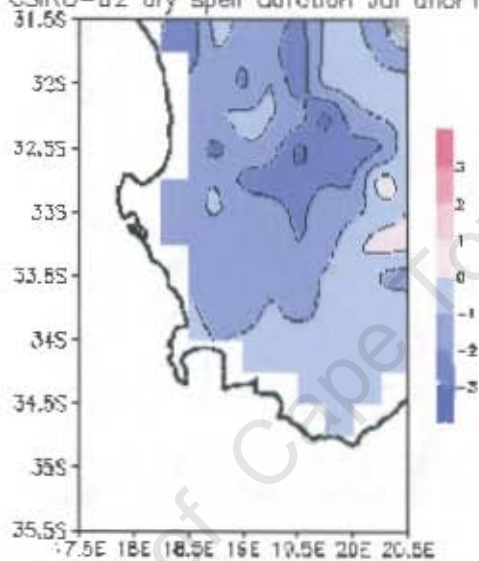
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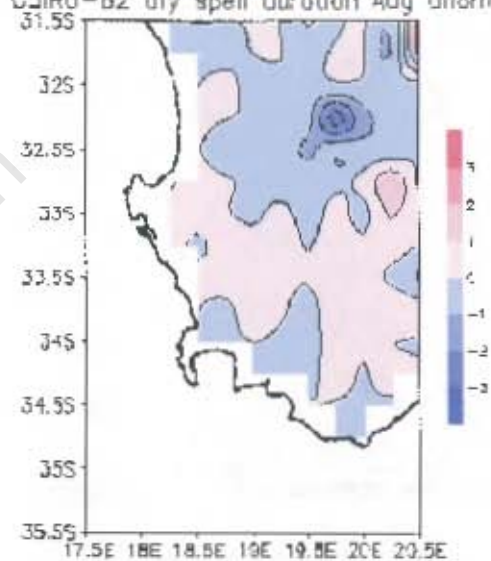
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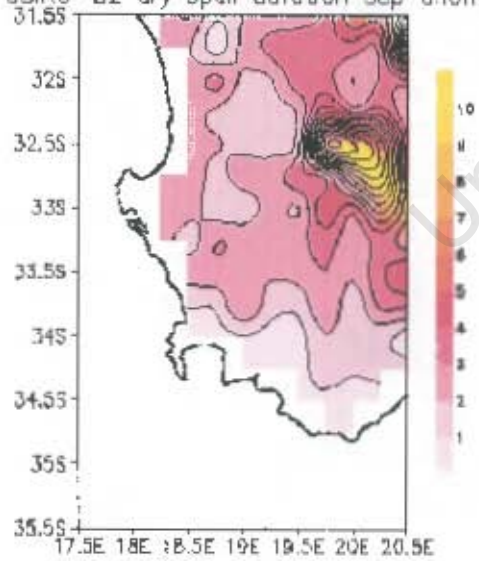
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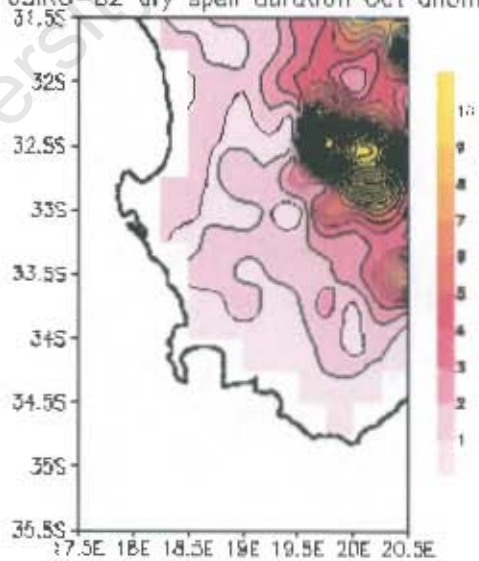
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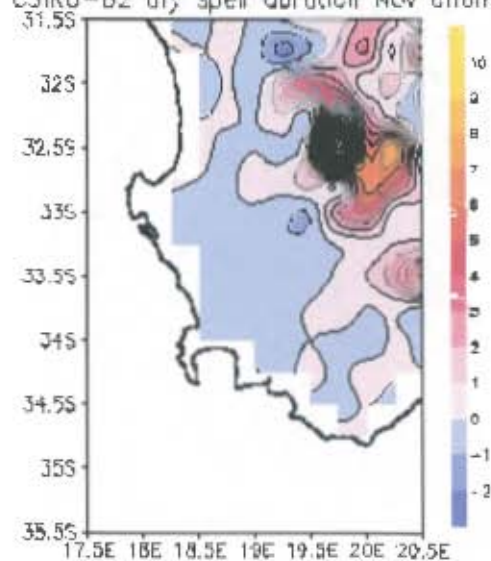
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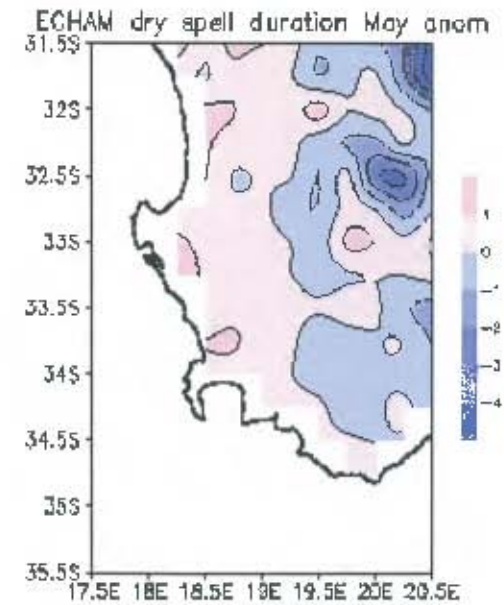
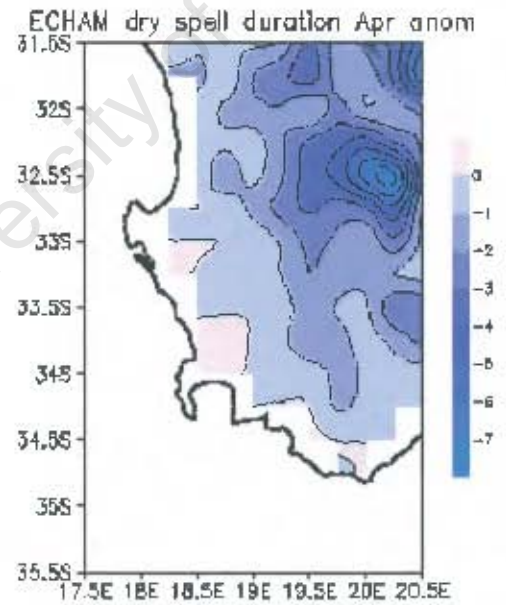
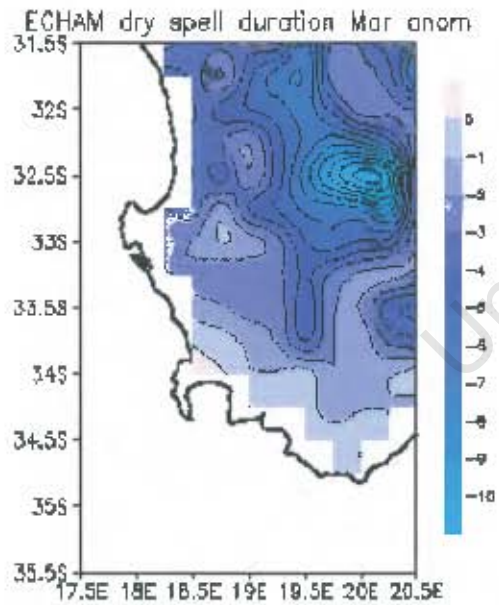
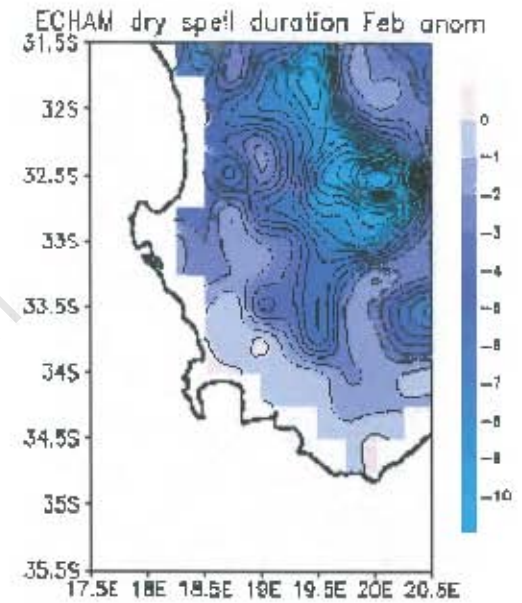
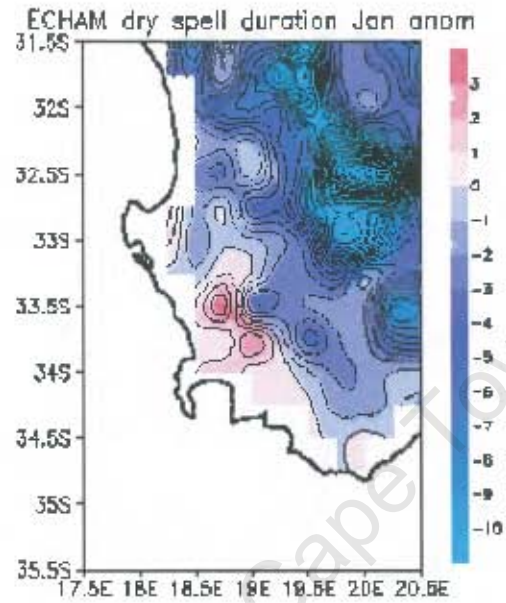
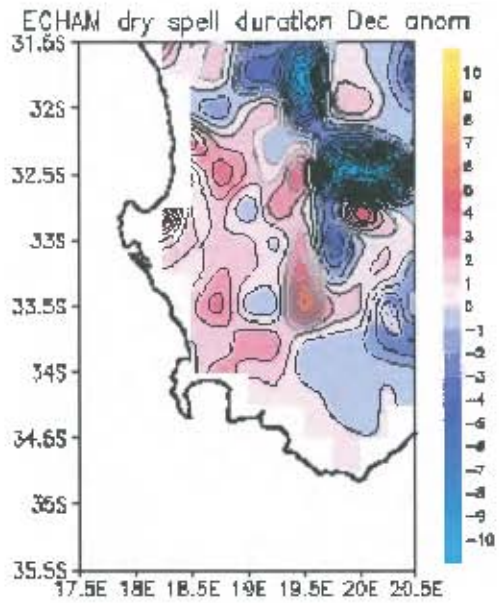


CSIRO-B2 dry spell duration Oct anom

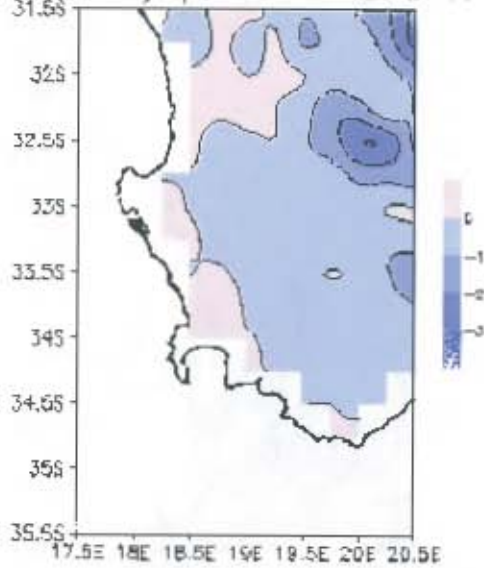


CSIRO-B2 dry spell duration Nov anom

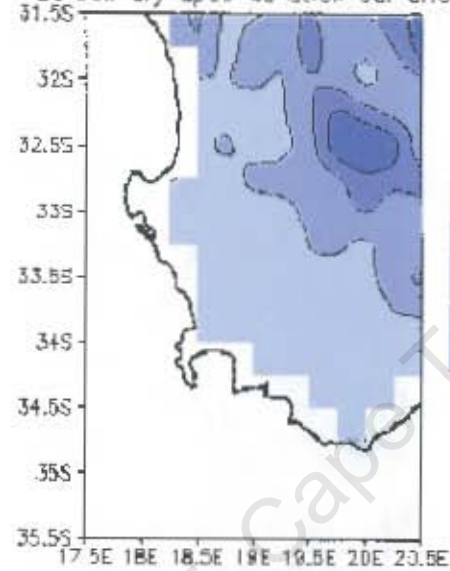




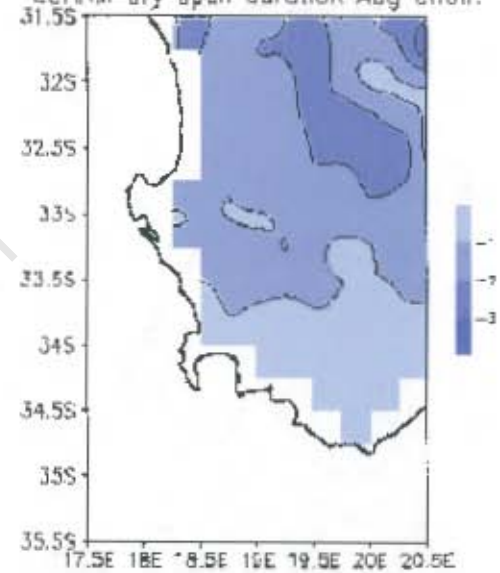
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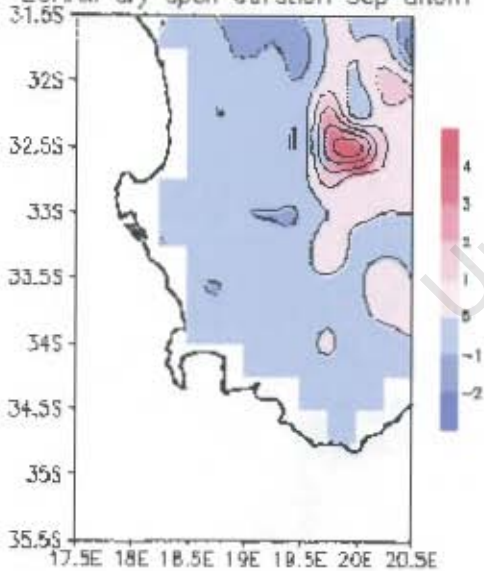
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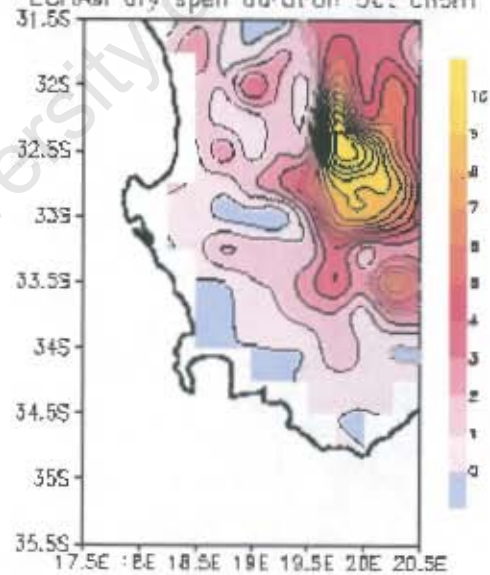
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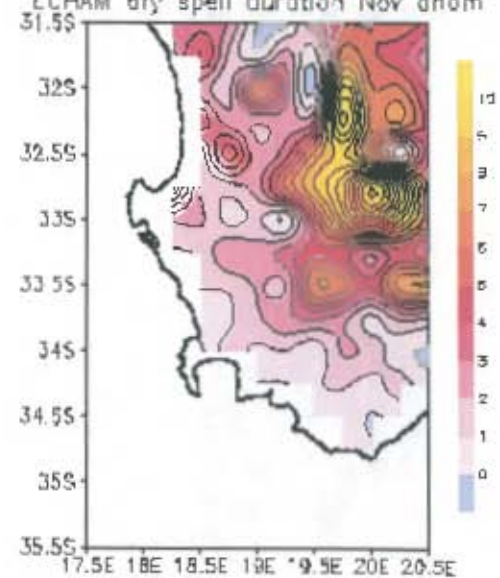
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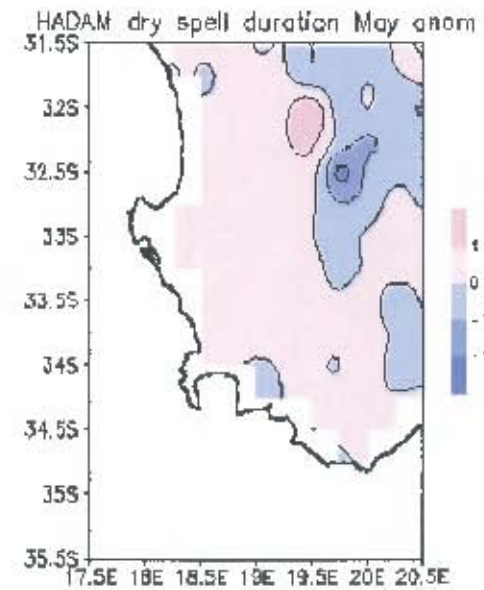
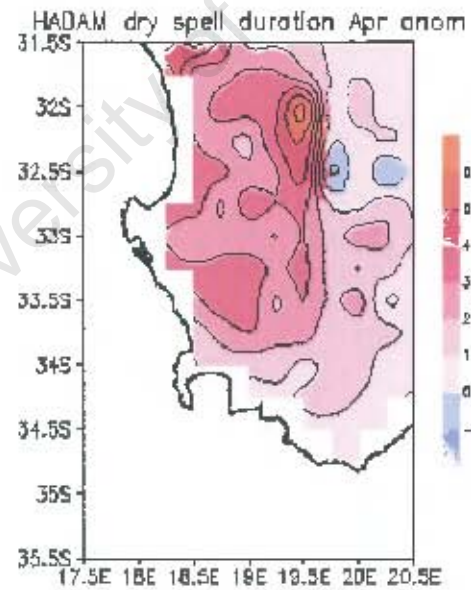
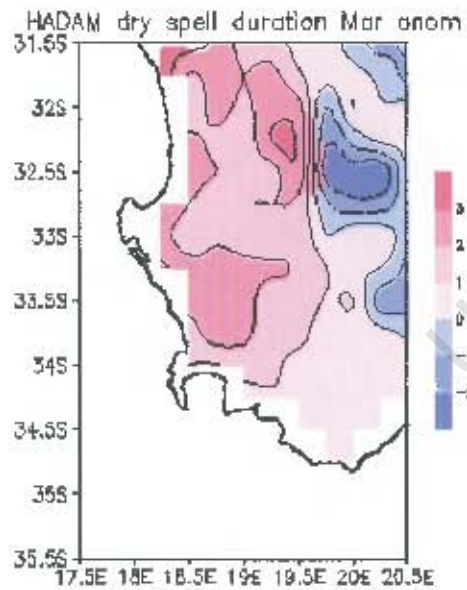
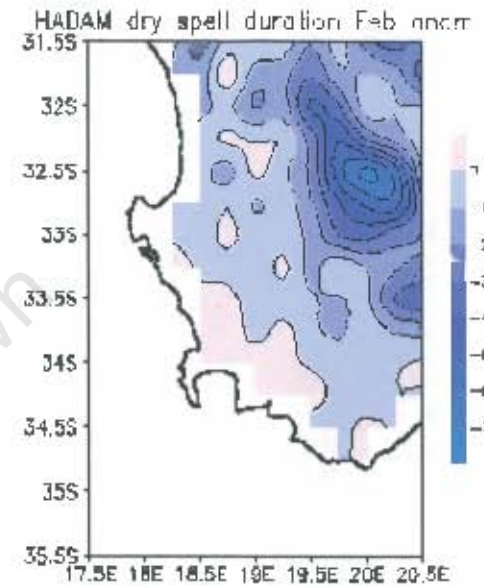
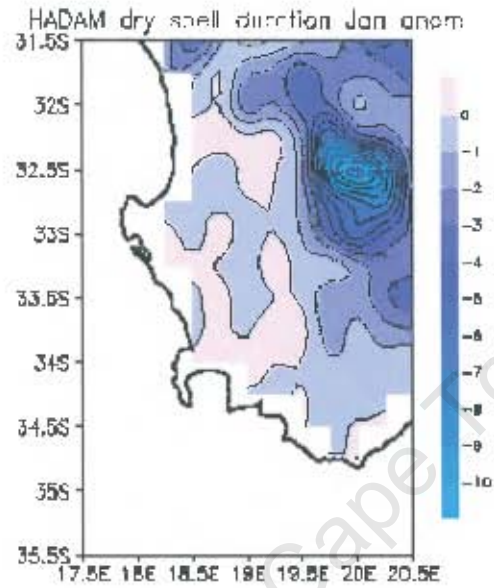
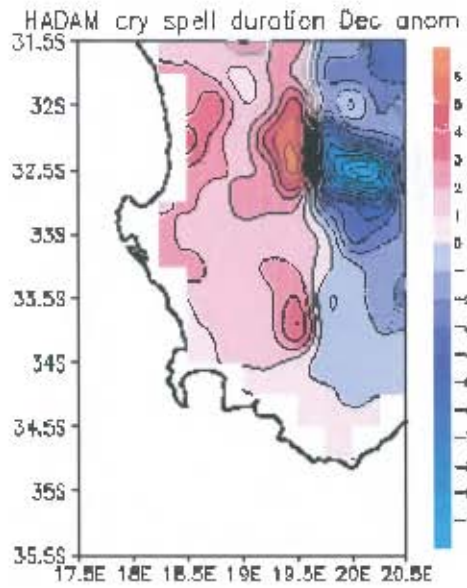


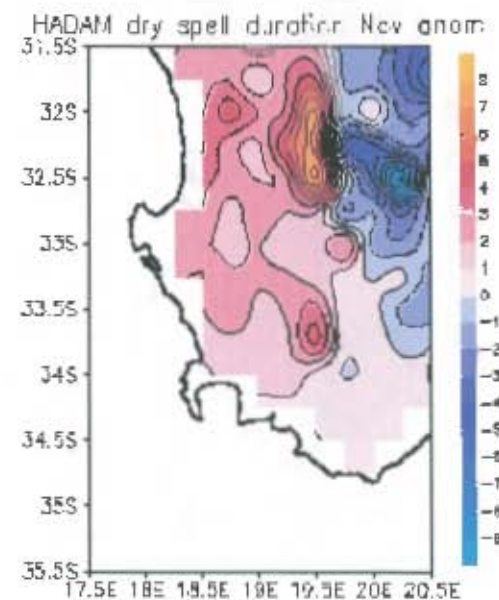
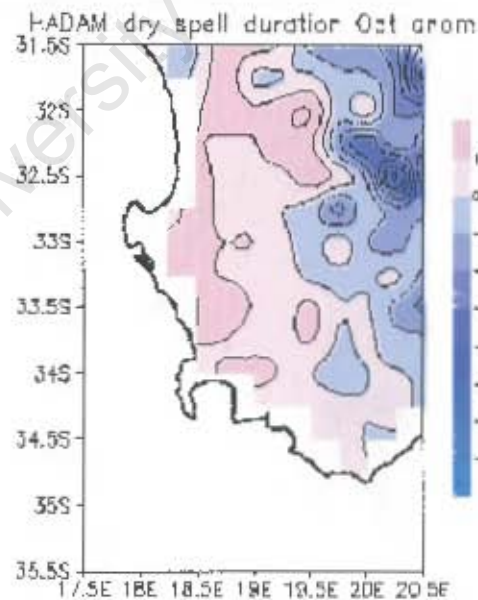
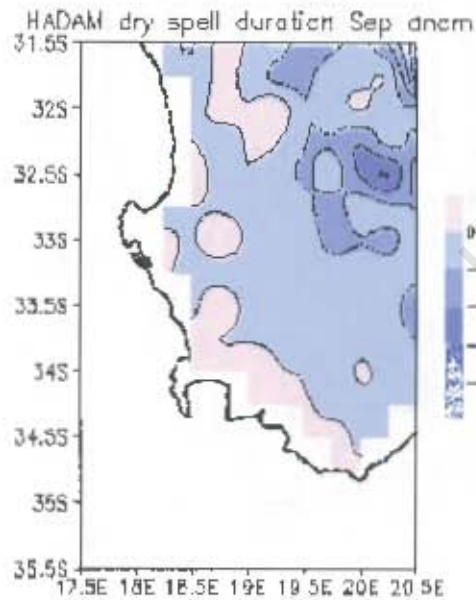
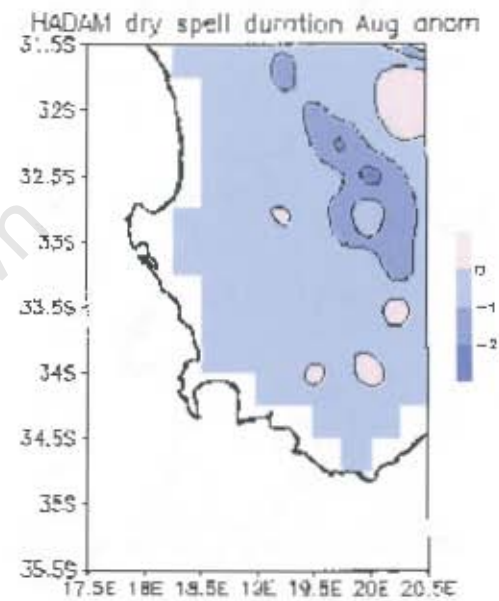
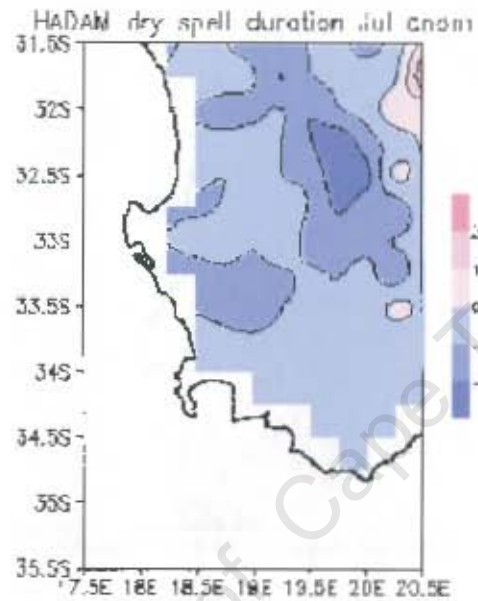
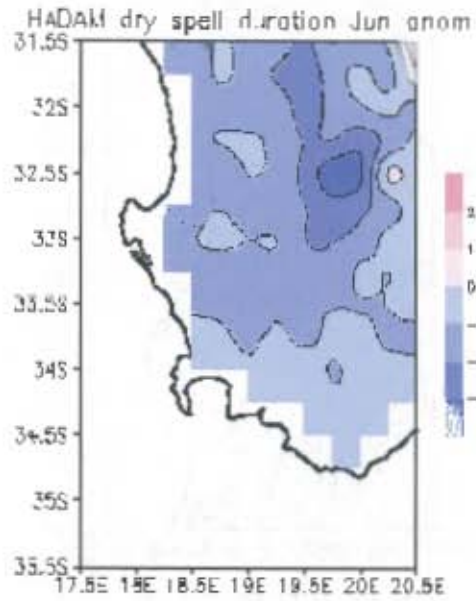
ECHAM dry spell duration Oct anom



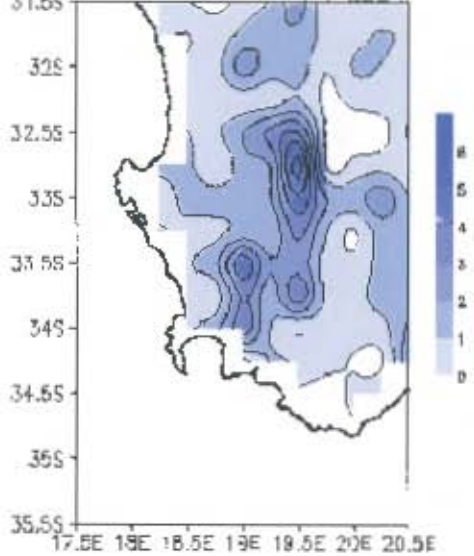
ECHAM dry spell duration Nov anom



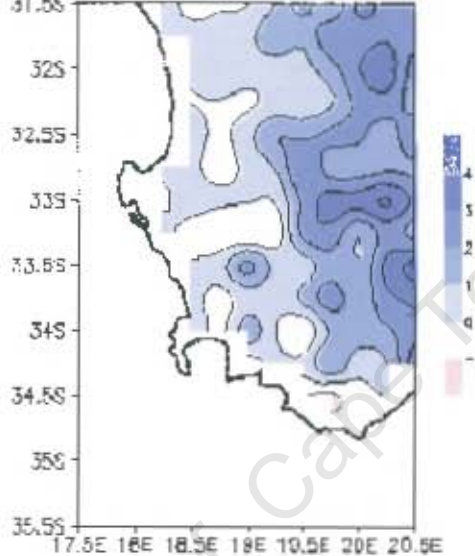




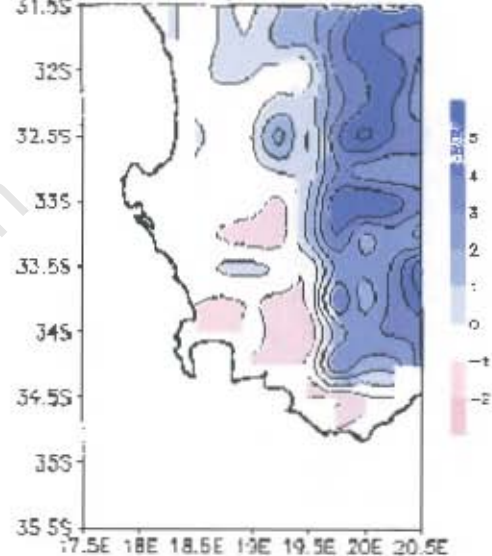
CSIRO-A2 90th percentile Dec anom



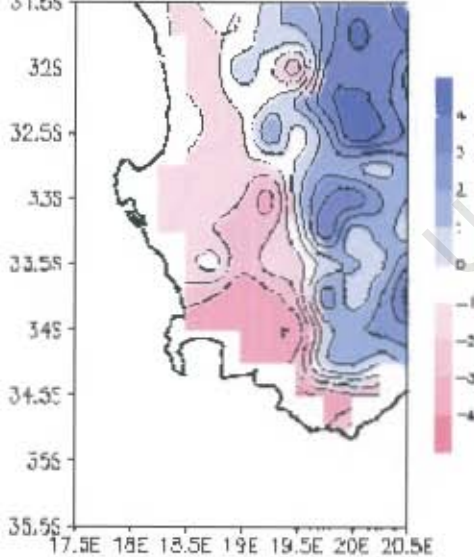
CSIRO-A2 90th percentile Jan anom



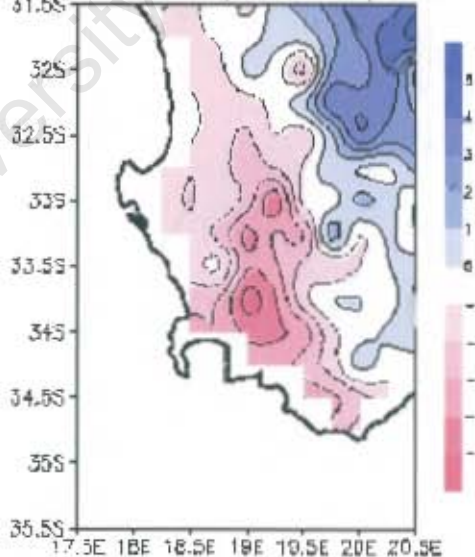
CSIRO-A2 90th percentile Feb anom



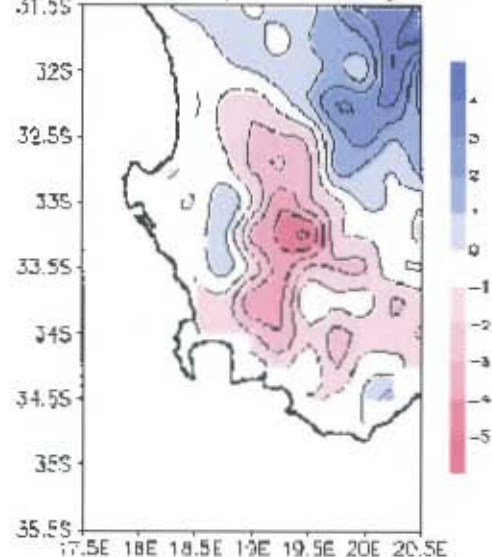
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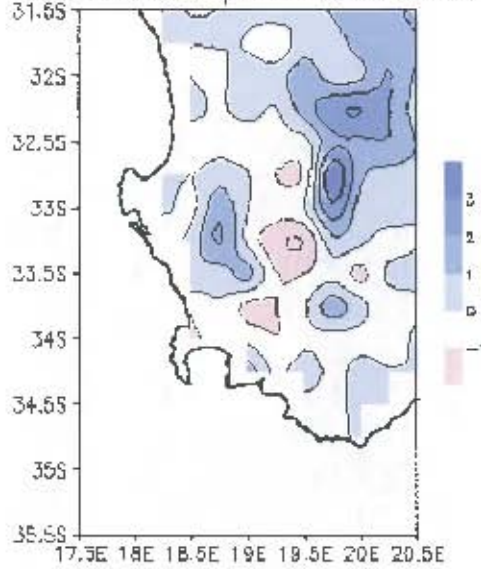
CSIRO-A2 90th percentile Apr anom



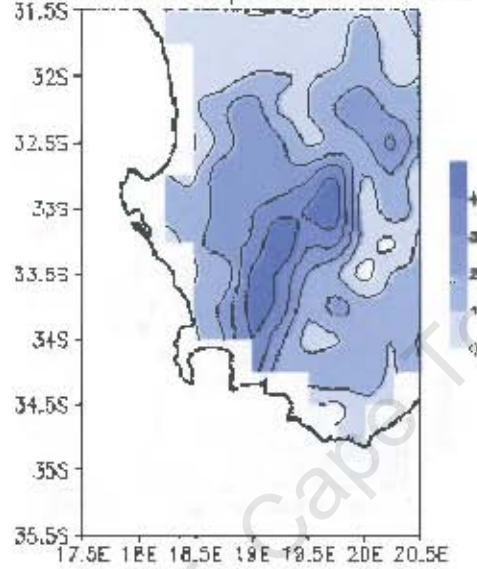
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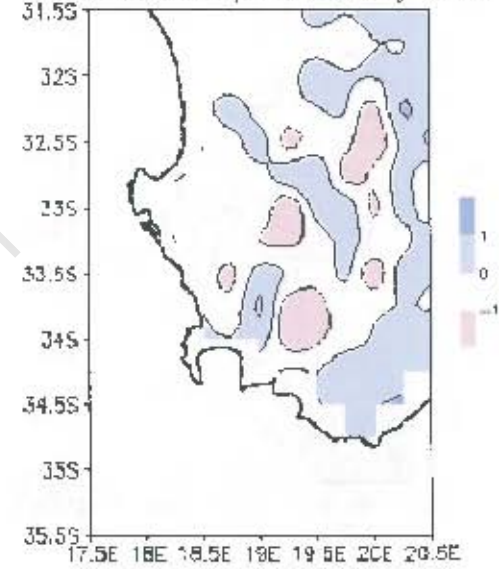
CSIRO-A2 90th percentile Jun anom



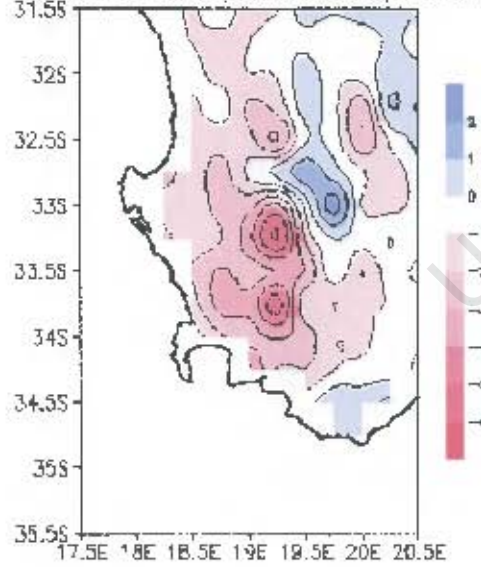
CSIRO-A2 90th percentile Jul anom



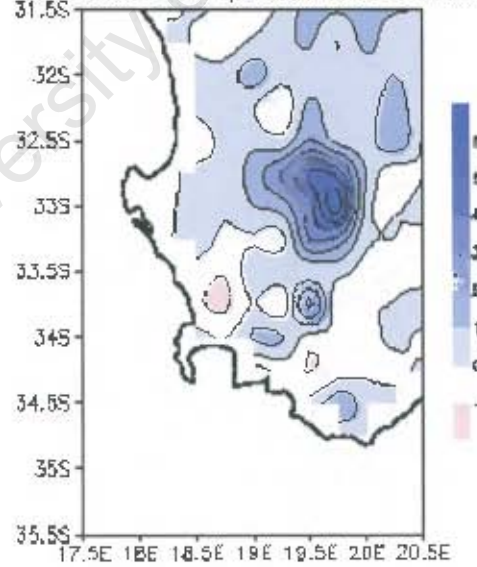
CSIRO-A2 90th percentile Aug anom



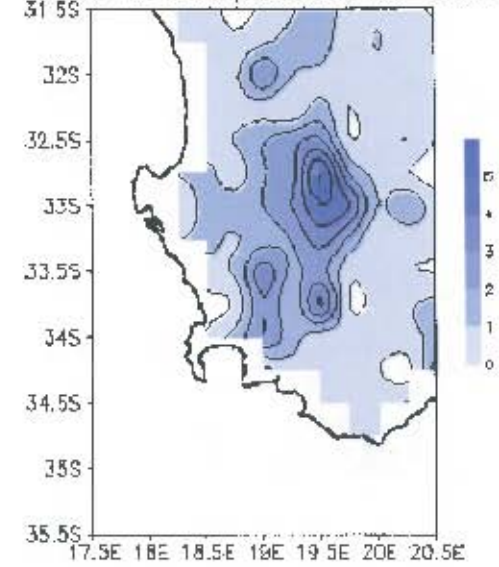
CSIRO-A2 90th percentile Sep anom



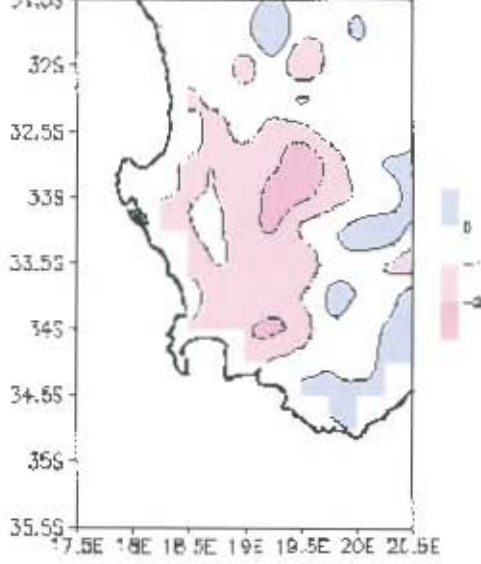
CSIRO-A2 90th percentile Oct anom



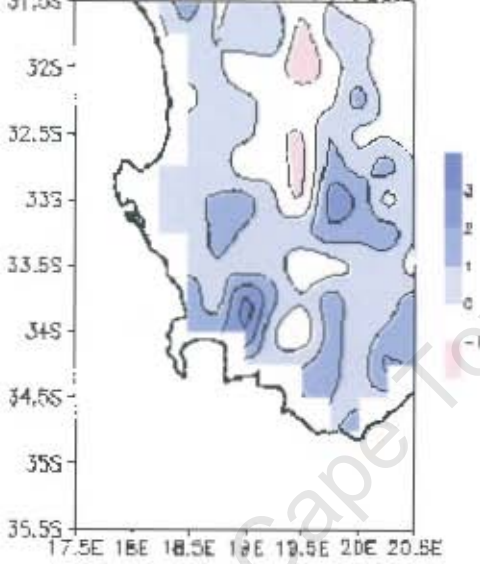
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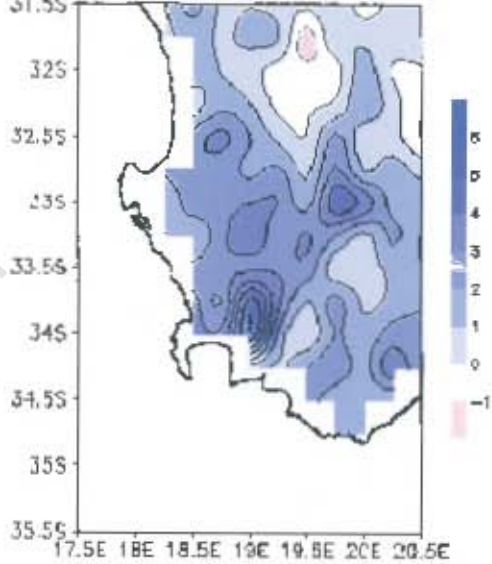
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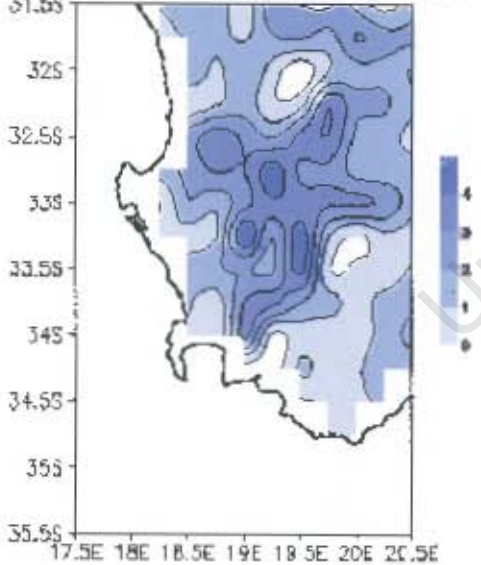
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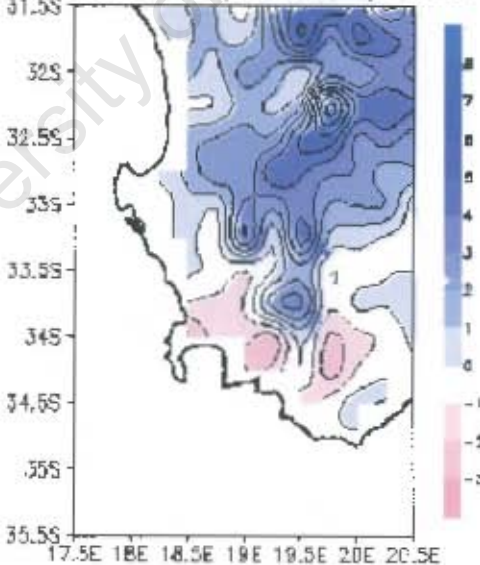
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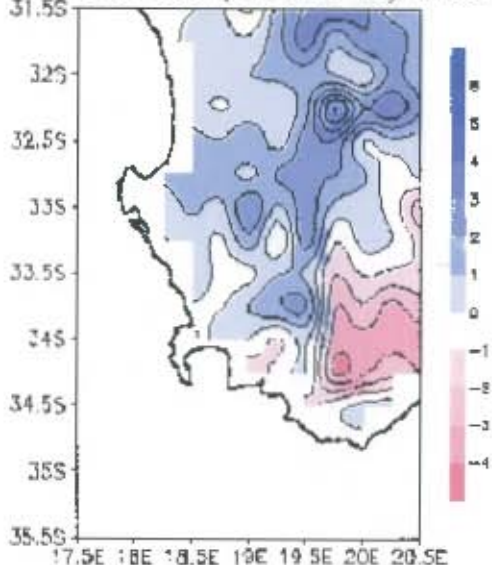
CSIRO-B2 30th percentile Mar anom



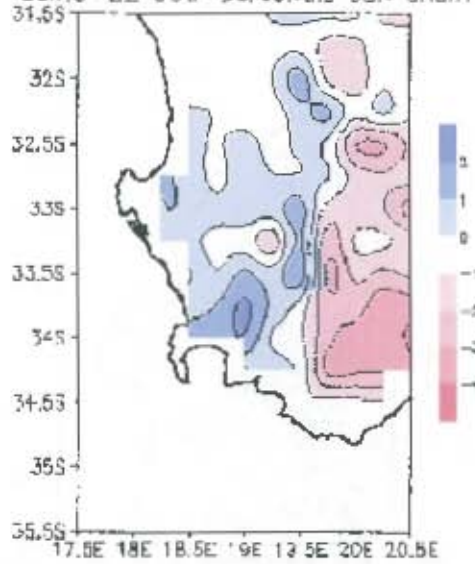
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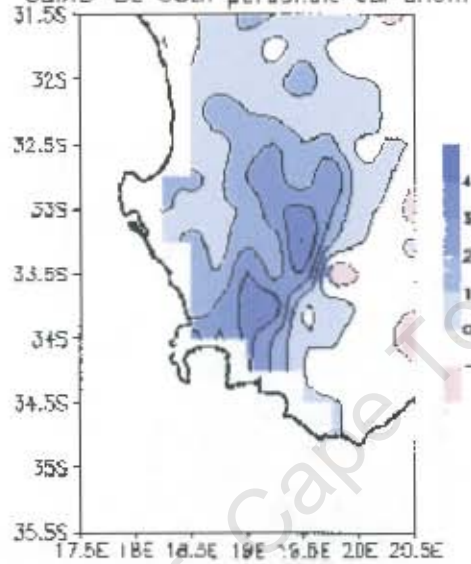
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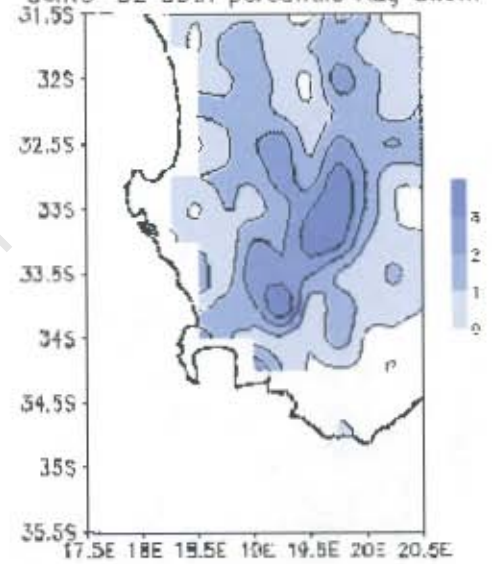
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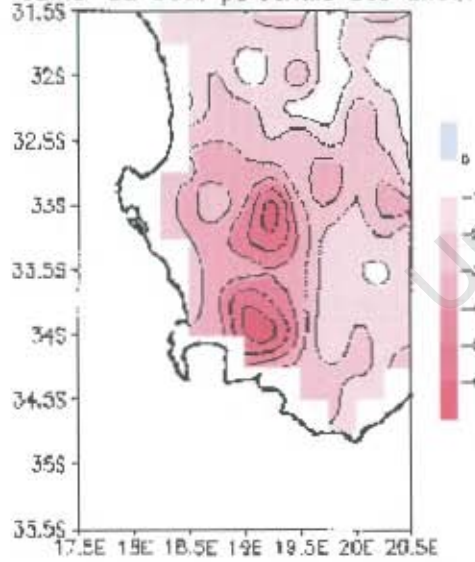
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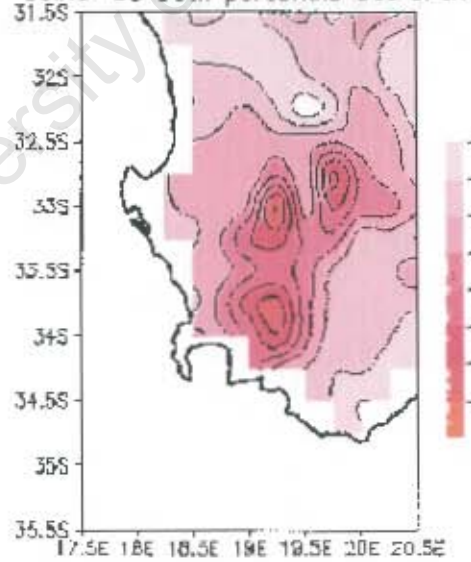
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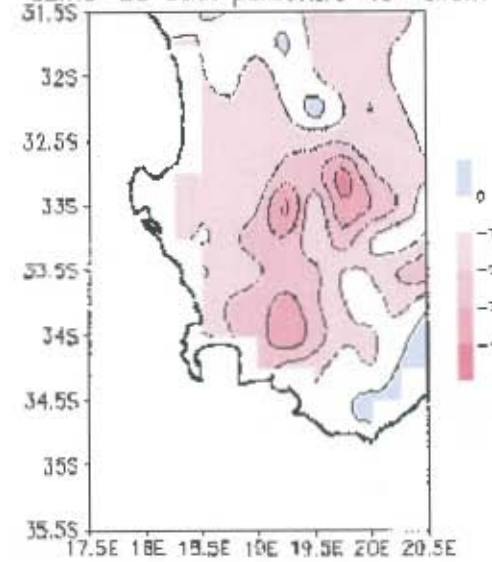
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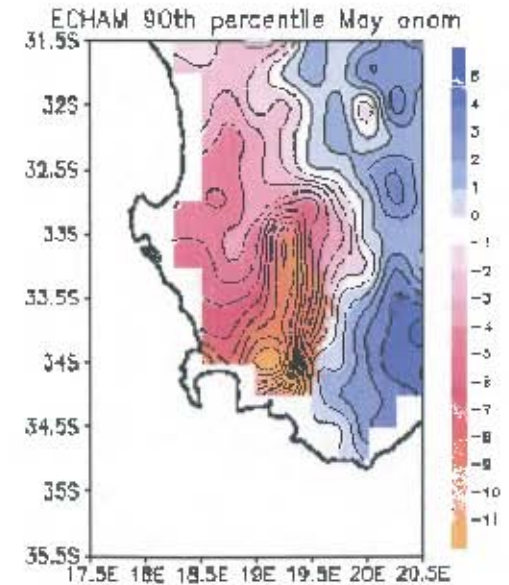
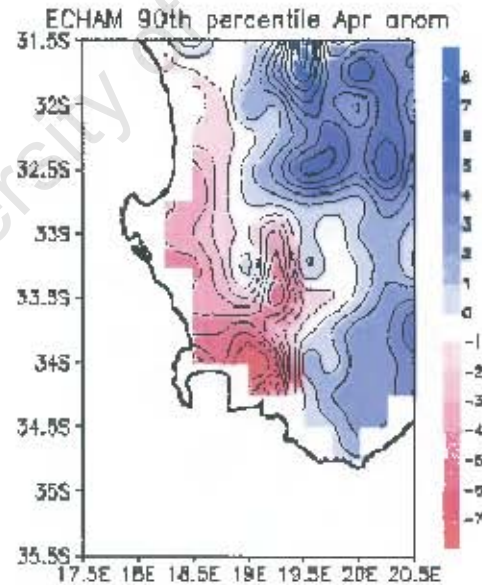
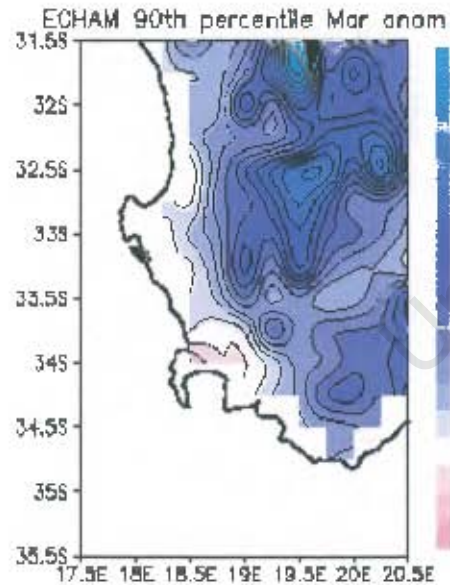
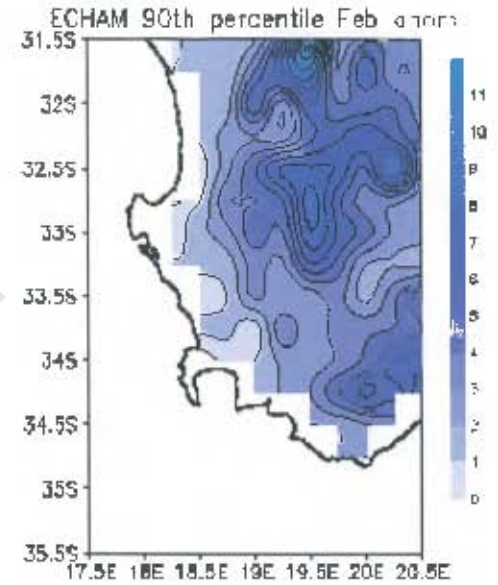
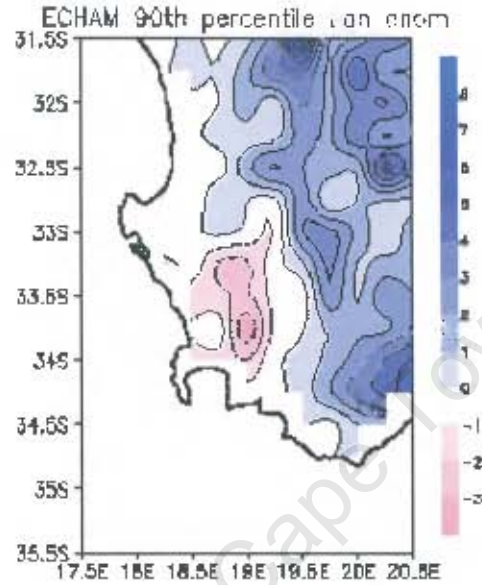
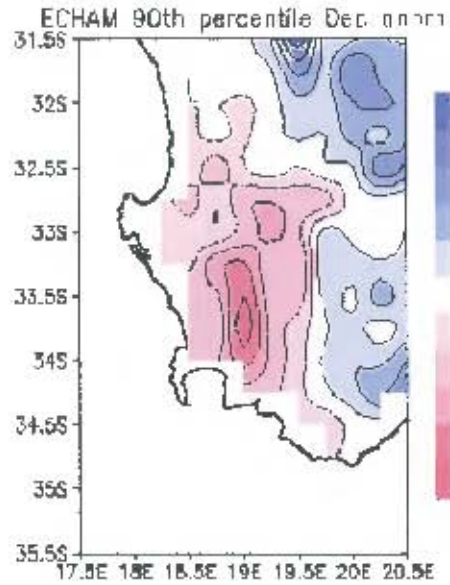


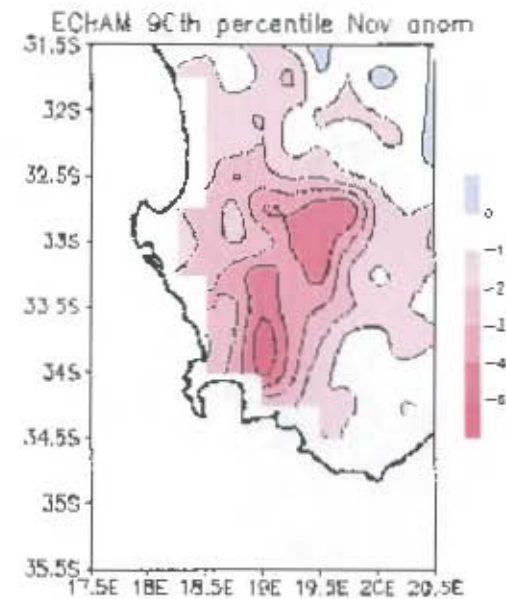
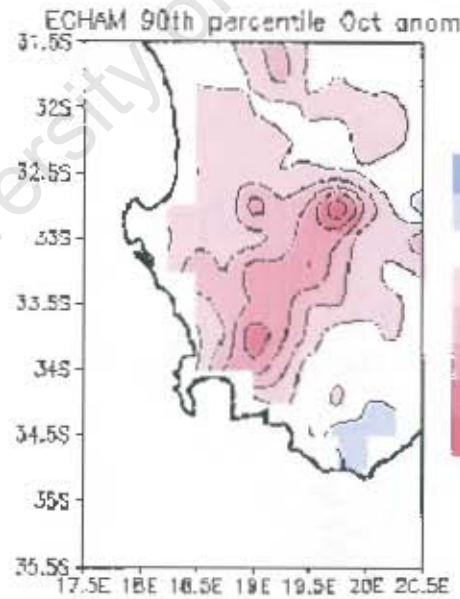
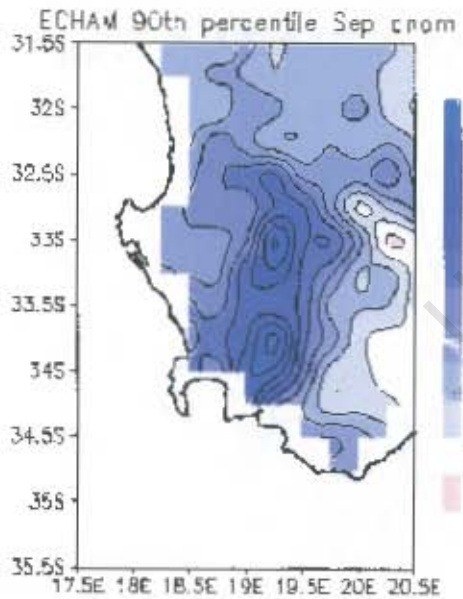
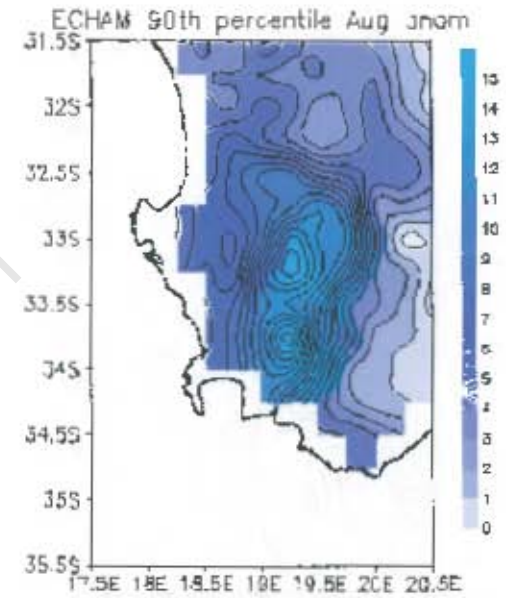
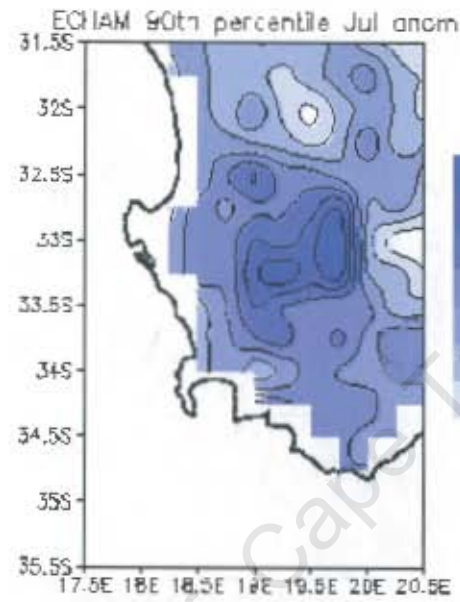
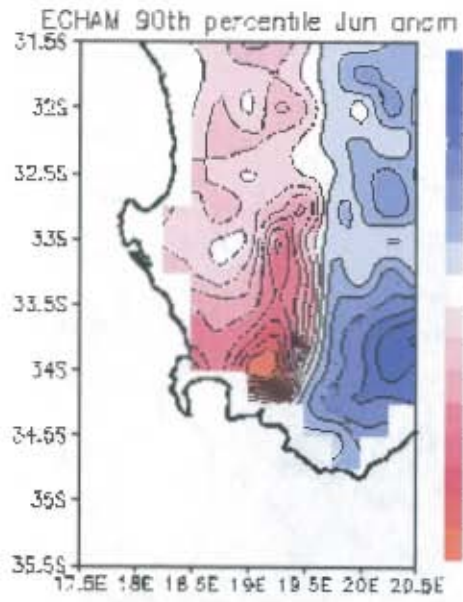
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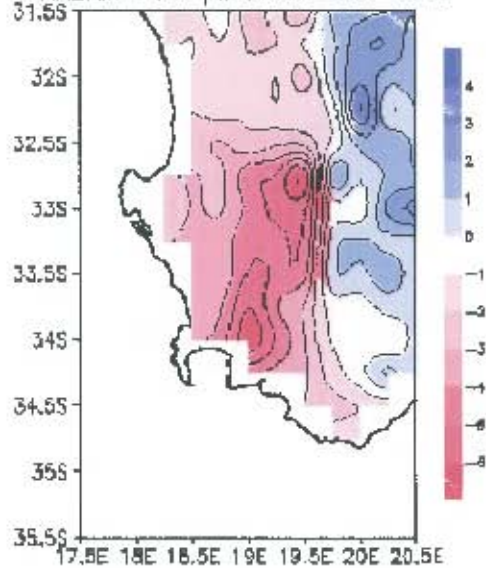
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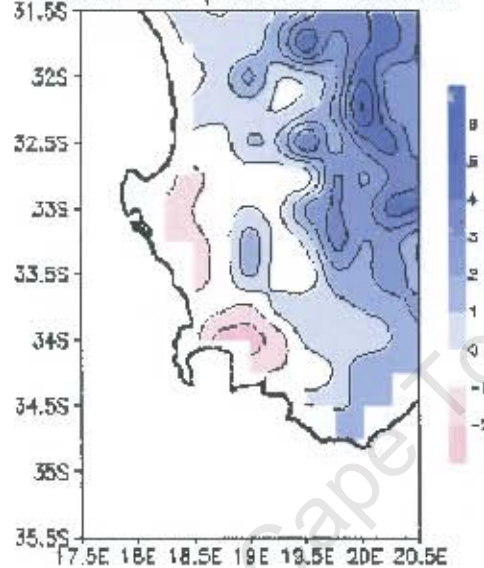




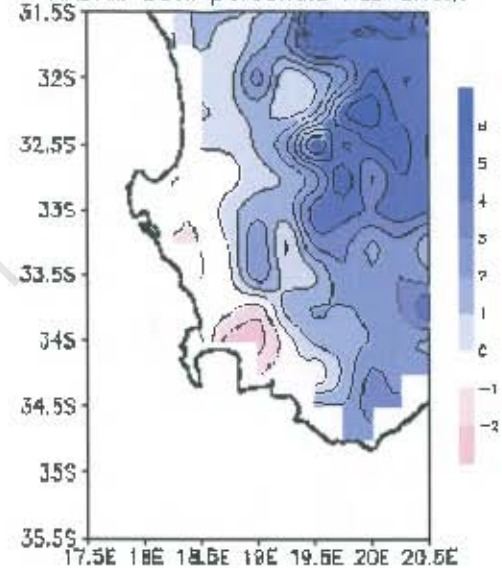
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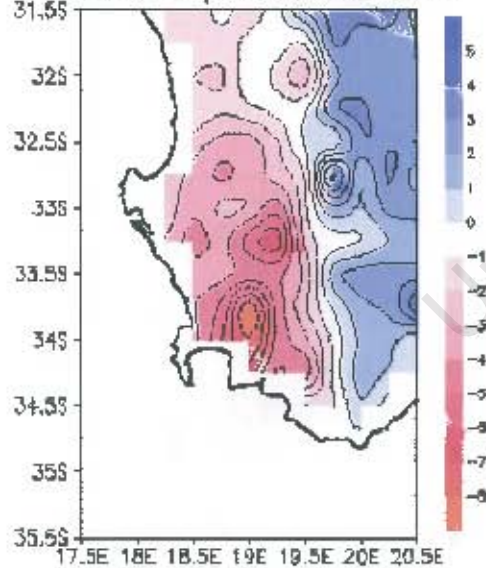
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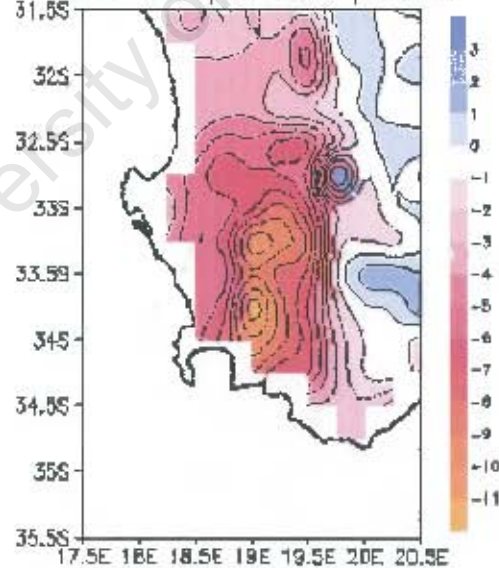
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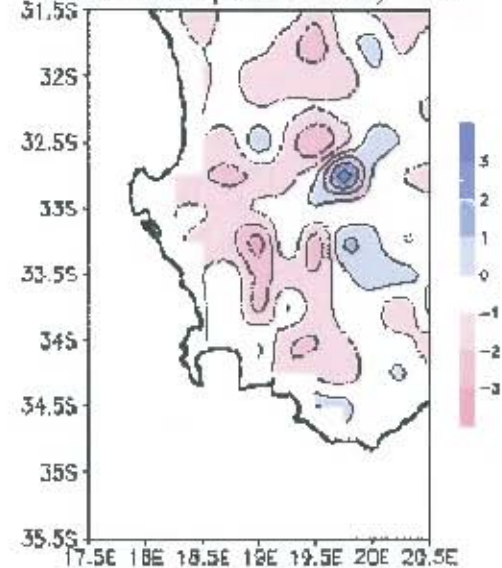
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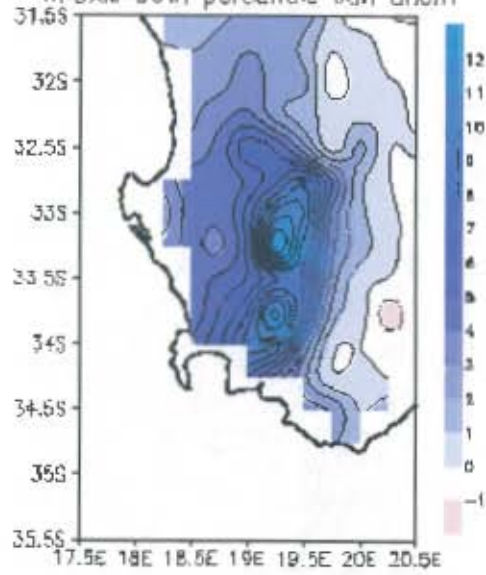
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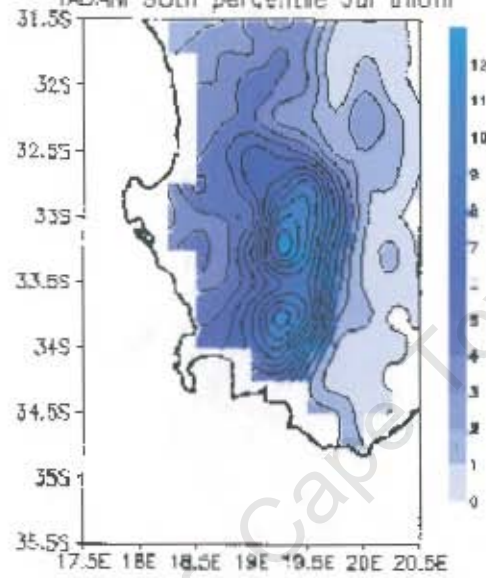
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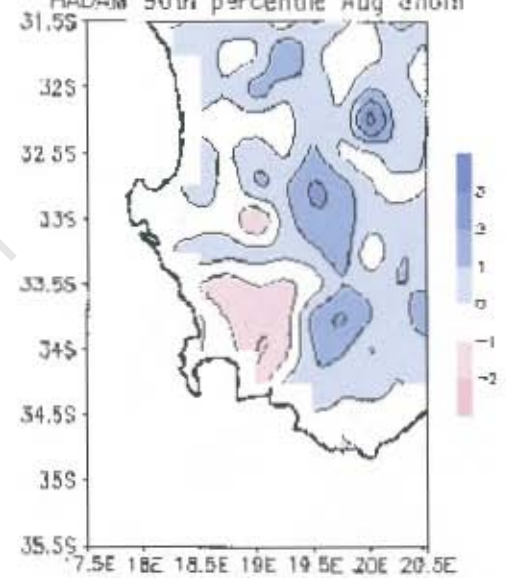
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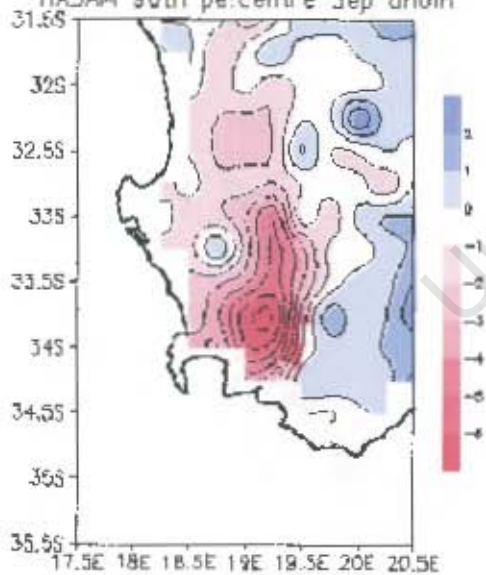
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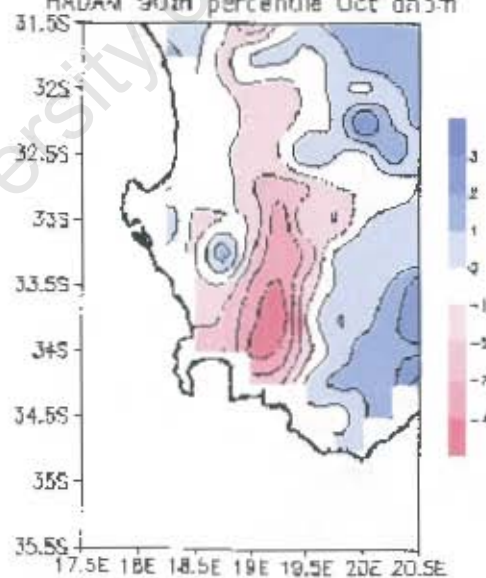
HADAM 90th percentile Aug anom



HADAM 90th percentile Sep anom



HADAM 90th percentile Oct anom



HADAM 90th percentile Nov anom

