CLIMATE CHANGE:
IMPLICATIONS FOR THE SOUTH AFRICAN SUGAR INDUSTRY

SUMMARY OF DISCUSSIONS AT A SASTA WORKSHOP HELD AT MOUNT EDGECOMBE ON 28 NOVEMBER 2002

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1. Introduction

Climate change is an area receiving increased attention with general consensus that in South African sugar producing areas, temperatures are expected to rise by 2-3 degrees over the next 50 years, with rainfall generally decreasing and becoming more variable. It is thus critical that the sugar industry assesses the implications of climate change on its activities. A SASTA workshop was convened to discuss climate change and the implications for the South African sugar industry. Five specialists in the area of climate change were invited to share their views in a morning plenary session. In the afternoon, small working groups developed a better understanding of how significant the impact of climate change would be on the sugar industry, mitigation and adaptive strategies that needed to be considered and research initiatives that are required. This paper summarizes some of the significant findings and recommendations from the workshop.

2. Presentations

Dr Hannes Rautenbach, the head of the Meteorology Group at the University of Pretoria began the morning session by examining existing and probable future climate systems and conditions in Southern Africa. Looking at predictions using Global Circulation Models, Dr Rautenbach indicated how predicted changes in mean sea level pressure would result in shifts in cloud bands, with resulting decrease in rainfall and increase in both maximum and minimum temperatures over the eastern parts of the country. Dr Rautenbach pointed out that measurements of warmer conditions were closely linked to human factors and higher concentrations of greenhouse gases. The response of the global atmospheric system to increased emissions is however difficult to model.

Prof Bruce Hewitson, an Associate Professor in the department of Environmental and Geographical Science at the University of Cape Town presented the second paper. This paper investigated the usefulness of climatic projections that arise out of both global and regional models, and cautioned against the use of any one model to provide an adequate scenario. The uncertainty in climate forecasts is due both to models, which are inadequate in representing global processes, the interactions that occur at local level with the land and also the uncertainty in what future greenhouse gas emissions would look like and the mitigation measures that would be put in place. Nevertheless use of a range of GCM's shows general agreement with a tendency towards drying and warming in the sugarcane producing regions.

Prof Roland Schulze from the School of Bioresources Engineering and Environmental Hydrology at the University of Natal in Pietermaritzburg, examined the agricultural impacts of anticipated climate change in South Africa, and concluded by evaluating possible pros and cons of potential climate change on sugarcane production, at three different levels: First order changes such as temperature; second order changes associated with heat units and frost occurrence / duration; and third order impacts on yields and pest breeding cycles.

Dr Rasack Nayamuth from the MSIRI described the approach adopted by the Mauritius sugarcane industry. His analysis of long-term data for Mauritius provided valuable insights into climatic trends in the region and served as a starting point for evaluating likely impacts on their industry. Application of four Global Circulation Models under a doubling of atmospheric CO_2 for Mauritius indicated increases in mean annual temperature of between 2.1^0C and 3.6^0C with annual rainfall declining between 13 and 2 %. Using the APSIM crop production model Dr Nayamuth predicted significant declines in sucrose yield, which would need to be countered with irrigation, drought resistant varieties and changes to crop cycles. It was noted that these model predictions did not account for the possible benefits to crop production of increased CO_2 fertilization. It was predicted that more dry matter would partition into trash and more fiber will accumulate at the expense of sucrose. Climate change could also lead to more profuse flowering while certain insect pests could colonize new areas.

Dr Bob Scholes presented the final paper from the CSIR. His view was that reduced sugarcane yields, owing to increased temperature and reduced rainfall, would be compensated largely by the rise in atmospheric $CO_{2,}$ which is essential for plant growth. He pointed out that there is a silver lining, with opportunities to use sugarcane, one of the world's most productive crops, as a 'biofuel' with zero net atmospheric impact. This can take one or more of several routes: the enhanced use of sugar by-products (e.g. bagasse and trash) as a fossil fuel substitute in efficient combined-cycle electricity generation; or the production of ethanol from sugar itself. Under scenarios of rising oil prices, stricter environmental controls and an emerging hydrogen economy, sugar-for-energy would become increasingly viable. In the immediate term, the sugar industry should look to reduce its climate impact by addressing the issue of cane burning. While combustion of cane or its residues has no net effect on the carbon balance of the atmosphere, it does increase the load of methane, and a series of ozone precursor gases (tropospheric ozone is a powerful greenhouse gas).

3. Workshop Session

In the afternoon a closed session built on the information gathered in morning presentations, to evaluate possible impacts that climate change would have on the sugar industry. Thirty invited delegates representing both millers and growers broke into two groups to evaluate the impact of climate change on the sugar industry and consider adaptive strategies that could be adopted and as well as to assess research requirements. Each of the likely impacts was given a priority rating in terms of the importance of and urgency for research.

A list of possible impact areas of climate change on the sugar industry is given below, and each will be reported on sequentially.

3.1 Will climate change result in a change in yield and sugarcane quality with a shift in production areas?
3.2 Will climate change require a change in agronomic practices (e.g. crop cycles, trash management)?
3.3 Will climate change impact on water security and availability for irrigation and mill operation?

3.4 Will climate change require new varieties?
3.5 Will climate change impact our vulnerability to pests and diseases?
3.6 Will climate change provide an opportunity to capitalize on carbon credits?
3.7 Will climate change provide an opportunity for better use of the cane plant at the mill through cogeneration or using cane as biofuel?
3.8 Will climate change impact significantly on small- scale grower viability and affect industry support requirements?
3.9 Will climate change impact our sugar quality and markets?

4. Comments and summary for each impact area

4.1 Will climate change result in a change in yield and sugarcane quality with a shift in production areas? (Impact 3.1 above)

Moderate urgency and importance

4.1.1 Impacts and adaptive strategies

The paper by Nayamuth predicted significant changes in yield and sugarcane quality for Mauritius as a result of climate change. The modeling approach however neglected the increased productivity owing to elevated CO_2 levels in the atmosphere. It is likely that sugarcane areas in the cooler south and midlands would have an advantage under climate change owing to elevated temperatures and increased yields. Higher rainfall areas or areas with access to irrigation water would best be able to cope with predicted lower and more variable rainfall.

Sugarcane must however be seen as a crop amongst other competing crops. The economic advantage of each crop will tend to overshadow the climate drivers. It will be an economic decision that forces a shift from a particular crop like sugarcane in a certain region and not one of climate change.

A shift in geographical production will impact on mill cane supply with longer haulage routes and increased cane diversion. Relocation of mills is unlikely owing to capital investment requirements.

4.1.2 Research

The impact of changing temperature regimes on crop production, and more specifically sucrose accumulation, and the crops physiological response to new temperature thresholds, needs further research. Improved models, which can capture the crop physiological processes, will be useful to simulate crop response to anticipated changes in climate. Such models can also be used to assess historical recorded changes in sugarcane quality using recorded climate trends. Physically based models need to be developed where one is able to divorce climate as a driver from management as a driver to differentiate the role of management and climate in sugarcane production and look historically as well as into the future on climate linked production trends. There is also a need to obtain from climatologists improvements in the general circulation models, and particularly in the regional climate forecasts.

Using such models one would be able to assess proposed adaptive strategies, which are largely agronomic and are discussed in the next question below. An important application of such models will be regional assessments of production trends in response to climate change.

4.2 Will climate change require a change in agronomic practices (e.g. crop cycles, trash management)? (Impact 3.2)

Intermediate importance and urgency

4.2.1 Impacts and adaptive strategies

The general consensus was that climate change would require a change in agronomic practices. Many of the proposed changes are in any event best agronomic practice under current climate conditions. Thus the industry should adopt a 'no regret' policy by doing the right things now, so that there will be no regrets if the climate does change. This is in a sense applying the precautionary principle.

The main adaptive strategies would be in terms of land use management practices that would alleviate the impacts of climate change. These could include revised field layouts, with appropriate conservation structures, able to cope with higher intensities of rainfall that are likely to be part of the greater variability in rainfall patterns. There is a need to improve the moisture holding characteristics of the soil, though minimum tillage, trashing and mulching with organic manures to reduce soil moisture stress during dry periods.

Changes to crop cycles to capture optimal growth stages of the crop, under the new climate regimes, and changes in pest and disease cycles brought about by higher temperature thresholds would also be required. Revised fertilizer strategies accounting for changing crop production potential and soil mineralisation processes, would be needed. Weed management strategies would need to be adapted to account for more rapid weed promulgation likely under more favorable climate conditions.

4.2.2 Research

These above aspects would need to be modeled individually and jointly to see where they have an effect, if they have an effect and what that effect would be. Ultimately integrated solutions are likely to be the most successful and would require an integrated modeling research approach. The role of trash management has been promoted in the sugar industry for some time but adoption is still slow with 90% of the industry burning before harvest.

In cooler areas where ratooning is a problem under a trash blanket, the need to burn is understood, although increased temperature through climate change may alter this trend. The increased cost of hand harvesting green cane is also a real one. Nevertheless an integrated view and economic assessment of the benefits of trashing (moisture retention, organic matter build up, shorter harvest to crush delay, erosion control, weed control etc) need to be balanced against the costs (harvesting, cane quality, pests etc) and assessed not only on terms of today's weather but that of the future.

4.3 Will climate change impact on water security and availability for irrigation and mill operation? (Impact 3.3)

High importance and urgency

4.3.1 Impacts and adaptive strategies

This is an important area since sugarcane production is very much dependent upon water transpired, be it water supplied by rainfall or irrigation. Rainfall is expected to decline under climate change (while temperatures, CO_2 levels and hence potential evapotranspiration rates increase). Irrigation water will become increasingly scarce since a 10% drop in rainfall often translates into a 3 or 4 fold drop in streamflow and water resources available for irrigation. Prime areas for sugarcane production are thus likely to be those with reliable access to irrigation water and higher rainfall regimes. The need to maximize rainfall effectiveness, through for example trash blankets and maximum canopy cover during the wet season, will increase.

Climate change could also result in a decrease in water quality both in high flow and low flow periods. Climate change is likely to bring higher rainfall variability with heavy rains bringing down excessive amounts of sediment and surface nutrient enriched wash-off. During low flow periods there are likely to be increased proportions of irrigation seepage and effluent flows in our rivers, and less dilution by natural streamflow. This will have an environmental impact on rivers and an impact on the water available for irrigation.

The impact of climate change on water resources could thus be acute. An adaptive strategy will be to increase water storage, both storage in the root zone using the practices mentioned earlier (trashing, mulching and minimum tillage) and storage in dams for irrigation purposes. There tends to be an anti-dam mindset, which ignores the socio-economic benefits storage dams constructed using environmentally sound principles.

Climate change will increase the importance of marginal areas where small changes can affect economic viability. As an adaptive strategy there needs to be more care when looking at marginal production areas, which will be most vulnerable in the future in terms of soil quality and water availability. Consideration needs to be given as to whether these areas will improve or get worse with climate change and whether they should be withdrawn from cultivation. New land expansion should take cognizance of future productivity under a less favourable climate regime.

The whole approach to irrigation management will require far greater attention, which will be in line with the requirements of the current Water Act. Irrigation scheduling to maximize water use efficiency and stretch water supplies will be critical. System selection with an emphasis on application efficiency and uniformity will become of prime importance.

4.3.2 Research

Currently models are probably adequate to assess the impacts of most of the above strategies on the crop and the water resource, under conditions of climate change. Model development to better represent agro-hydrological processes is thus not as important as model development to account for, for example, the impact of climate change on pest and disease populations and sucrose accumulation. More critical from a research perspective is model application across all climate regimes of the industry, using appropriate GCM forecasts of climate change, to assess trends and determine appropriate management strategies.

4.4 Will climate change require new varieties? (Impact 3.4)

Important but not urgent

4.4.1 Impacts and adaptive strategies

It is critical that new varieties are bred for likely future climate conditions. However this is not an urgent action, since the plant-breeding program is already accommodating change since varieties are selected in different regions with different climate regimes and on an ongoing basis accounting for the present rate of climate change.

Climate change is likely to result in changes in optimum crop cycles, changes in pest and disease threats, changes in cane quality patterns through the season, all of which will require an evolution of new varieties suited to the conditions.

4.4.2 Research

Plant breeders need to look more at causative reasoning. At the moment there is a tendency to looking at climate change by implication in our breeding programs, because variety selection is taking place in different regions. There needs to be a more explicit assessment of climate change and varieties to try to explain why certain varieties should perform better under certain conditions. If one can explain why one can extrapolate it to a new climate - to a new region - more easily. Models should thus be improved to mimic the crop physiological processes of, for example, partitioning and flowering under changing climate conditions.

4.5 Will climate change impact our vulnerability to pests and diseases? (Impact 3.5)

High importance and urgency

4.5.1 Impacts and adaptive strategies

It is possible that climate change could have a huge impact on pest and disease outbreaks. The industry is very vulnerable to pests and diseases, especially the eldana borer and smut, which both have temperature and stress as primary factors in their development and life cycles.

Many industry strategies to counter pests and diseases are already in place. Changes to climate regime could however help pests to thrive under less effective biological control as the ecological balance is disrupted. Disease and pest outbreaks could shift to new areas where economic impacts could become more severe. Existing strategies will need to be refined as conditions change.

4.5.2 Research

Research needs are to identify regions in the industry which are at greatest risk, using daily temperature driven models, accounting for not only the impact of changes to “average” temperature but also changes to temperature thresholds. A greater understanding of the drivers of pest and disease cycles is required in order to answer such questions as “how many consecutive days out of 30 would this combination of temperature and moisture thresholds need to be in place for a significant outbreak to be expected?”

It is clear that climate change is going to affect a whole lot of issues which are interlinked, this requires better understanding of the production system as a whole and the impact climate change will have on pests and diseases, partitioning sucrose and fibre, soil-plant-water balances and nutrition. A good understanding of the system, through models, is a priority for research.

4.6 Will climate change provide an opportunity to capitalize on carbon credits? (Impact 3.6)

High urgency and moderate to low importance

4.6.1 Impacts and adaptive strategies

There is much opportunity for the sugar industry to capitalize on carbon credits, but this should be regarded as a bonus to the industry rather than the core business of the industry. The industry should be looking at strategies of better land management, energy efficiency and cogeneration. Most importantly, the industry must act in a cohesive fashion in relation to other stakeholders such as the government, international negotiators, and the carbon traders.

4.6.2 Research

Research that is needed is fairly technical in most cases. There is a need to document changes in the other trace gases with changes in practices, for example burning vs green cane harvesting. While burning cane may be CO_2 neutral there are a host of other emissions such as methane, which are damaging to the environment and affect climate change. Trading of carbon savings can only take place where the climate benefits and sustainable development goals are met. Thus land management practices will have to be shown to have limited environmental and social impacts. Thus research would need to look at developing a full greenhouse gas account to prove that nitrous oxide or the methane emissions offset the positive carbon balance.

Research will also need to show what the co-benefits of sugarcane production are. If there are negative co-benefits, it will not be possible to satisfy the requirements of sustainability. Existing soil databases should be investigated to document changes in soil carbon in the past, to establish a baseline. The impact of changes in field practices on this baseline can then be determined.

4.7 Will climate change provide an opportunity for better use of the cane plant at the mill through cogeneration or using cane as biofuel? (Impact 3.7)

Moderate urgency High Importance

4.7.1 Impacts and adaptive strategies

There are a range of opportunities offered in this area, not necessarily only due to climate change, but also to the deregulation of the power industry in South Africa, which is imminent, and the emergence of green energy markets. Irrespective of whether there is climate change or not, the opportunities are there for a more profitable and diversified industry with the additional incentive of substantial carbon credits. While this is an area of high importance there can be no urgency since the responsibility lies with government to initiate a process, which would recognize carbon credit trading in South Africa. There is need for a cohesive approach to promote the concept to government including cogeneration, carbon sequestration in the soil and ethanol production from cane. It would be advisable to lobby government together with other interested industries rather than do it in a fragmented way.

4.7.2 Research

The challenge is for the sugar industry to change focus on sugarcane as an energy crop rather than a sweetener crop. This may change the sugarcane variety selection criteria away from maximum sucrose production. There is an important need for the sugar industry to document the greenness of its products taking account of the potential of the crop for renewable energy generation, benefits in terms of the CO_2 balance and the many other social and environmental factors. These issues need to be clearly documented. Further research is also required on the details of cogeneration, including optimal configurations and processes.

4.8 Will climate change impact significantly on small-scale grower viability and affect industry support requirements? (Impact 3.8)

Moderate urgency and importance

4.8.1 Impacts and adaptive strategies

It was agreed that with climate change there would be an increase in the risk profile to a group that is already in many cases close to the threshold in terms of viability. It is likely that the small-scale grower sector will be the first to feel the pinch under changing climate regimes.

4.8.2 Research

Many of the research requirements are not specific to the small-scale grower sector. There is need for a strategy to optimize varieties, not only for maximum production but also for robustness under variable circumstances. There is need for sufficient extension support and risk-spreading strategies for this high-risk group. Research should concentrate on quantifying risk for developing growers with research and extension products specifically developed for this group. Consideration needs to be given to regions where it might be possible for small-scale growers to grow sugarcane in the future, and particular problems associated with these areas. This should be given a high priority, largely because there is a negative perception to not being seen to take actions in areas enhancing previously disadvantaged communities. The sugar industry is not financially dependent on small growers, but the industries political and social sustainability is critically hinged on its ability to demonstrate that it is taking this issue seriously.

4.9 Will climate change impact our sugar quality and markets? (Impact 3.9)

Moderate urgency and importance

4.9.1 Impacts and adaptive strategies

In considering whether climate change will affect our sugar quality and markets, the key issue is what the effects of climate change will be on our competitors, because it's what's available in the marketplace in terms of both quality and quantity that controls what we are able to sell. The SA sugar industry is already in the situation where the sugar quality is quite variable given diverse climate, management and environmental factors across the industry. The issue of variability in sugar quality is thus already being managed and climate change will impose an incremental shift in a baseline, which is already quite variable.

4.9.2 Research

One of the key research requirements will be to understanding and forecasting the long-term effect on competitors and the short-term ability to forecast what competitors are putting into the market in terms of quantity and quality. GCM models have been used to assess winners and losers across the world and it would be sensible to review the results of this research in the context of sugarcane production.

There is a need to better integrate the climate change (long-term) and climate variability (seasonal) research scales. A lot of emphasis is being placed on integrating climate variability predictions with management and decision models. Short-term climate variability is in a sense a compressed microcosm of what the future is likely to be. Emerging economies (like South Africa) need to pay more attention to the immediate problems of climate variability. This does however allow the tools and models to be developed for assessing the impacts of climate change.

CLIMATE CHANGE – IMPLICATIONS FOR THE SA SUGAR INDUSTRY

PROGRAMME

08h30–09h30	Registration
09h30-13h00	**Chairman: Abraham Singels**
	Welcome – Erik Schmidt
09h30-10h00	***Model simulations of global and regional scale climate change scenarios over sub-Sahara Africa*** Hannes Rautenbach
10h00-10h30	***Climate change projections: Scale and uncertainty*** Bruce Hewitson
10h30-11h00	***Climate change: Sweetener to South Africa's sugarcane production or the acid test?*** Roland Schulze & Mark Horan
11h00–11h30	Tea
11h30–12h00	***Addressing climate change impacts on the Mauritian sugarcane industry*** Rasack Nayamuth, S Koonjah & FC Cheeroo-Nayamuth
12h00-12h30	***Climate change, international treaties and the sugar industry*** Bob Scholes
12h30-13h00	Discussion
13h00–14h00	Lunch

MODEL SIMULATIONS OF GLOBAL AND REGIONAL SCALE CLIMATE CHANGE SCENARIOS OVER SUB-SAHARA AFRICA

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Concern has been expressed about the gradual increase in surface temperatures recorded at many weather stations, especially in the Northern Hemisphere, over the past 140 years. This global temperature increase was preceded by a long period (approximately 1000 years) of temperatures with an average deviation of less than 0.2^{o}C. What is more alarming is the fact that the 1990s have been regarded as the warmest decade, and more recently, 1998 the warmest year on record. One also has to keep in mind that more severe natural temperature fluctuations have occurred in Earth's history over the past four billion years. What makes the temperature increase over the past 140 years significant is not the magnitude in change related to the longer history, but the impact that it might have on the present structure of biodiversity on Earth.

The immediate, and rather complex, question is whether recent temperature increases are due to natural climate fluctuations or human activities (anthropogenic factors). To find answers one needs to search for human related contributions that might have altered atmospheric temperatures over the past 140 years. Associated graphs from atmospheric measurements of anthropogenic emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and sulphate (SO_4) concentrations produce curves that relate well with the recent observed increase in atmospheric temperatures. Higher concentrations of greenhouse gasses such as CO_2, CH_4 and N_2O (and water vapour) will lead to a positive radiative forcing which might result in an increase in atmospheric temperatures.

However, the response of the global atmosphere system, with its interaction with Earth surface properties, to increased anthropogenic emissions is complex. Improvements in mathematical models, which simulate physical and dynamic properties of the atmosphere, allow for reasonable accurate simulations of present day climate. An obvious approach would be to employ these models, with prescribed estimated future trends in the concentration of atmospheric constituents, to determine the response of climate variables such as global temperatures, winds and rainfall patterns.

In this study future model simulated results from the global general circulation model (GCM) developed by the CSIRO Atmospheric Research in Australia, namely the CSIRO-9 GCM, have been considered. Simulations for the 10-year periods 1991-2000 (present), 2021-2030 and 2051-2060 were performed with prescribed concentration of atmospheric constituents as defined by the A2 SRES scenario. Global temperature, mean sea-level pressure (MSLP) and rainfall fields for January (austral mid-summer) and July (austral mid-winter) are compared with results obtained in the latest report of the Intergovernmental Panel on Climate Change (IPCC). It is concluded that the CSIRO-9 GCM is capable to capture the most prominent present synoptic scale circulation patterns of the atmosphere, and that results from CSIRO-9 GCM climate change scenario simulations agree well with those published in the IPCC report. On a more local scale model estimations points towards general drier conditions over South Africa for both months, and wetter conditions over Mozambique as a result of the prescribed A2 SRES scenario. The CSIRO-9 GCM (and other global GCMs) with its coarse resolution of approximately 300km x 500km makes it difficult to produce climate change scenarios focused on the mesoscale (< 100km).

For this purpose a limited area model with a finer resolution of 60km x 60km was nested into the simulated fields of the GCM. Results from the GCM therefore served as boundary input for the limited area model that was nested over the Sub-Sahara region. The limited area model used is known as the Division of Atmospheric Research Limited Area Model (DARLAM) - also developed by the CSIRO Atmospheric Research in Australia. Mesoscale simulations have been performed for the same months and periods defined in the GCM simulations. Simulations representative of present day rainfall, MSLP, minimum temperatures and maximum temperatures climate as well as the associated future climate change scenarios have been completed.

Summer rainfall and occasional showers that might develop during winter months mainly affect the South-African sugar industry. During winter-months South African rainfall confined to the southern coastal region is usually formed by means of frontal convection when cold air masses (fronts) sweep over the southern parts of South Africa. Even summer rainfall might be influenced by mid-latitude frontal systems that propagate eastwards, and is normally followed from behind by higher pressures - a phenomenon known as the Atlantic High that ridges to the south of the country. Such a system of anti-cyclonic circulation will result in an onshore flow of moisture along the southern and eastern coastline. Summer rain might also emanate from continental convection of moisture flux from the tropics caused by surface and upper air troughs over the interior.

DARLAM climate change scenario results are analysed by first considering model-simulated changes in the major synoptic scale rain producing systems over southern Africa and secondly to asses the impact of these alterations on the local scale rainfall and temperature of the country. In general it is indicated that continental MSLPs and atmospheric temperatures are expected to rise which might results in a decline of moisture flux from the tropics and a southward displacement of the route followed by frontal systems to the south of the country. The latter will result in more frequent summer and winter droughts as indicated on the spatial maps of estimated mesoscale changes in the climate variables considered.

CLIMATE PROJECTIONS: SCALE AND UNCERTAINTY

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The issues of projecting climate beyond the time scales of a few days has long been of great importance to Africa, and at the same time presented a significant challenge. Methodologically, the most viable approach is through the use of climate modeling to simulate the earth system processes. Such models, both global and regional in their domain, are computational representations of the fundamental physics and dynamics of the climate system. This talk investigates the usefulness of such climate projections, and some of the caveats and cautions that are essential in order to draw valid conclusions about the future.

Prior to considering future climate, however, it is important that the past climate be understood. In this regards one needs an adequate baseline climatology – not just means and variances. For example, what has happened to wet spell duration over the last 50 years, or have the seasonal boundaries shifted? This allows one to assess the model simulation results for firstly, validity, and secondly, whether the projections of the climate system concur with how the system has responded in the recent past. This is no trivial task, and requires careful consideration of how to compare point station data to the area averages from models.

While the models are an effective tool, no single model should be considered "the truth". Rather, an attitude of "all models are wrong, but some are more useful than others", should be adopted. This is to say models are erroneous, yet much useful information may be derived from them. Over time different model developers have evolved a range of computational approaches to simulating the climate system, with the result that each model has different spatial and temporal characteristics, and more importantly, different skill which is dependant on the geographic location, seasonal period, and variable under examination. In regard to the latter, precipitation (the variable often of greatest interest) is the variable most poorly simulated by models. The skill level of a model, that is, the spatial scale at which specific values of the model can be trusted to approach reality, is often 5-7 grid cells. For a global model, this can translate to spatial scales of 700km or larger. Compounding the issues of differences in physics, models also contain extensive components of parameterization – aspects of the climate system that cannot be explicitly resolved in the model physics, and are at best statistical or empirical approximations of real-world processes.

The implications of such parameterizations is one of stationarity; are the empirical approximations, which are based on the present observed climate, still valid under a future climate. An example would be that of cloud formation which is contingent in part on the particulates in the atmosphere. If the concentration and/or size of particulates were to change into the future, cloud formation (and hence precipitation) would change, and a simple parameterization would be wrong.

The net consequence of the above is to introduce uncertainty into any climate projections – creating an uncertainty envelope within which one may be fairly confidant the future lies, but not with exactness. For example, a given model, if run repeatedly (an ensemble) to simulate the same period, but initialized with slightly differing conditions, will generate an envelope of possible climates. Using additional models expands this envelope of uncertainty. Yet is important to use multiple models as there is no clear indication which model is more justifiable, nor which model is more skillful for a given location. Unfortunately, the larger the envelope the greater the difficulty in utilizing the results.

To make matters worse, it is recognized that there are other factors affecting future climate which are not (currently) considered in climate change simulations. Apart from uncertainty arising from future anthropogenic gas emission, perhaps the most important of these is land use and land cover change, whether from climate change forcing or from human activities. It has been shown that land use change can give rise to a regional change signal of comparable magnitude to the anthropogenic climate change signal.

Ultimately, in order to be proactive about climate change it becomes essential to use output from models, either for direct assessment of potential impacts, or for further downscaling (discussed below). In this case, it is important to approach with the following questions in mind:

- What variable, time, and spatial scale is of importance?
- How skillful is the model in reproducing these for the present day climate?
- What are the bounds of the uncertainty envelope for these?

If at least the sign of the change is agreed upon by the models, than the direction of the potential impact can be know. However, if the uncertainty envelope is so wide as to preclude usefulness then the baseline model output must either be disregarded, or further processed to enhance the information content. In the latter approach, potentially much can be achieved. At the very least, one can consider whether the uncertainty envelope may be constrained through consideration of the skill level of the models used. If, for example, model A can be shown to be half as skillful as model B, then this information may be used to reduce the influence of model A on setting the bounds of the uncertainty envelope.

Having undertaken the above, the next step is to regionalize the climate change information. Downscaling, the common term for this approach has become a major focus of research in order to derive greater spatial and temporal information from the relatively coarse global model resolutions. Two approaches are possible; empirical downscaling and nested regional climate models. Both of these approaches use the fact that the large-scale circulation aspects of the global models are relatively robust fields, and that these are these dominant determinant of local climate.

The first approach, empirical downscaling, utilizes cross-scale relationships derived from present day observations that are then applied to the large-scale data from the global model. This is computationally relatively simple and cost effective. The downscaling can cover a broad range of variables at different time and spatial scales. If future climate change is manifest primarily in terms of changes in persistence, frequency, and intensity of events then empirical downscaling is likely to be very effective. The alternative is to use regional climate models – effectively a global model scaled to some limited spatial domain and forced at its boundaries with the data from the global model. This approach of computationally demanding, and requires rigorous validation of the regional climate model before climate change simulations can be undertaken. As with empirical downscaling, this approach is also vulnerable to stationarity issues.

At present, both approaches are considered to be of equal skill (and both may introduce additional uncertainty!). It is important to note that both techniques will propagate any error in the driving fields from the global model. As such, it is imperative that the global fields are adequately evaluated in order to understand the validity of the downscaled product.

To conclude, the climate change projections of a number of models will be presented, and the envelope of uncertainty examined, and the regional projections considered for the north east coastal plain of South Africa. Finally, pertinent information about constraints for climate change research, and the current development of climate change projections will be discussed.

CLIMATE CHANGE : SWEETENER TO SOUTH AFRICA'S SUGARCANE PRODUCTION OR THE ACID TEST?

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Anthropogenically forced climate change scenarios for an effective doubling of atmospheric carbon dioxide concentration may still display inconsistencies when results from a number of General Circulation Models are compared, but they do share the commonality that a 2-3°C temperature increase is expected, coupled with a general decrease in rainfall. To the multi-million Rand sugarcane industry in South Africa repercussion could be significant to both growers and millers, with possible shifts in climatically optimal growth areas and changes in yields likely over the next few decades.

This paper commences by outlining some general agricultural impacts of anticipated climate change over South Africa. These include first order changes, e.g. of temperature, second order changes such as those on heat units and frost occurrence/duration and third order impacts such as changes in yields and pest breeding cycles. Thereafter a sensitivity study is undertaken with the *ACRU*-Thompson cane yield model, assessing in turn sugarcane=s sensitivity to changes in CO_2 and associated transpiration feedbacks, changes in temperature (which, while accelerating growth, also results in higher evaporative demand) and changes in rainfall magnitudes, while keeping the other variables unchanged. This is followed by an assessment of potential changes in cane yield, as estimated by the *ACRU*-Thompson model, using the inputs of ΔT and ΔP for a 2 x CO_2 scenario from the HadCM2 GCM.

The paper concludes by evaluating possible pros and cons of potential climate change on sugarcane production with the aid of a schematic representation of an agricultural sector analysis.

ADDRESSING CLIMATE CHANGE IMPACTS ON THE MAURITIAN SUGARCANE INDUSTRY

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The science of climate change has progressed significantly in recent years and scientific evidence strongly supports climate change as factual. Increased concentrations of the main anthropogenic greenhouse gases carbon dioxide, methane and nitrous oxide stemming from combustion of fossil fuels, agriculture and land use change have resulted in global warming and related changes in the climate system. These changes include sea level rise, precipitation distribution and intensity, cloud cover and wind regimes. Climate variability has increased as well as the frequency and intensity of extreme weather events.

Analysis of long-term data for Mauritius revealed a nominal increase in maximum temperature but a significant one for minimum temperature and the amplitude. Rainfall decreased while solar radiation increased. The trend is a reduction in the number of cyclones but with increasing intensity. Drought recurrence increased during the last decade. Simulations with four Global Circulation Models under a doubling of atmospheric CO_2 for Mauritius indicated a mean annual temperature increase of 2.12^{o}C to 3.59^{o}C, annual rainfall and solar radiation varying from -13% to +19% and -2% to +6% respectively.

A vulnerability and adaptation assessment of the sugarcane crop to climate change in Mauritius was undertaken using the APSIM-Sugarcane model to quantify the impacts on sugar productivity and to evaluate the adoption of irrigation, changes in cropping schedules and the possibility of using existing genetic potential as adaptative measures.

The industry was found highly vulnerable with sucrose yield decreasing from 32% to 57%. The water use efficiency (WUE) decreased to 14.2 mm t^{-1} cane and 17.2 mm t^{-1} cane from 10.5 mm t^{-1} cane. A sensitivity test within anticipated limits revealed that for every 2^{o}C rise, a reduction of about 32% in sucrose yield is expected while every 154mm (10%) rainfall increase/decrease resulted in about 15% change in sucrose yield.

Adoption of irrigation increased sucrose yield, improved WUE and reduced temporal variation. Under the GCM scenarios it nullified almost completely the effects of climate change. When water is not limiting, a 2^{o}C rise in temperature resulted in a 2% yield increase whereas a 4^{o}C rise was never compensated and sucrose yield decreased by 5%. Varieties responded differently to the changed climate thus indicating the possibility of using the interaction of existing genetic potential with the environment as an adaptive measure. A change in the harvest season appeared an attractive adaptive option only when the crop was fully irrigated.

Findings to-date, support a higher productivity and WUE in response to increased levels of CO_2 but this is not proven for the sugarcane in its natural environment. Due to constraints at the plant and/or soil level and in terms of water availability, the higher water needs resulting from elevated temperatures will most probably not be satisfied, thus depressing yields. Water storage capacity will have to be increased while taking care of the changed hydrological and irrigation cycle/regime. Coastal boreholes servicing irrigation could have reduced productivity and be affected by salt-water intrusion due to sea level rise. Such water will increase salinity problems. The new C:N atmospheric ratio will affect nitrogen mobilisation and release while nitrogen volatilisation could increase. N_2

application schedules and amounts will have to be reviewed in light of new cropping patterns, crop demands and phenological changes.

The crop's phenology is expected to change with varying effects on productivity. Higher temperatures will affect partitioning and it is highly probable that more dry matter will be partitioned into trash and more fibre will accumulate at the expense of sucrose in the stalk. Climate change could lead to profuse flowering and eventual yield reductions while reduced flowering will affect the breeding programme and the industry in the long-term.

Insect pests are expected to thrive with less effective biological control as the ecological balance is disrupted. Insects may colonise new areas and new species could make their appearance. Disease boundaries could change and non-economic diseases develop as the climate becomes more favourable. C_3 weeds will benefit more from CO_2 fertilisation and will complete their cycle more rapidly. The distribution and weed mix could thus change, rendering chemical control more difficult.

Land suitability will change and sugarcane areas will shift poleward and in altitude. It may compete with other crops for the same appropriate areas. Land use change has to be analysed in relation to mills, infrastructure and the society. The potential of vast areas will change necessitating a review of milling capacity and/or siting. Any deterioration in cane quality will reduce milling efficiencies.

The C_3 sugar beet will benefit more than tropical sugarcane from climate change. The cost of production and evolution in world market prices could play on the viability of the sugarcane industry.

The ratification and implementation level of the Framework Convention on Climate Change will determine the future increase of atmospheric greenhouse gases and climate change, hence the difficulty to forecast the magnitude of change in crop production. Nonetheless the completion of an impacts and adaptation assessment can be very enlightening, especially when identified adaptation options demand for decisions at the policymaker's level over and above contributing to the awareness and preparedness of all stakeholders.

One optimistic note for the sugarcane industry is that it is more environment-friendly than the sugarbeet industry being a lower emitter of greenhouse gases. This characteristic could be very determining for its continued existence and viability within a world in quest of sustainability.

CLIMATE CHANGE, INTERNATIONAL TREATIES AND THE SUGAR INDUSTRY

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The climatic future of the eastern seaboard of South Africa remains somewhat uncertain. Temperatures of up to several degrees warmer are highly likely in the next fifty years, and effective rainfall may decrease somewhat. The counterbalancing effect of elevated carbon dioxide in the atmosphere may keep production levels approximately the same as at present.

There is a silver lining, provided by the opportunities to use sugarcane, one of the world's most productive crops, as a 'biofuel' with zero net atmospheric impact. This can take one or more of several routes: the enhanced use of sugar byproducts (eg bagasse and trash) as a fossil fuel substitute in efficient combined-cycle electricity generation; or the production of ethanol from sugar itself. Under scenarios of rising oil prices, stricter environmental controls and an emerging hydrogen economy, sugar-for-energy would become increasingly viable.

In the immediate term, the sugar industry can reduce its climate impact by addressing the issue of cane burning. While combustion of cane or its residues has no net effect on the carbon balance of the atmosphere, it does increase the load of methane, and a series of ozone precursor gases (tropospheric ozone is a powerful greenhouse gas). Preliminary calculations indicate that eliminating burning in 40% of sSouth African canefields would have the equivalent effect of avoiding the emission of 300 000 tons of CO_2 annually – a small fraction of South Africa's emissions, but a useful contribution. The nuisance and health impacts of the smoke would also be reduced.

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