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Seasonal Maize Yield Simulations for South Africa using a Multi-Model Ensemble System

by

Noelien le Roux

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Supervisor:	Prof. W.A. Landman
Co-supervisor:	Dr. F.A. Engelbrecht
Department:	Department of Geography, Geoinformatics and Meteorology
Faculty:	Faculty of Natural and Agricultural Sciences
University:	University of Pretoria
Degree:	Master of Science

ABSTRACT

Agricultural production is highly sensitive to climate and weather perturbations. Maize is the main crop cultivated in South Africa and production is predominantly rain-fed. South Africa's climate, especially rainfall, is extremely variable which influences the water available for agriculture and makes rain-fed cropping very risky. In the aim to reduce the uncertainty in the climate of the forthcoming season, this study investigates whether seasonal climate forecasts can be used to predict maize yields for South Africa with a usable level of skill. Maize yield, under rain-fed conditions, is simulated for each of the magisterial districts in the primary maize producing region of South Africa for the period from 1979 to 1999. The ability of the CERES-Maize model to simulate South African maize yields is established by forcing the CERES-Maize model with observed weather data. The simulated maize yields obtained by forcing the CERES-Maize model with observed weather data set the target skill level for the simulation systems that incorporate Global Circulation Models (GCMs). Two GCMs produced the simulated fields for this study, they are the Conformal Cubic Atmospheric Model (CCAM) and the ECHAM4.5 model. CCAM ran a 5 and ECHAM4.5 a 6-member ensemble of simulations on horizontal grids of 2.1° x 2.1° and 2.8° x 2.8° respectively. Both models were forced with observed sea-surface temperatures for the period 1979 to 2003. The CERES-Maize model is forced with each ensemble member of the CCAM-simulated fields and with each ensemble member of the ECHAM4.5-simulated fields. The CERES-CCAM simulated maize yields and CERES-ECHAM4.5 simulated maize yields are combined to form a Multi-Model maize yield ensemble system. The simulated yields are verified against actual maize yields. The CERES-Maize model shows significant skill in simulating South Africa maize yields. CERES-Maize model simulations using the CCAM-simulated fields produced skill levels comparable to the target skill, while the CERES-ECHAM4.5 simulation system illustrated poor skill. The Multi-Model system presented here could therefore not outscore the skill of the best single-model simulation system (CERES-CCAM). Notwithstanding, the CERES-Maize model has the potential to be used in an operational environment to predict South African maize yields, provided that the GCM forecast fields used to force the model are adequately skilful. Such a yield prediction system does not currently exist in South Africa.

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I declare that the thesis that I hereby submit for the degree .... at the University of Pretoria is my own work and has not previously been submitted by me for degree purposes at any other university or institution.

SIGNATURE DATE

University of Pretoria, 2009

PREFACE

Agricultural production is highly sensitive to climate and weather perturbations (Podesta *et al.*, 1999; Chimeli *et al.*, 2002; Cantelaube and Terres, 2005; Sivakumar, 2006). Rainfall as such, can be considered as the atmospheric variable with the largest limiting effect on crop growth and development (Taljaard, 1986; DoA, 2007), which makes rain-fed agriculture particularly vulnerable to extreme weather events that significantly influences water availability. In South Africa, crop production is predominantly rain-fed, with only about 1% of the total cultivated area being irrigated (Chenje and Johnson, 1994). Due to the extreme variability of South Africa's climate, crop production is exceptionally risky. Therefore, the climate can be seen as one of the main factors responsible for year-to-year variations in South African crop yields.

Agriculture represents one of the main pillars of the economy of South Africa as a developing country, not only in terms of crop production and the main source of food, but also in terms of employment (Oram, 1989; Sivakumar, 2006; DoA, 2007). In a country like South Africa, where rain-fed agriculture dominates, a good rainy season normally results in good crop production, whereas a season with insufficient rain or the occurrence of a natural disaster (drought or flood) can result in crop failure (Arndt *et al.*, 2002; Sivakumar, 2006). This vulnerability of crop production to fluctuations in the climate, which consequently leads to variable yields, can cause the economy of the entire country to suffer (Cantelaube and Terres, 2005; Sivakumar, 2006). Southern Africa is a region subject to climate extremes (Tyson, 1986; Reason *et al.*, 2006a) and as a result often faces threats of food shortages (Devereux, 2000). The world's population is expected to exceed 8 billion by the year 2020, which places even more pressure on the agricultural sector in terms of food security (Sivakumar, 2006).

To ensure food security, excellent crop management is of utmost importance. This is a complicated practice, as weather is the primary source of uncertainty in crop management (Vossen, 1995). From the start of the season and right through, farmers have to make critical land and water management decisions which are primarily based on climatic conditions (Sivakumar, 2006). These decisions are often made weeks to months in advance of a specific weather event, like for instance the onset of the rainfall. Since unexpected climatic extremes can have detrimental effects on the yield, there is a need to investigate ways by which the uncertainty in the expected climate regime of the forthcoming season can be reduced. Seasonal climate forecasts provide insight into the expected mean weather conditions of the approaching season, but farmers can benefit more from information when it is presented in terms of production outcomes.

In this study a maize yield forecast system is constructed using a crop model and two Global Circulation Models (GCMs) that aims to produce useable maize yield predictions for South Africa which will allow farmers to take advantage of probable good seasons and reduce unwanted impacts in probable poor seasons.

The hypotheses that will be tested are:

1. that the crop model has skill in simulating South African maize yields when forced with observed weather data;

2. that crop model-GCM based maize yield simulation systems can produce skill levels comparable to the target skill level set by forcing the crop model with observed weather data;

3. that the skill of a simple Multi-Model maize yield ensemble system outscores that of the best crop model-GCM based maize yield simulation system.

The steps required to test these hypotheses are to:

1. run the crop model for each of the magisterial districts in the primary maize producing area of South Africa for the period 1979/80 to 1998/99 with observed weather data;

2. quantify the skill of the crop model by comparing the simulated maize yields to actual maize yields and so that a target skill level can be set;

3. use the GCM-simulated fields as forcing in the crop model and perform the same crop model runs as done with the observed weather data;

4. combine the simulated maize yields from the two crop model-GCM based simulation systems to form a simple Multi-Model maize yield ensemble system;

5. verify the simulated maize yields obtained from the crop model-GCM based systems and from the Multi-Model maize yield ensemble system against actual maize yields and against the target skill level.

This dissertation consists of four chapters. Chapter 1 describes the growth stages of the maize plant, the factors influencing South Africa's climate, the seasonal predictability of South African rainfall, seasonal climate forecasting, ensemble and multi-model forecasting as well as an overview of crop yield forecasting worldwide. The data and models used and set up of the maize yield simulation experiments are detailed in Chapter 2. The methods used to verify the simulated maize yields are also described in this chapter. Chapter 3 discusses the maize yield simulation results. The simulated maize yields are verified spatially, inter-seasonally and probabilistically. The results are summarized and conclusions are made in Chapter 4.

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