Linking satellite imagery, surveying and crop modeling to assess impacts of climate change on maize production at district level in South Africa

Wiltrud Durand — Agricultural Research Council-Grain Crops Institute, Potchefstroom, South Africa, DurandW@arc.agric.za
Fanie Ferreria — GeoTerraImage, P.O. Box 295, Persequor Park, 0020 Pretoria, South Africa, Fanie.ferreira@geoterraimage.com
Deon du Toit — Agricultural Research Council-Grain Crops Institute, Potchefstroom, South Africa, DutoitDL@arc.agric.za
Oliver Crespo — Climate System Analysis Group, University of Cape Town, 7701 Rondebosch, South Africa, olivier@csag.uct.ac.za
Yacob Beletse — Agricultural Research Council-Roodeplaat, KwaMahlanga Road, Pretoria 0001, South Africa, beletsey@arc.agric.za

1. Background

Although most dynamic crop models have been developed and tested for plot scale (homogeneous fields), applications related to climate change, often require broader spatial scales that can incorporate considerable heterogeneity (1). The most adopted approaches to overcome this limitation is to either model representative sites (points), homogeneous regions (vector) or partitioning into grid cells (raster) (2). The approach, similar to using representative points, of using household survey information suggested by Rozengweig et al. 2014 (3) could not be implemented in South Africa due to the non-existence of surveys with the required information. As alternative, a maize crop field level land cover was developed using satellite imagery, producer independent crop estimate survey (PICES) and crop type classification. This approach honours the scale of a homogeneous plot at which the crop model (DSSAT) was developed, but takes into account district level yield variation as the whole population of maize fields within a district is modeled. Crop management such as row spacing, plant population and planting dates were derived from objective yield surveys based on a point sampling frame and associated with the fields proportionally to their occurrence. GIS and pedo-transfer functions were used to derive soil profile descriptions for each field based on land types. Fertilization was based on the average modeled 50 year yield potential of each field. Crop model applications related to climate prediction depend critically on the assumption that the models can capture the year-to-year pattern of response to climate variability (1). The objective of the study was to test whether the approach of using a field level crop land cover could be used to simulate past (1980-2010) and future (5 General Circulation Models (GCMs) for the time period 2040-2070, with Representative Concentration Pathway (RCP) 8.5 and CO2 of 571 ppm) maize productivity, using the DSSAT crop model, and then summarising to either quinary or district level. The approach was tested within three districts of the Free State province of South Africa. The flexibility of the maize crop field level land cover approach is demonstrated by a graphing the inter-annual probability of exceedance using simulated yields for a field the Bloemfontein district (Figure 8), mapping the average yields per quinary in the Bethlehem district (Figure 9) and summarising yields inter-annual yield variation at district level using Box-plots for the Bothaville district (Figure 10).

2. Modeling Framework

Management

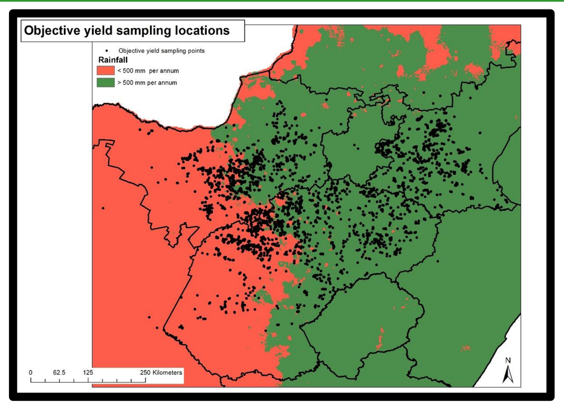

Figure 1 Objective yield sampling locations (2008 – 2013) for the Free State, North West and Mpumalanga provinces of South Africa and average precipitation higher and lower than 500 mm per annum.

The Free State province was divided into two zones i.e. above and below 500 mm rainfall per annum. 1542 samples within the Free State obtained from objective yield surveying over a 6 year period (2008-2013) were used to calculate the proportion of fields with certain row widths, planting dates and plant population. The same proportion was used to assign the management strategies to all the fields within the Free State using the "Sample Features" command of Geospatial Modeling Environment (Version 0.7.2.1) (4).

Climate

Historical Climate Conditions
1980-2010
CO_2 360 ppm

Future Climate Scenario's
2040-2070
CO_2 571 ppm
RCP 8.5

- CCSM4
- GFDL-ESM2
- HADGEM2-ES
- MICRO5
- MPI-ESM-MR

Baseline climate for the three districts were obtained from the climate team (5), covering a thirty year period from 1980 to 2010. Data contained daily minimum and maximum temperature, precipitation and solar radiation. Following AgMIIP protocol, climate change outlooks were generated by the climate team based on five GCMs. The GCM's used were, CCSM4 (E AgMIIP code), GFDL-ESM2G (H AgMIIP code), HadGEM2-ES (K AgMIIP code), MICROC5 (O AgMIIP code) MPI-ESM.-MR (R AgMIIP code). The future simulated was that for mid-century (2040-2070) under RCP8.5. Baseline CO_2 level used was 361 ppm and future was 571 ppm.

Table 1 Arable field land cover and maize field land use statistics for the Bethlehem, Bloemfontein and Bothaville districts in the Free State province of South Africa .

District	Total area arable fields (ha)	Area planted to maize dry-land (ha)	Number of dry-land fields	Area planted to maize irrigation (ha)	Number of irrigated fields	% of total area arable fields planted to maize
Bethlehem	127 771	93 510	4 945	595	44	74
Bloemfontein	121 604	44 115	1 512	5 533	422	41
Bothaville	179 032	152 798	4 548	1 123	89	86

Maize crop land cover

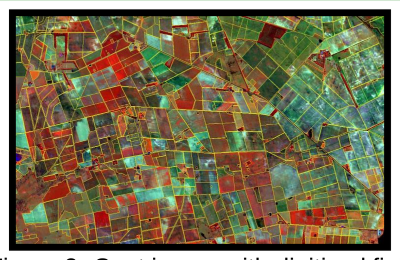

Figure 2 Spot image with digitized field boundaries

Digitize field boundaries from Landsat and SPOT images

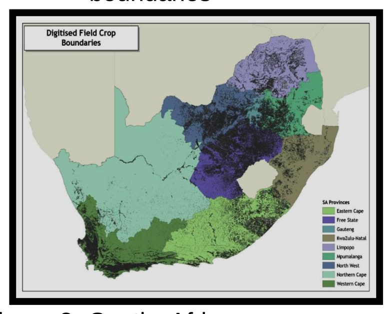

Figure 3 South African coverage of field crop boundaries.

South African coverage of field crop boundaries. 14 million ha

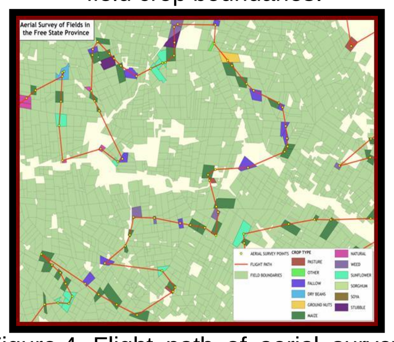

Figure 4 Flight path of aerial survey of fields in the Free State.

Field crop boundaries are used as basis for an aerial-survey of fields for Producer Independent Crop Estimates Survey (PICES) identifying crops planted.

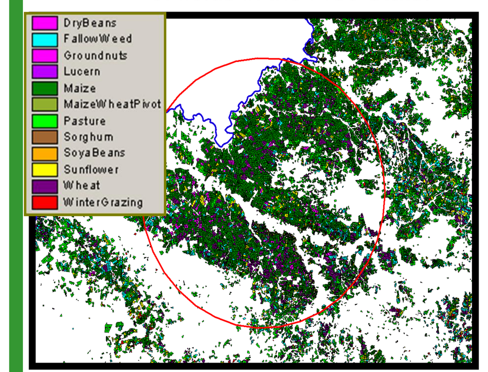

Figure 5 Satellite image classification of fields.

The PICES points are used for satellite image classification and calibration is adjusted annually.

For the maize crop land cover all fields that have been identified to have been panted to maize for the period 2006 to 2009 have been used.

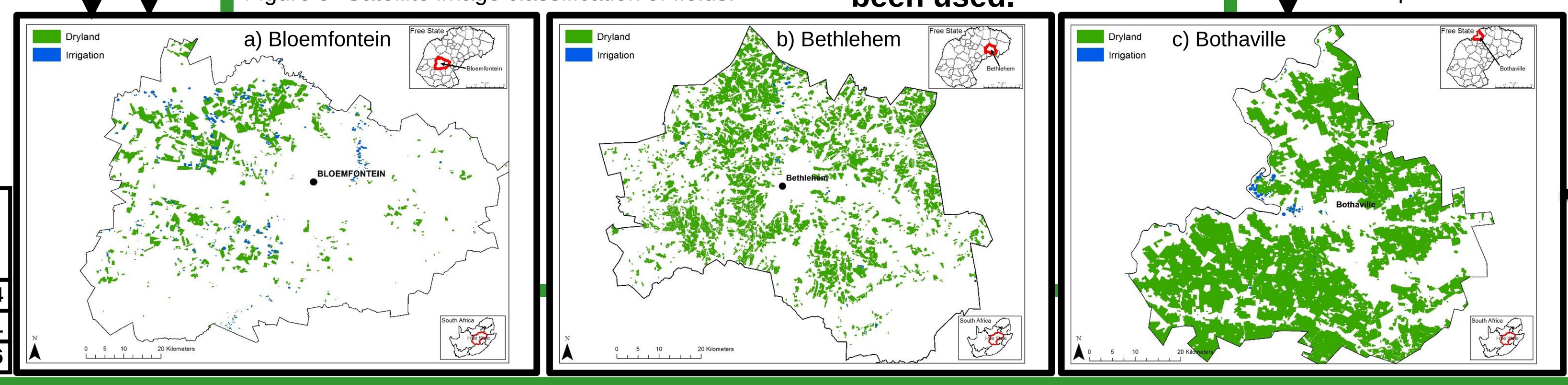

Figure 6 Dryland and irrigated maize crop field level land cover of a) Bloemfontein, b) Bethlehem and c) Bothaville districts within the Free State province of South Africa.

Soils

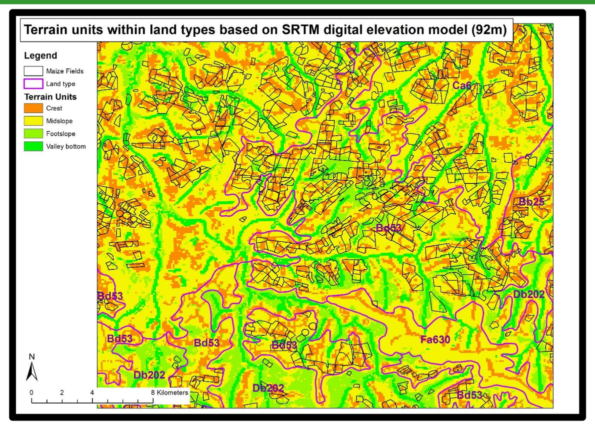

Figure 7 Maize crop field level land cover and terrain units within land types based on Shuttle Radar Topography Mission (STRM) digital elevation model (92m).

The soil properties required for crop yield modeling were derived using the identified soil series suitable for maize production. This was derived by eliminating soils with mechanical restriction, a depth of < 400 mm and a clay content > 50% within each Terrain Unit (TU) (1:50 000 scale). To determine the soil properties for each field, firstly the weighted averages of the soil properties were calculated for each TU. Secondly, the soil properties in each field were calculated based on the percentage representation of each TU within a field using zonal statistics (GIS). This results in each field having an unique soil description. Drained lower limit (DUL), lower limit (LL), saturation (SAT), were derived from pedo-transfer functions based on clay content (6,) and bulk density, drainage rate, the evaporation limit and organic carbon used similar pedo-transfer functions developed for the South African ARCU-model (7,8). Runoff was based on a slope and hydrological grouping (9).

Geographic Information System (GIS)

QUAD-UI

DSSAT crop model

3. Modeling Outputs

Field

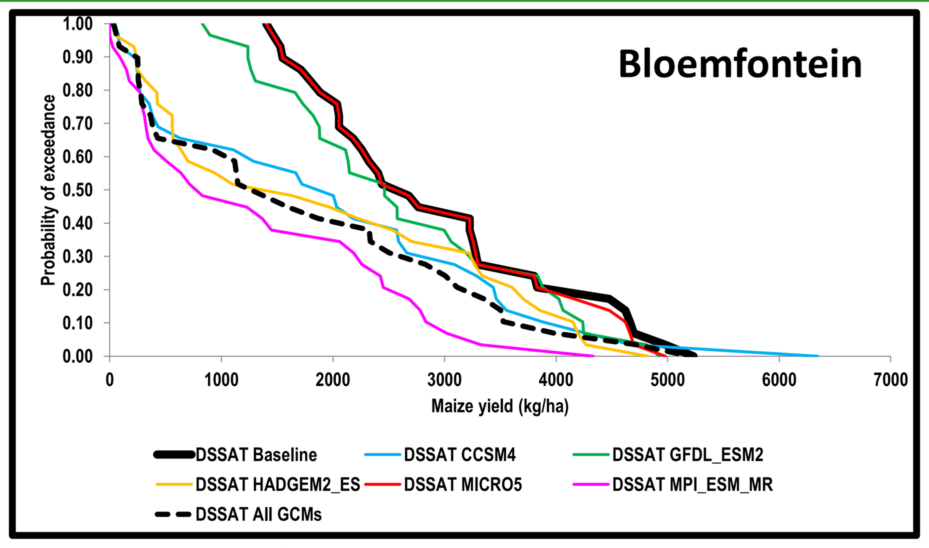

Figure 8 Probability of exceedance of inter-annual variation in baseline and future irrigated maize yields based on five different GCM's for a single dry-land field in the Bloemfontein district for the mid-century period (2040-2070) under RCP8.5.

Quinary

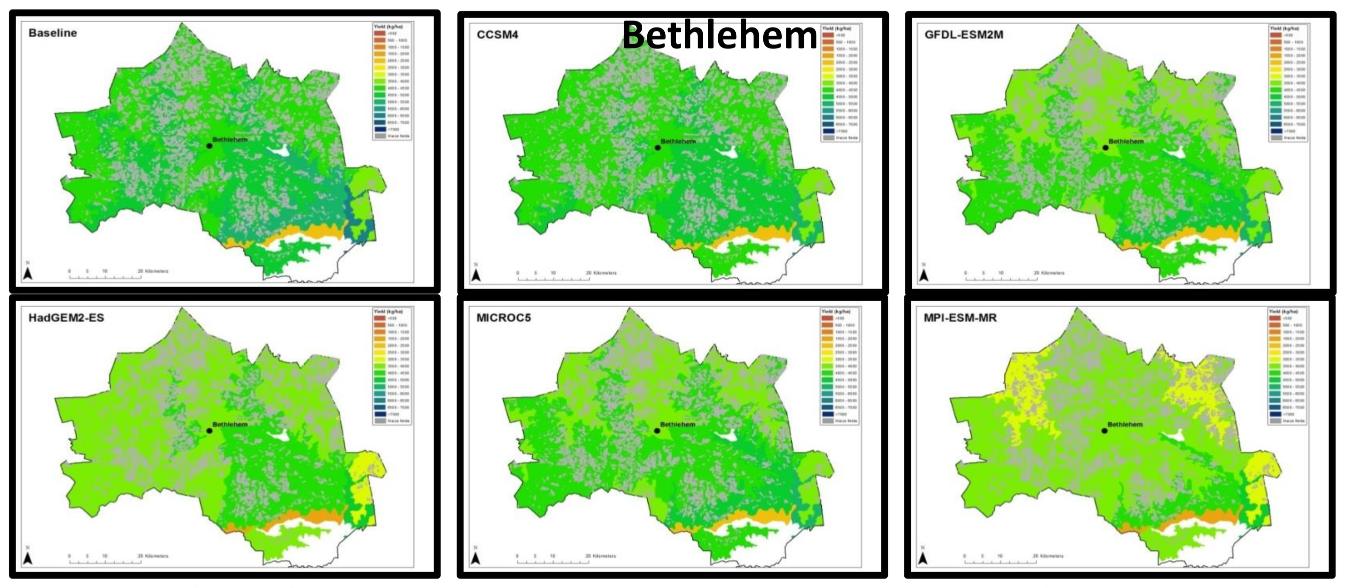

Figure 9 Yield of fields (kg/ha) averaged over quinary catchments for the Bethlehem district, mid-century period (2040-2070) under RCP8.5.

District

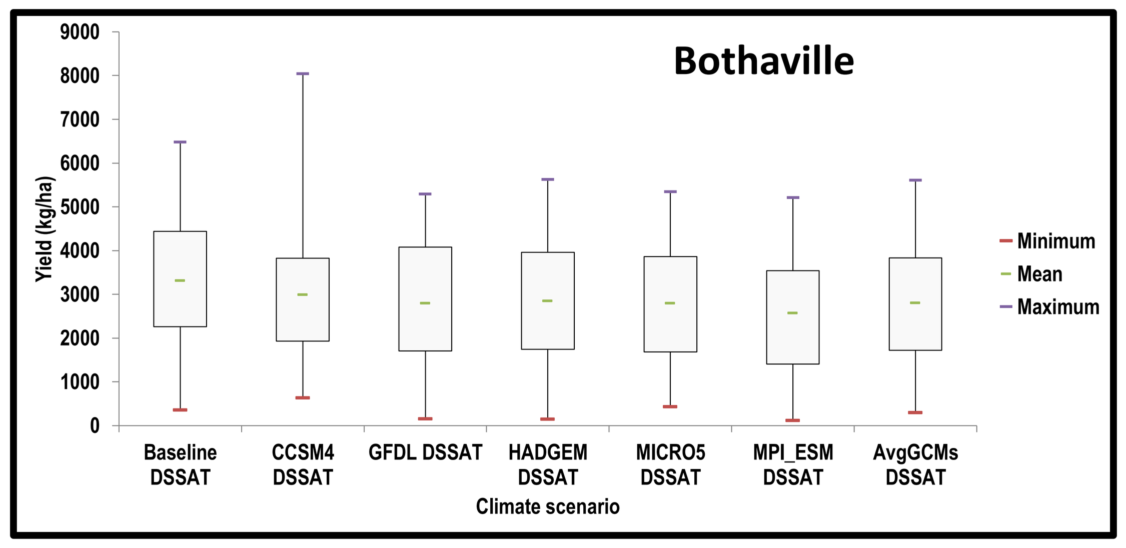

Figure 10 Box plots of inter-annual variation in baseline and future irrigated maize yields based on five different GCM's for the Bothaville district for the mid-century period (2040-2070) under RCP8.5.

4. Key Findings and Conclusions

- **Using GIS all the climate, soil and management inputs required to run the crop model for each field could be collated and exported to excel as input to the QUAD-UI.**
- **QUAD-UI tool allows for the rapped assembly of large amounts of crop model runs required for climate change studies.**
- **Field level simulations have the advantage that they can be summarized to different levels such as, farms, quinary catchments or districts.**
- **Results can easily be presented in table, graph, and because of the existing link to a GIS in map format.**

Linking satellite imagery, surveying and crop modeling can be used as an alternative household survey to assess impacts of climate change on maize production at field to district level in South Africa.

5. References

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6. Acknowledgements

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