# THE DEVELOPMENT OF A COMPUTERIZED CROP-SPECIFIC DROUGHT MONITORING SYSTEM

Uys W. Lourens and James M. de Jager
Department of Agrometeorology
University of the Orange Free State
P.O. Box 339
Bloemfontein 9300
South Africa
Voice: +27-51-4012882
Fax: +27-51-4012117
E-mail: uys@landbou.uovs.ac.za

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**ABSTRACT**

A near real-time crop-specific drought monitoring system (DMS) that combines crop modelling and a Geographical Information system (GIS) has been developed in South Africa. The system is intended for use in decision support by resource managers concerned with drought aid. The condition of maize, wheat and rangeland can presently be monitored in the DMS. The system is a spatially distributed system with individual simulations being run for areas covering approximately 14 km$^2$. Values of the weather elements used to drive the models, are obtained through interpolation of ground observations and processing of weather satellite imagery. Monitoring is undertaken throughout a production season, with updates provided on a fortnightly basis. Predictions of expected yield at the end of the season are made by using observed data up to the current date and completing the season with surrogate historical weather data. Appropriate surrogate scenarios are chosen based on the current season. After each monitoring run, simulated yield predictions for the season are compared with expected long-term yields of the crop produced in a particular region. A drought index class is assigned based on this comparison. Maps and tabulated information are produced in the GIS showing the spatial distribution of drought stricken areas and the intensity of drought in these areas. The maps and tables are distributed to government institutions and agricultural co-operatives.

## INTRODUCTION

Drought occurs the world over and through the famine that it engenders has probably claimed more lives than any other natural disaster (Riebsame 1991). Droughts are unique in that unlike floods, earthquakes, or hurricanes; during which violent events of relatively short duration occur, droughts are more like a cancer on the land that seems to have no recognized beginning (Mather 1985).

The African continent is particularly drought prone. Drought in the semi-arid regions of Africa is a recurrent but aperiodic phenomenon (Glantz 1987). The southern tip of Africa and South Africa in particular is not excluded. Considerable agricultural production takes place in South Africa under arid or semi-arid where drought is a recurring hazard (Bruwer 1989).

The term drought however means different things to different people (Day 1991). Wilhite and Glantz (1987) group drought definitions into four types:

* Meteorological drought - defined solely on the basis of the lack of rainfall and the duration of such dry periods,
* Hydrological drought - definitions concerned with effects of drought on surface or sub-surface hydrology,
* Agricultural drought - links various characteristics of meteorological drought to agricultural impacts, and,
* Socio-economic drought - definitions that express features of the socio-economic effects of drought, but can incorporate features of meteorological, agricultural and hydrological drought.

This paper focuses on the development of a near real-time, crop-specific, agricultural drought monitoring system for early warning of impending disaster. The system is intended for utilization in decision support for resource managers.

## SYSTEM DESIGN CRITERIA

Drought is a spatially related phenomenon (Karl and Koscielny 1982; Mather 1985). The first requirement of a drought monitoring system then is an ability to describe drought intensity quantitatively on a spatial basis (Bruwer 1989; Shelly 1991).

The second requirement for an agricultural drought monitoring system is that the sensitivities of specific crop growth stages to drought, must be taken into account (Easterling and Riebsame 1987). A plant's demand for water is dependent on the prevailing meteorological conditions, biological characteristics of the plant, its stage of growth, and the physical and biological properties of the soil (World Meteorological Organization 1975). The monitoring system must be a synthesis of these factors.

The third requirement is that the output from such a system will be readily usable by decision makers involved in drought planning or drought relief management. The typical decision maker weighs a wide variety of inputs in reaching a decision (Redmond 1991). Presenting information succinctly will assist in sound decision making. A useful way of presenting drought information to decision makers is through the use of an index. A major reason for using indices is that they are simple, usually consisting of a single number, which is easy to remember (Redmond 1991). The fourth requirement of an agricultural drought monitoring system is that the index used should be easily updated from observed weather data obtained from the national observation network.

The fifth requirement is that an agricultural drought monitoring system should be crop-specific. Meyer, Hubbard, and Wilhite (1993) point out that the advantages of a crop-specific drought index are threefold: (i) weather's probable impact on crop production can be assessed any time during the growing season using standard meteorological variables, (ii) probabilities of projected outcomes can be assigned based on historical climate data, (iii) specific outcomes can be inferred using climatological analogs.

## SYSTEM DESIGN PROCESS

The first step in the design process was to decide on the base unit to use when describing drought severity quantitatively on a spatial basis. The base unit chosen covers an area of 2° of longitude and 1° of latitude. This base unit was selected as it is a common division used by the Surveyor General for topographical and cadastral mapping and many thematic maps produced by other organizations (eg soil maps) also use these boundaries. These maps are known as the South African 1:250 000 map sheet series. There are a total of 70 such map sheets on which South Africa is mapped.

The second step in the design process was that of satisfying the requirements that the system should be sensitive to crop development stage and that it should be crop-specific. Applying crop growth models in the drought monitoring system was decided on as the solution. Selection of the particular crop model to run for a given map sheet or part thereof, would depend on the geographic area mapped and the time of year.

The models and their input data would however have to be spatially distributed. It was decided to divide the base unit into a number of smaller cells for which simulations could be performed. Each base unit was divided into cells covering an area of two minutes by two minutes of latitude and longitude (± 14 km$^2$). There are thus 1800 grid cells (60 columns and 30 rows) in one such unit.

The third step in the design process was to decide on a mechanism to use in determining drought severity, for a particular crop in a particular area. It was decided to use the probability distribution of crop yield as the norm for defining drought severity.

Yield norms would be obtained by using crop modelling to establish the cumulative probability distribution function (CDF) of a particular crop for given soil, climate and management (planting date, density and row widths) combinations. The CDF would be subdivided into classes to obtain threshold levels for the drought index classes (Table 1). The same approach as used in the Palmer Drought Severity Index (Palmer 1965), where numerical values are linked to brief definitions of drought intensity, was followed.

**Table 1** Drought index class definition

| Index | Description | Range in probability of non-exceedence on CDF of seasonal yield (%) |
|---|---|---|
| 1 | Extreme drought | 0 - 10 |
| 2 | Severe drought | >10 - 20 |
| 3 | Moderate drought | >20 - 30 |
| 4 | Mild drought | >30 - 40 |
| 5 | No drought | >40 - 100 |

The final step in the design process was to plan the functioning of the DMS, for regular drought monitoring during a production season, such that the requirements for easily comprehensible output and readily updateable indices could be met.

It was decided that a fourteen day interval would be used for reporting on the drought situation. However the system would be designed so that the interval could be shortened if so desired. Simulations would be performed using the observed weather data series up to the current calendar date and completing the season with surrogate data. Final expected grain yield for each of the 1800 cells within the bounds of map sheet would be forecast.

Three scenarios would be used to complete the weather data series for the simulations: i) the season continues below normal (rainfall of the 1st decile), ii) the season continues normally (median rainfall), and iii) the season continues above normal (rainfall of the 10th decile). Surrogate weather scenarios would have been previously established for each homogeneous climate zone. The homogeneous climate zone within which a cell lies would be identified in choosing the appropriate surrogate data set.

The grid of forecasted yields for below, above and normal seasons would then be fed into the GIS. Here the yield forecast for each cell would be compared to the CDF of the particular crop, for its particular soil, climate and management situation. On the basis of this comparison a drought index value would be assigned to each grid cell. Maps and tabulated information produced from the GIS would then be distributed to decision makers.

The system designed would be iterative, continuing to the end of the season, with the observed weather data base increasing while less use would be made of the surrogate data base. The drought monitoring system designed is shown in Figure 1.

## INITIAL TESTING

The DMS, as described above, was implemented and tested on three 1:250 000 map sheets covering the main summer grain producing areas in South Africa. Three historical production seasons, for which yield data were available, were examined; namely 1988/89, 1991/92 and 1993/94. The maize growing season of 1991/92, was a season of severe drought and therefore a good test of the system. Above average yields were achieved in the 1988/89 production season while for 1993/94 yields could be considered as normal. The system was tested both quantitatively and qualitatively. Qualitative assessment was done by showing maps from the DMS to persons familiar with the area and obtaining their comment. Quantitative assessment was done by comparing magisterial district average maize yields recorded by the Department of Agriculture, with magisterial district averages computed from the system.

Some of the maps produced from regular monitoring of the 1991/92 season, using the median rainfall scenario to complete the season, are shown in Figures 2a - 2c. Figure 2a, shows the prognosis for the remainder of the season shortly after the crop has been planted. Here it can be seen that even if normal rainfall were to occur for the remainder of the season many areas would experience yield losses as a result of drought. Rainfall in the latter part of December and early January altered the prognosis. In Figure 2b it can be seen that the situation in the south east of the map sheet has improved with moderate or mild drought losses predicted if the rainfall remained normal.

The critical flowering period of the crops occurred towards the end of January and beginning of February when virtually no rain fell. The devastating effect of this is apparent in Figure 2c, where most of the areas on the map sheet are marked as extreme drought which resulted in almost entire yield loss. The effect of isolated rain in the area covered by the south west corner of the map sheet can be seen in that the prognosis for certain areas was that normal yields would occur. The general trends shown in the three maps were verified in the quantitative analysis.

The results of the quantitative analysis are shown in Figure 3. From Figure 3 it can be seen that the DMS and the Department of Agriculture data agree well for the 1988/89 and 1991/92 seasons. The discrepancy in the 1993/94 data can be ascribed to rainfall data interpolation method used. The interpolated values for certain cells appear to be higher than what was recorded, resulting in higher yields in these cells and consequently a higher average.

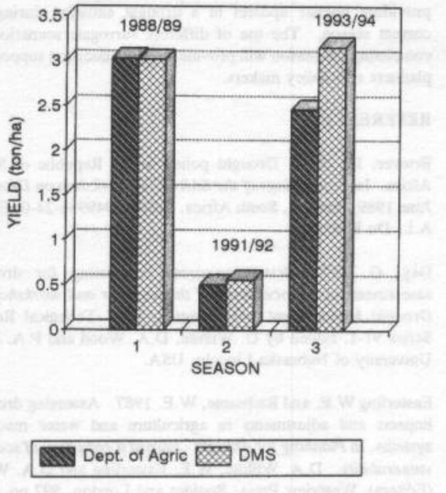


**Figure 3** Comparison of Dept. of Agriculture average maize yields and Drought Monitoring System (DMS) average maize yields.

## CONCLUSIONS

A crop-specific drought monitoring system, based upon simulation models, has been developed, implemented and tested with excellent results. The PUTU suite of crop growth models was successfully adapted to work on a spatially distributed grid, in order to compute an objective crop-specific drought index on a daily basis. Mechanisms to obtain, process and interpolate the weather, soil and crop data inputs required for running the models have been established and tested.

The crop modelling approach to drought assessment takes the interaction of the soil, plant and atmosphere into account. The important influence of both the amount and timing of rainfall in relation to crop growth stages is reflected in the index. A major requirement for an effective and reliable drought index is that it should be crop and region specific. The present system ensures this by using the cumulative probability distribution function for each homogeneous climate zone as an accurate norm against which current season performance is compared. This provides an assessment of drought severity which meets these requirements.

The use of a GIS makes for convenient display of the spatial extent and severity of a current drought together with other spatially significant information, such as magisterial district boundaries. Furthermore the GIS/modelling system permits both delimitation of drought stricken areas and indication of the intensity of the drought. The system is dynamic in the sense of providing regular updates of a drought situation during the current season. The use of different surrogate scenarios for completing the season will provide valuable decision support for planners and policy makers.

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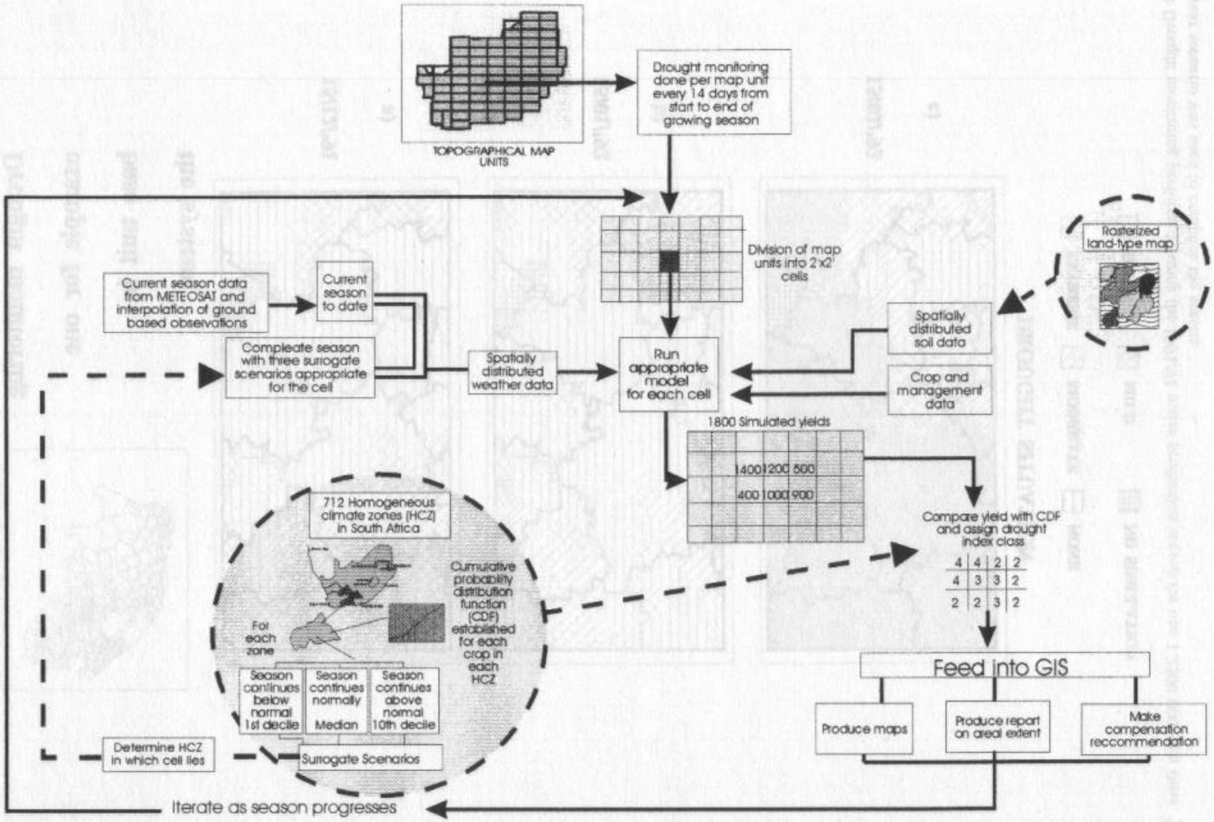


**Figure 1** The drought monitoring system

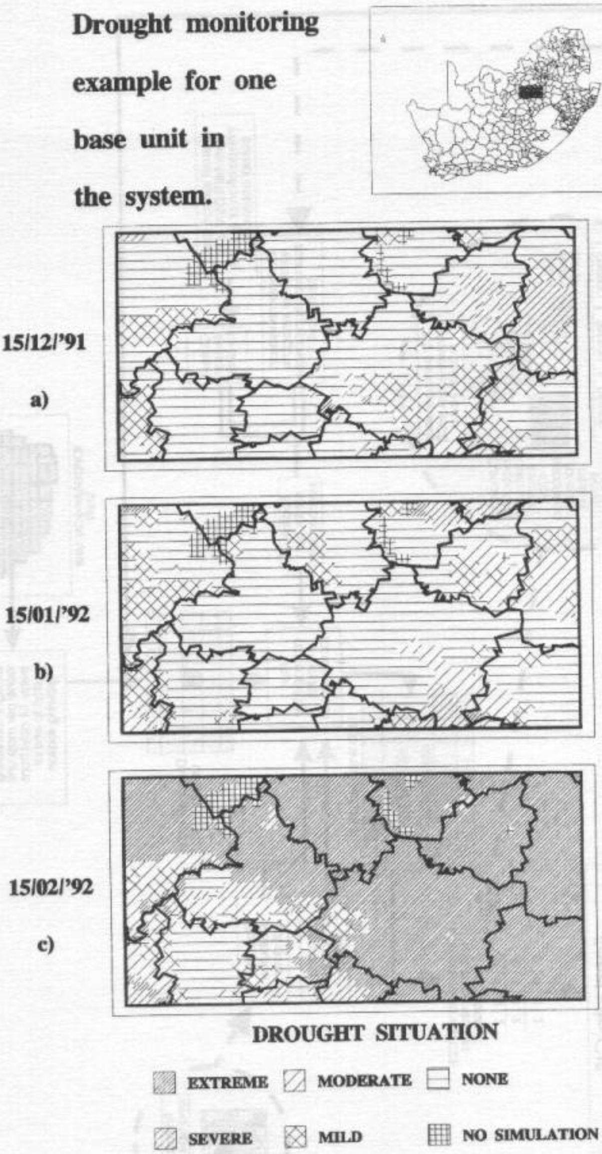


**Figure 2** Drought monitoring performed during the 1991/92 maize production season for one 1:2500 000 map sheet. The median rainfall year scenario was used to complete the season.