Statement of Accomplished Research and Self-Assessment

1. Accomplished research

Dr W. A. Landman obtained his B.Sc., B.Sc. (Honours)(Cum Laude), M.Sc. (Cum Laude) in Meteorology at the University of Pretoria, and his Ph.D. degree in Science at the University of the Witwatersrand. He participated in the first International Training Course on Theoretical and Practical Aspects of Short-Term Climate Prediction during 1993, a nine-month course presented at the Lamont-Doherty Earth Observatory of Columbia University, New York, USA. On his return to the South African Weather Service at the beginning of 1994, its seasonal forecasting programme came into being. The main goals of the programme are to conduct research on seasonal to interannual climate variability and to issue operational monthly to seasonal rainfall and temperature forecasts for southern Africa. The first seasonal outlook for South Africa was released during June of 1994. The code of a Canonical Correlation Analysis (CCA) model was developed by Landman during the training course at the Observatory and was used as the main seasonal prediction tool during the first few years of the programme. Although this model and its performance as operational seasonal forecast tool were presented at local and international conferences, the first paper to appear on the assessment of the model as seasonal rainfall forecast tool for South Africa appeared in 1999 in the International Journal of Climatology (19, 1073-1090), co-authored by Dr Simon Mason and entitled Operational long-lead prediction of South African rainfall using canonical correlation analysis.

Through the investigation of the relationship between sea-surface temperatures and southern African rainfall, it was discovered that the relationship between southern Africa’s summer rainfall and the sea-surface temperatures of the western equatorial Indian Ocean is unstable. Purely statistical models, especially those that are linear (i.e. the CCA model mentioned above), cannot take this instability into account. However, it was shown in an International Journal of Climatology paper (19, 1477-1492) entitled Change in the association between Indian Ocean sea-surface temperatures and summer rainfall over South Africa and Namibia (W. A. Landman and S. J. Mason 1999) that such changing associations may be simulated by a general circulation model (GCM), at least qualitatively. Therefore, further improvements to the prediction of southern Africa’s summer rainfall on a seasonal scale should be best achieved by using GCMs. This notion was subsequently tested by comparing the skill levels of statistical and GCM summer rainfall forecast systems for southern Africa over a ten-year retroactive forecast period that includes most of the 1990s. The main aim was to assess whether a GCM-based approach to seasonal rainfall estimation can produce rainfall forecasts for southern Africa with skill that outscores that of statistical modelling. Only when this is so is operational forecasting using GCMs justified because of the much greater expense involved. In this experiment, the lower boundary conditions of the GCM were monthly-mean global sea-surface temperatures predicted using a CCA-based statistical model. Details of the global sea-surface temperature model and its austral summer prediction skill levels can be obtained from Landman’s Ph.D. thesis entitled A Multi-Tiered Seasonal Prediction Scheme for Summer Rainfall of Southern Africa, Chapter 5 (University of the Witwatersrand, South Africa). It was found that the GCM-based approach can be applied in an operational environment, provided that the spatial characteristics and amplitudes of the sea-surface temperature forcing fields are described adequately. In addition, the GCM-based scheme was able to produce skill levels that are better than chance and to outscore the baseline skill level of the statistical
model, therefore justifying its use in an operational forecast environment. Furthermore, with improved prediction of sea-surface temperature fields, the GCM-based scheme has the potential to improve seasonal rainfall forecasts significantly. A detailed description of the skill comparison between the two techniques is described in the Landman et al. 2001 paper that appeared in the International Journal of Climatology (21, 1-19) entitled Retro-active skill of multi-tiered forecasts of summer rainfall over southern Africa.

The sea-surface temperature forecast skill levels produced by the CCA model in the abovementioned GCM-based forecast approach, were only assessed over the austral summer rainfall regions. The skill of the CCA sea-surface temperature model was further tested over the remainder of the year and at lead-times of up to eleven months. A detailed description of the model setup and output can be found in the 2001 Journal of Climate paper (14, 3819-3833) entitled Forecasts of near-global sea surface temperatures using canonical correlation analysis, co-authored by Dr S. J. Mason. This sea-surface temperature forecast model is of significant importance, because the output is used by the GCM that is currently being run operationally at the South African Weather Service.

Although GCMs have demonstrated forecast skill at global or even continental scale, they are unable to represent local sub-grid features, subsequently producing rainfall over southern Africa that is typically overestimated. Such systematic biases have created the need to recalibrate GCM simulations to regional levels over southern Africa. Owing to the existence of semi-empirical relationships between the observed large-scale circulation and rainfall, mathematical equations can be constructed to predict regional precipitation from simulated large-scale circulation, provided that these relationships are valid under future climate conditions and also that the large-scale structure and variability are well characterized by GCMs. GCM recalibration was already shown to be viable for southern Africa in the following papers that appeared in the International Journal of Climatology: Statistical downscaling of monthly forecasts (W. A. Landman and W. J. Tennant 2000, 20, 1521-1532), and Retro-active skill of multi-tiered forecasts of summer rainfall over southern Africa (W. A. Landman, S. J. Mason, P. D. Tyson and W. J. Tennant 2001, 21, 1-19). In addition to these already published papers, a paper was recently submitted to the Journal of Climate entitled Statistical recalibration of GCM forecasts over southern Africa using model output statistics, co-authored by Dr Lisa Goddard. The paper investigates the skill of a recalibration method applied to GCM output produced operationally at the International Research Institute for Climate Prediction. The paper demonstrated the efficacy of statistical interpretation of GCM output at a lead-time that could be beneficial to the users of such forecasts in southern Africa. The recalibration showed improved skill over both the GCM-simulated rainfall as well as over a linear statistical forecasting technique, and demonstrated through real operational forecast examples the added value that could be obtained if such forecasts are used in a probabilistic sense.

GCMs do not explicitly simulate streamflow, necessitating the statistical link between GCM-simulated fields and streamflow. A GCM-based forecast procedure to simulate real-time operational seasonal forecasts of streamflow at the inlets of twelve dams of the Vaal and upper Tugela river catchments in South Africa, is described in detail in a paper entitled Statistical downscaling of GCM simulations to streamflow (W. A. Landman, S. J. Mason, P. D. Tyson and W. J. Tennant), in press to appear soon in the Journal of Hydrology. Although surface characteristics of each catchment that affect the variability of streamflow are not considered in the proposed downscaling system, successful
forecasts of streamflow categories (below-normal, near-normal and above-normal) were obtained for some of the years forecast independently. The potential to make highly skilful categorized streamflow operational forecasts over relatively short lead-times was demonstrated in the paper, especially if the GCM is supplied with highly skilful sea-surface temperature forecasts that capture the large sea-surface temperature anomalies during strong El Niño / Southern Oscillation (ENSO) events.

Further efforts to understand how seasonal predictability is related to spatial-scale can best be investigated through the nesting of regional models into GCMs. The nesting will improve on topography features that are poorly resolved by global models and the simulation of significant synoptic features inadequately simulated by coarser GCM resolutions. The ESKOM Research Report RES/FI/00/10713 entitled Downscaling GCM simulations to rainfall and runoff using a regional climate model: a first approach (Landman 2000) describes an experiment where the simulation by a regional model, forced with observed initial and boundary fields reminiscent of GCM output fields, of an anomalously wet summer rainfall season over southern Africa is compared to that of an anomalously dry season. It was found that the regional model was successful in simulating lower and mid-tropospheric flow and also the frequency of a range of rainfall thresholds at three major rainfall centres within South Africa. A paper on the comparison between the regional model simulations of the two seasons, entitled A first approach to simulate southern African seasonal rainfall and runoff using a regional climate model and co-authored by Dr Anji Seth, has recently been submitted to the Water SA, a journal of the Water Research Commission of South Africa.

2. Self-assessment

Dr Landman has since the mid 1990s played a leading role as seasonal climate forecaster in southern Africa, both in operational and research mode. He uniquely has strong experience at both statistical and dynamical forecasting methods, as well as in downscaling and applications forecasting. He has extensive experience in the field of seasonal forecasting emphasized by his attendance of the nine-month training course on Theoretical and Practical Aspects of Short-Term Climate Prediction presented in 1993 at the Lamont-Doherty Earth Observatory of Columbia University, the two-year postdoctoral fellowship at the same institution during 2000 and 2001, the several years of forecasting experience, and that he has published widely on this topic in a good number of papers in international journals. In recognition as a statistical modeller, Dr Landman was asked by the World Meteorological Organization to contribute to the CLIPS curriculum on creating empirical models.

Towards the end of the 1990s, most of the constructed prediction algorithms for southern African seasonal rainfall made extensive use of linear statistics. However, many important climate processes demonstrate strong non-linearities. Purely statistical methods of seasonal forecasting are unable to take instabilities within sea-surface temperature – southern African summer rainfall associations into account. Such association changes have been discovered by Drs Landman and Mason in their 1999 International Journal of Climatology paper entitled Change in the association between Indian Ocean sea-surface temperatures and summer rainfall over South Africa and Namibia. Dr Landman’s main contribution to this paper was the discovery of the change in the association between western equatorial Indian Ocean austral summer (December to February) sea-surface temperature variability and southern African rainfall variability
During the same season: prior to the late 1970s, warm (cold) events in the tropical western Indian Ocean were typically associated with anomalously dry (wet) conditions over much of southern Africa; over the most recent two decades warm (cold) events in the tropical western Indian Ocean have become associated with wet (dry) conditions over predominantly the northeastern half of South Africa. Dr Mason’s most significant contribution to the paper was showing that these changes in rainfall – sea-surface temperature associations can be successfully simulated using a GCM.

Further improvements to the prediction of southern Africa’s summer rainfall on a seasonal time scale should be best achieved using GCMs. In order to test if GCM-based rainfall simulations can produce improved forecast skill over linear statistical models, their performances must be compared, preferably over an independent test period. Only when GCM-based seasonal rainfall estimation can produce rainfall forecasts with skill that outscores that of statistical modelling, can operational forecasting using GCMs be justified because of the much greater expense involved. The statistical model used to establish the baseline skill level that has to be outscored by the GCM-based forecasts, was developed by Dr Landman. The performance of the model over the South African summer rainfall months is described in detail in the paper entitled *Operational long-lead prediction of South African rainfall using canonical correlation analysis*, co-authored by Dr Mason while co-supervising Landman’s Masters dissertation on the predictability of South Africa’s seasonal rainfall using CCA. The performance of the CCA model was assessed over a ten-year retro-active period starting in 1987/88, and compared to that of a GCM-based forecast scheme. The GCM forecast scheme consists of a number of tiers of which the first tier is the prediction of global sea-surface temperature fields as the boundary forcing of the GCM. Bias-corrected GCM simulations during the same ten-year period were subsequently related to regional rainfall using the perfect prognosis approach, and compared to that of the statistical model. The results are described in detail in a 2001 International Journal of Climatology paper entitled *Retro-active skill of multi-tiered forecasts of summer rainfall over southern Africa*. The statistical sea-surface temperature model, the GCM bias-correction and the perfect prognosis equations that relate GCM circulation to regional rainfall, were designed and tested by Dr Landman. This paper is one of the major outputs from Landman’s Ph.D. thesis entitled *A Multi-Tiered Seasonal Prediction Scheme for Summer Rainfall of Southern Africa*, supervised by Prof Tyson of the University of the Witwatersrand and Dr Mason. Mr Tennant provided the GCM fields. This paper has made a significant contribution to seasonal forecasting research in southern Africa by comprehensively demonstrating that a GCM-based forecast scheme of seasonal rainfall is able to produce skill levels that are better than chance and to outscore the statistical model baseline skill level. In addition, if the prediction skill of global sea-surface temperatures can be improved, the multi-tiered scheme has the potential to improve seasonal rainfall forecasts significantly. In the past statistical modelling offered the best prospects for seasonal forecasting for southern Africa, but in the future GCMs will undoubtedly provide the best basis for doing so. The multi-tiered scheme was additionally applied to streamflow at the inlets of some of the dams of the Vaal and upper Tugela river catchments in South Africa. The paper on the streamflow forecasts, soon to appear in the Journal of Hydrology, is entitled *Statistical downscaling of GCM simulations to streamflow*.

Model output statistics (MOS) is the preferred approach used to develop equations relating GCM quantities to a forecast quantity such as rainfall. MOS is preferred because it can directly compensate for systematic errors. These errors can be overcome because MOS uses predictor values in both the development and forecast stages. The 2000
International Journal of Climatology paper entitled *Statistical downscaling of monthly forecasts*, was the first to test the applicability of a MOS system in a South African seasonal forecasting environment. Significantly, the paper illustrated that the MOS skillfully predicted extreme events over the summer rainfall regions of South Africa, even during years that are not related to ENSO. In addition, the paper demonstrated that the origins of the MOS forecast skill were found to be in agreement with observations. The MOS equation design and the analyses were done by Dr Landman; Mr Tennant provided the GCM fields and the regional rainfall indices. The second MOS paper, submitted recently to the Journal of Climate and entitled *Statistical recalibration of GCM forecasts over southern Africa using model output statistics*, demonstrated that statistical interpretation of GCM output has shown improved skill over both the GCM-simulated rainfall as well as over a linear statistical forecasting technique. These results are of great significance, especially for developing countries, because the recalibration is relatively cheap to run and can be applied successfully to other regions and for other applications such as streamflow. All MOS model development and analyses were done by Dr Landman, while Dr Goddard supplied the GCM data and contributed through discussions and recommendations.

The Journal of Climate paper entitled *Forecasts of near-global sea surface temperatures using canonical correlation analysis*, should additionally be considered as a major contribution by Dr Landman to seasonal forecasting research. A number of models have been developed for making extended-range forecasts of sea-surface temperature anomalies of the equatorial Pacific Ocean, but predicting the inter- and intra-seasonal variability of ocean areas other than the tropical Pacific has enjoyed attention only recently. There is, however, a need for global sea-surface temperature forecasts for initializing the boundary conditions of atmospheric GCMs in multi-tiered forecasting approaches such as the one described above. In addition, in many areas of Africa, for example, climate variability is significantly affected by ocean areas other than the equatorial Pacific. A need for an *a priori* indication of the expected seasonal variability of ocean areas outside the equatorial Pacific lead to the designing of the sea-surface temperature model described in the paper. Forecast skill was investigated over an eighteen-year independent retro-active period from 1982/83 to 1999/2000 by comparing forecasts with observations and persisted sea-surface temperature anomalies. The model presented useful skill in predicting tropical sea-surface temperatures over the Indo-Pacific region and beats persistence after two seasons for the Pacific and after one season for the Indian Ocean regions. Dr Landman designed the forecast algorithm and did the data post-processing, while Dr Mason contributed through suggestions and discussions.