Update of the Save Basin Self-Organising Maps Analysis

Final Report

February 2019

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Contents

List of Abbreviations

Abbreviation	Full name
CMIP	Coupled Model Intercomparison Project Phase
FAO	Food and Agricultural Organisation of the United Nations
GAEZ	Global Agro-Ecological Zones
RCPs	Representative Concentration Pathways
SOMS	Self-Organising Maps

Summary

This document provides an update with additions to results presented originally in the document entitled "Southern Africa Climate Projections". Details such as the area considered, time periods used, and the techniques employed are provided in that document. In brief the base period is 1986 to 2005, and the three projected periods 2016 to 2035, 2046 to 2065 and 2081 to 2100. In the following three updates to the original analyses are provided:

1. An assessment of extreme scenarios based on the original self-organising maps (soms)
2. Inter-annual variability (iav) statistics based on the scenarios derived from the soms analyses
3. An assessment of adjustments under climate change in the region over which maize might be cultivated in southern Africa.

1 Extreme Scenarios

Updated from the original report on Southern Africa and the Save Basin.

Extreme scenarios based on temperature against rainfall analyses based on RCP2.6, RCP4.5 and RCP6.0 (focussed primarily on rainfall changes)

	2040	2065	2080
Increased	0.75ºC/1.05	1.00ºC/1.10	2.00ºC/1.10
Decreased	1.00ºC/0.90	2.00ºC/0.80	2.50ºC/0.80

Extreme scenarios based on temperature against rainfall analyses based on RCP8.5 (focussed primarily on rainfall changes)

	2040	2065	2080
Increased	1.00ºC/1.10	3.00ºC/1.15	5.00ºC/1.10
Decreased	1.00ºC/0.80	2.50ºC/0.75	5.00ºC/0.80

2 Inter-Annual Variability

Two approaches have been used below to examine inter-annual variability (iav). Both approaches examine iav for the scenarios as recommended in the original report for Southern Africa and the Save Basin (rather than scenarios for the individual soms), namely:

Table 1. Recommended scenarios copied from the earlier report on Southern Africa and the Save River Basin.

	Most likely		Least likely
RCP2.6	O1°/-5%	O1.5°/-15%	O0.5°/+5%
RCP4.5	1/-5➔1.5/-5➔1.5/-5	1/-5➔2/-20➔2/-20	1°/-5➔2.5/+10➔2.5/+10
RCP6.0	1/-5➔1.5/0➔2.5/-5	1/-20➔2/-20➔3/-20	
RCP8.5	1/-5➔2/+5➔4.5/-10	1/-20➔2.5/-15➔4.5/-30	

Several tests were made to identify the most appropriate approach to the calculations for each scenario given that projections for all three periods from each model may not always reside in the individual soms that together form a specific scenario. In the interests of maximising the number of data points for the subsequent trend calculations the approach taken is to select simulations when possible that have all three periods included within the soms forming a given scenario; otherwise models were selected that provide simulations in two of the periods. Thus, necessarily not all projections have been included in the calculations.

The first approach is to present scenario time series for annual temperature and rainfall totals illustrating the complete range of values within CMIP5. Mann-Kendall statistics have been used to estimate trends and to assess significance at the 5% level. Note that these are estimated linear trends across the three simulated periods of the 21st Century.

The second approach is to estimate probabilities of decadal values of two- and three-year sequences during which, compared to the base period of 1986 to 2005, temperatures will exceed two and three standard deviations, or rainfall will fall below the 10th or the 25th percentile (possible drought conditions), or rainfall will exceed the 75th or the 90th percentile (possible flood conditions). Mann-Kendall statistics have been calculated for these decadal probability values as above.

Note that Mann-Kendall statistics, as a non-parametric approach, tend to be conservative as compared to normal parametric trend calculations. Results for the trend calculations are summarised in tables at the ends of each section.

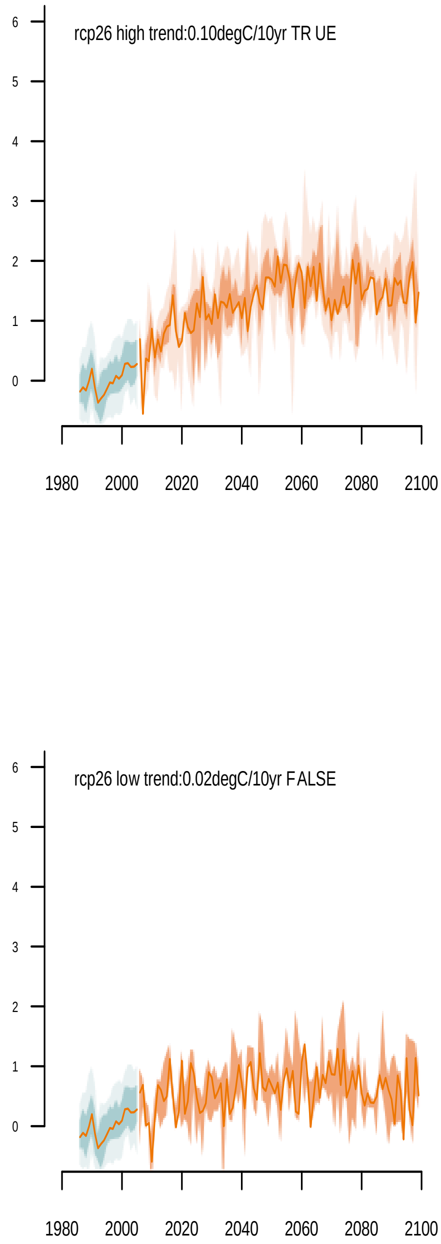


Figure 1. Future trends of annual temperatures under RCP2.6 for the highest likelihood scenario as in Table 1 (top left), the medium likelihood scenario (top right) and the lower likelihood scenario (bottom right). The blue curve on the left covers the base period of the calculations, the orange/red on the right the scenario projections. The central red line indicates the mean of the projections, the solid fill the 10th to 90th percentile range. Trend values, in ºC per decade, calculated using the Mann-Kendal statistic are indicated at the top of each diagram, together with an indication of significance at the 5% level: TRUE = significant at the 5% level; FALSE = not significant. Y axis shows temperature change from the base period.

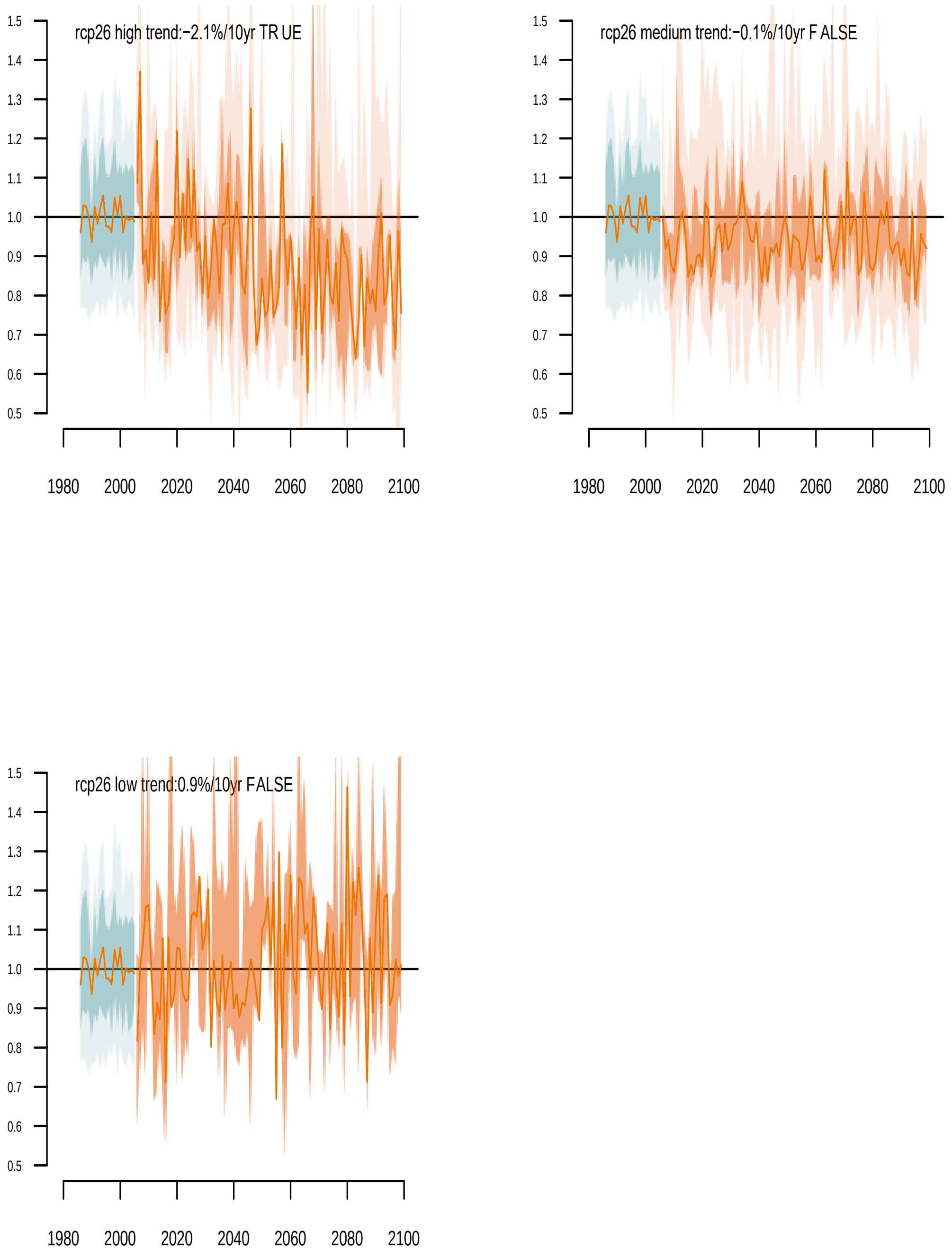


Figure 2. As Figure 1 but for annual rainfall totals under RCP2.6. Trends are given in % per decade. Y axis shows rainfall ratio from the base period.

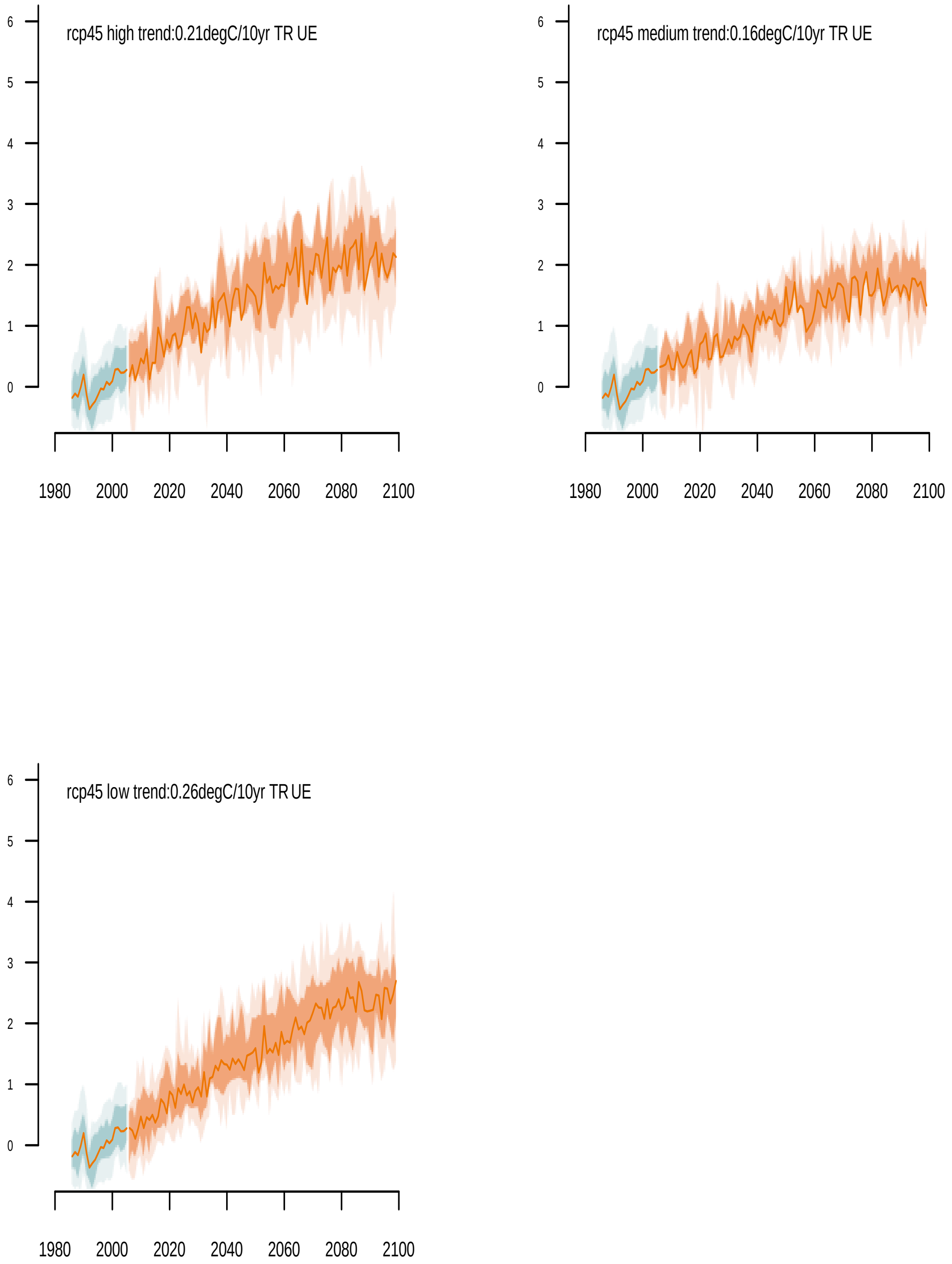


Figure 3. As Figure 1 but for annual temperatures under RCP4.5.

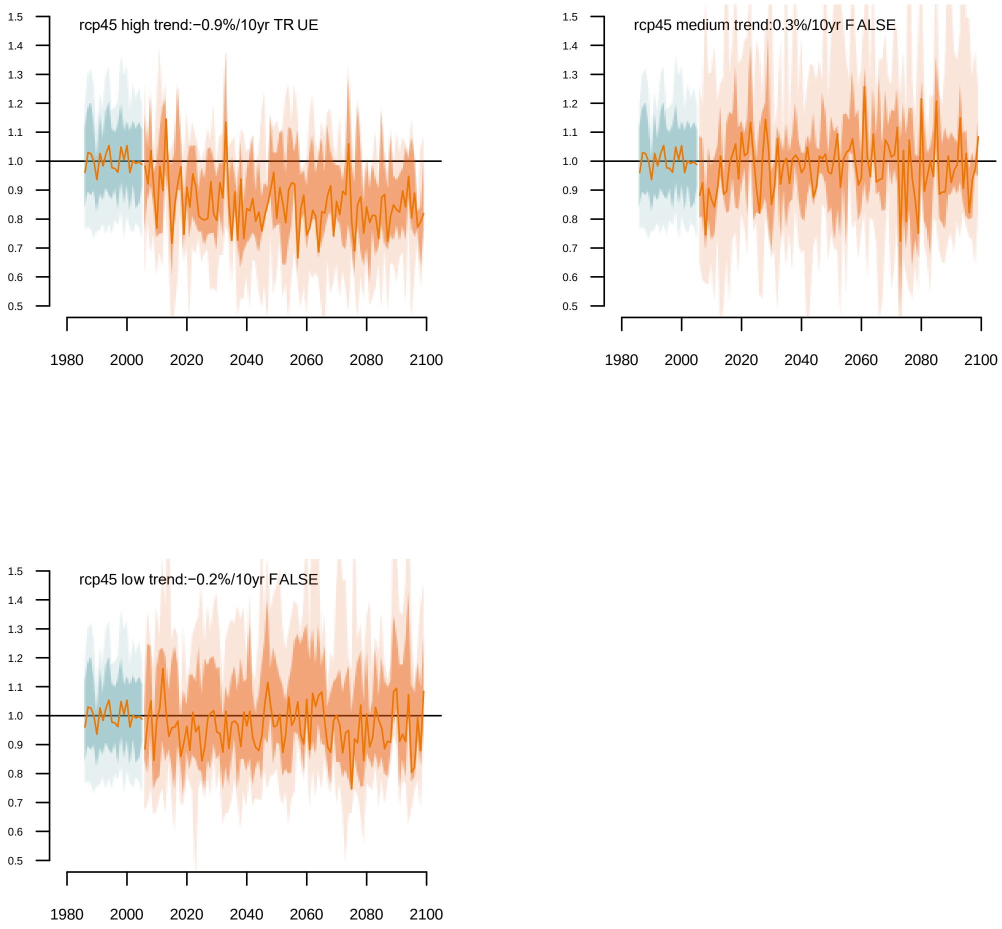


Figure 4. As Figure 1 but for annual rainfall totals under RCP4.5. Trends are given in % per decade.

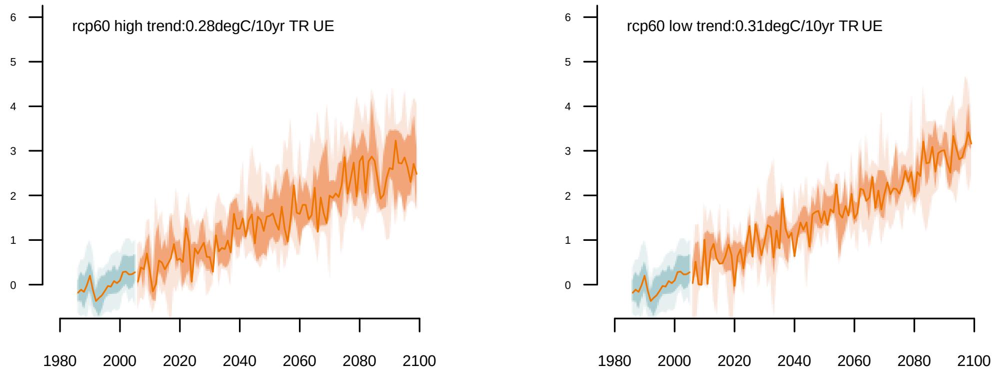


Figure 5. As Figure 1 but for annual temperatures under RCP6.0. In this case only two scenarios were suggested.

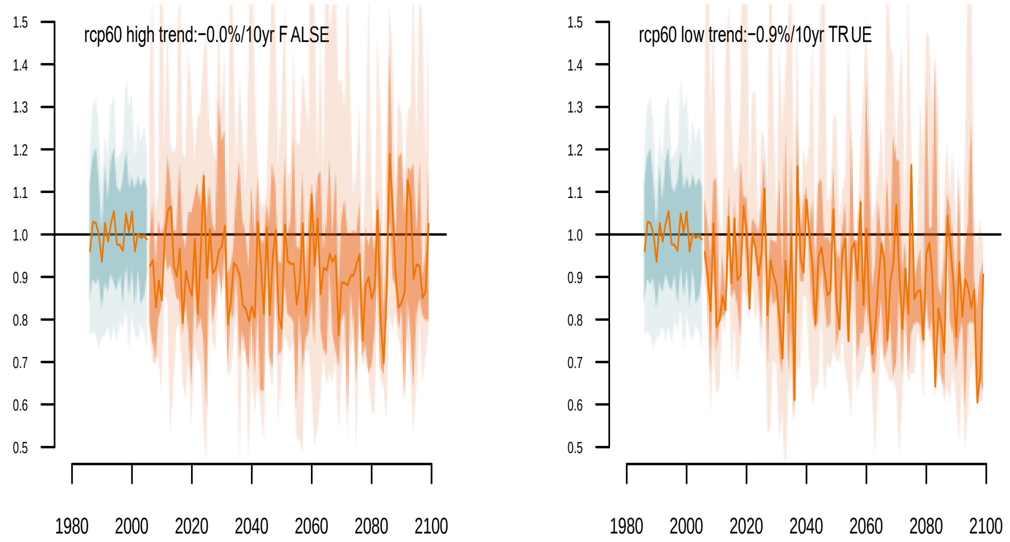


Figure 6. As Figure 1 but for annual rainfall totals under RCP6.0. Trends are given in % per decade. In this case only two scenarios were suggested.

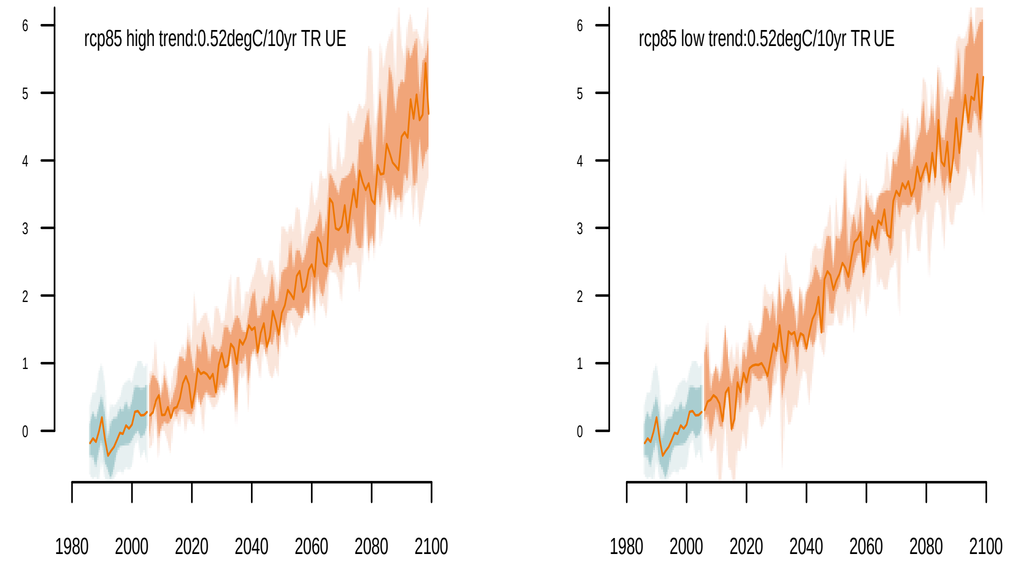


Figure 7. As Figure 1 but for annual temperatures under RCP8.5. In this case only two scenarios were suggested.

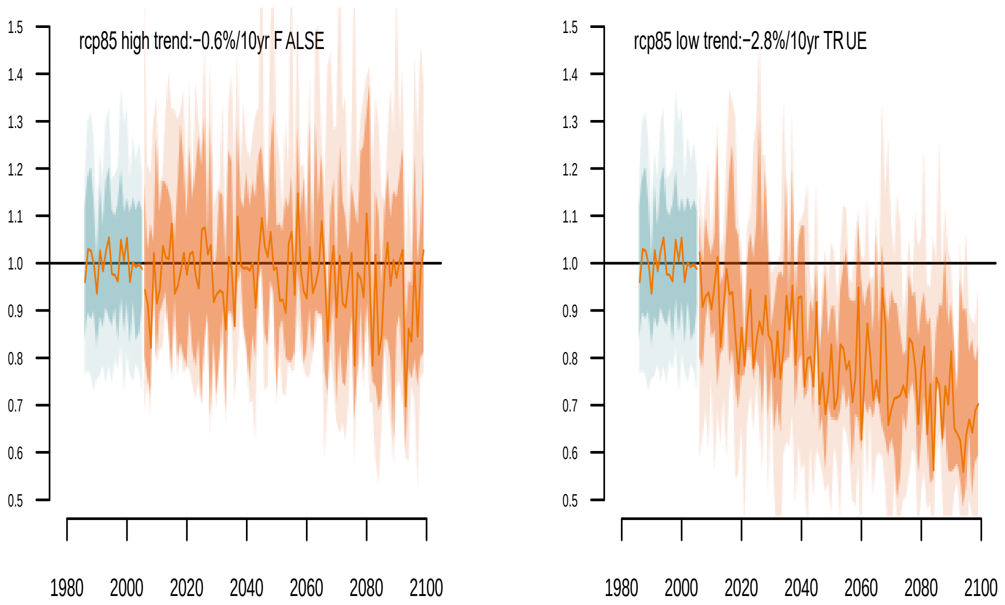


Figure 8. As Figure 1 but for annual rainfall totals under RCP8.5. Trends are given in % per decade. In this case only two scenarios were suggested.

Table 2. Trends according to Mann-Kendall collated from Figures 1 to 8, in ºC per decade and % per decade for annual temperature and rainfall totals respectively, for the scenarios in Table 1. Figures in bold indicate significance at the 5% level.

	Temperature			Rainfall		
Likelihood	Higher	Medium	Lower	Higher	Medium	Lower
RCP2.6	0.10	0.06	0.02	-2.1	-0.1	+0.9
RCP4.5	0.21	0.16	0.26	-0.9	+0.3	-0.2
RCP6.0	0.28		0.31	0.0		-0.9
RCP8.5	0.52		0.52	-0.6		-2.8

Trends in temperature increase with RCP, as is to be expected; all trends are significant at the 5% level according to the Mann-Kendall statistic except for the lower-likelihood scenario at RCP2.6 (Table 2). Fewer rainfall than temperature trends are significant in Table 2, but those that are significant are all negative. Apart from that for the lower-populated RCP6.0 projections, all trends for the higher likelihood scenarios are negative. More of the trends might have been assigned significance at the 5% level had parametric statistics been calculated.

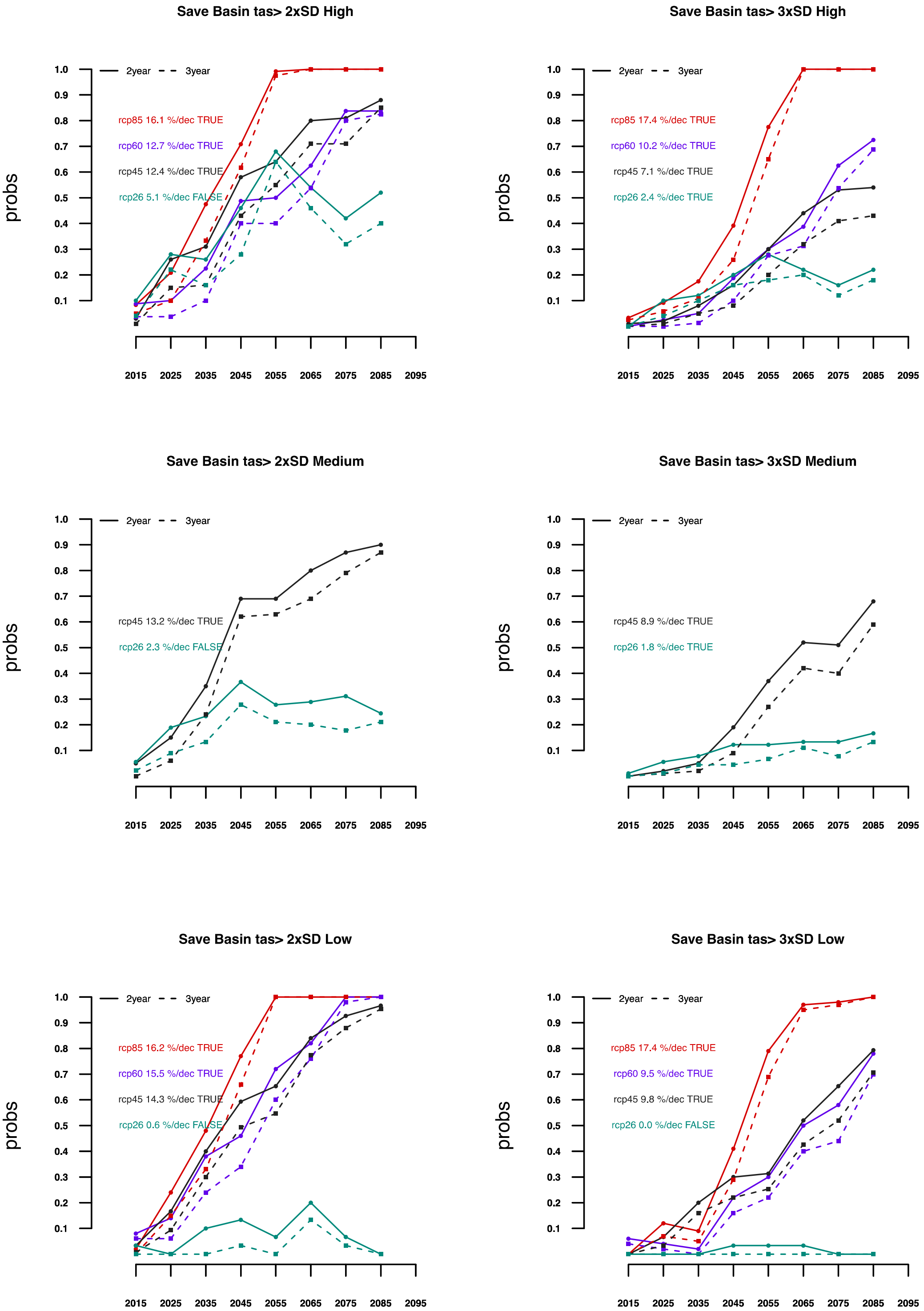


Figure 9. Decadal likelihoods of annual temperatures exceeding two (left-hand diagrams) and three (left-hand diagrams) standard deviations (calculated over 1986 to 2005) over future consecutive two (solid lines) and three (dotted lines) year periods. Green: RCP2.6; black: RCP4.5; blue: RCP6.0; red: RCP8.5. The top row is for the highest likelihood scenarios in Table 1; the bottom row for the lowest likelihood scenarios listed. For RCP2.6 and RCP4.5 three scenarios were provided, with the medium likelihood scenarios shown on the central row.

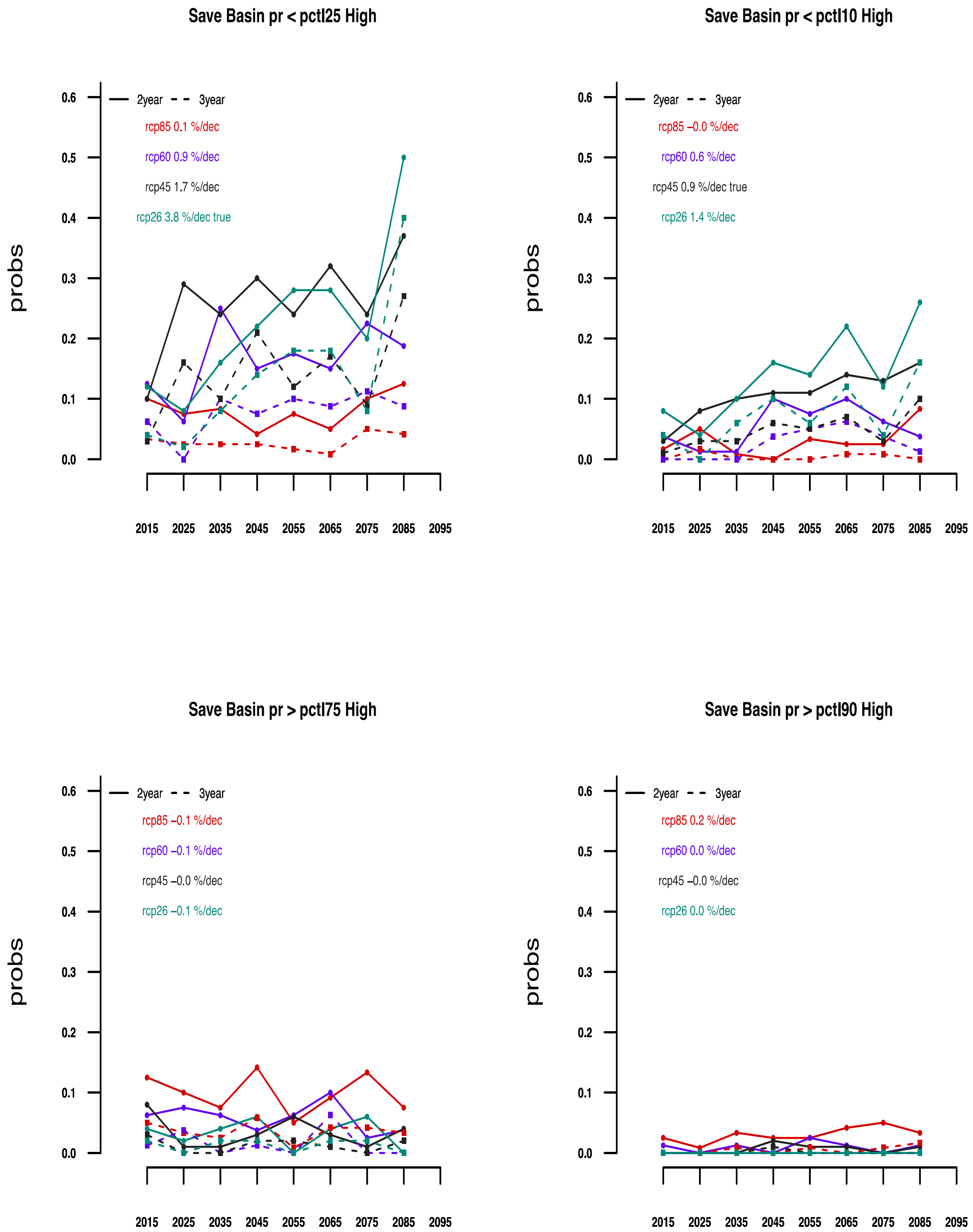


Figure 10. Decadal likelihoods for the higher likelihood scenarios in Table 1 of annual rainfall totals being below the 25th (top left) and 10th (top right) or above the 75th (bottom left) or 90th (bottom right) percentiles (calculated over 1986 to 2005) over future consecutive two (solid lines) and three (dotted lines) year periods. Green: RCP2.6; black: RCP4.5; blue: RCP6.0; red: RCP8.5.

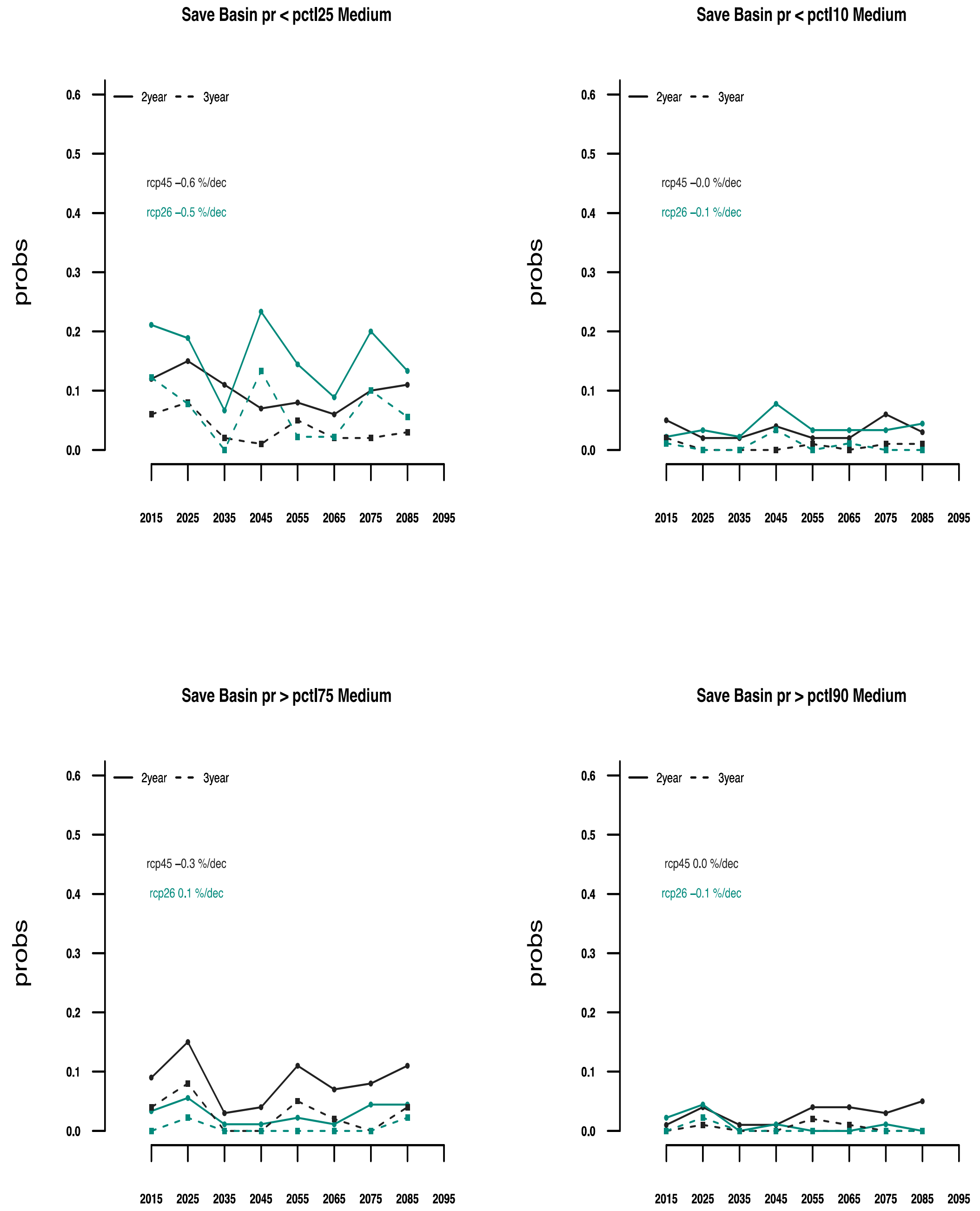


Figure 11. Decadal likelihoods for the medium likelihood scenarios in Table 1 (RCP2.6 and RCP4.5 only) of annual rainfall totals being below the 25th (top left) and 10th (top right) or above the 75th (bottom left) or 90th (bottom right) percentiles (calculated over 1979 to 2005) over future consecutive two (solid lines) and three (dotted lines) year periods. Green: RCP2.6; black: RCP4.5.

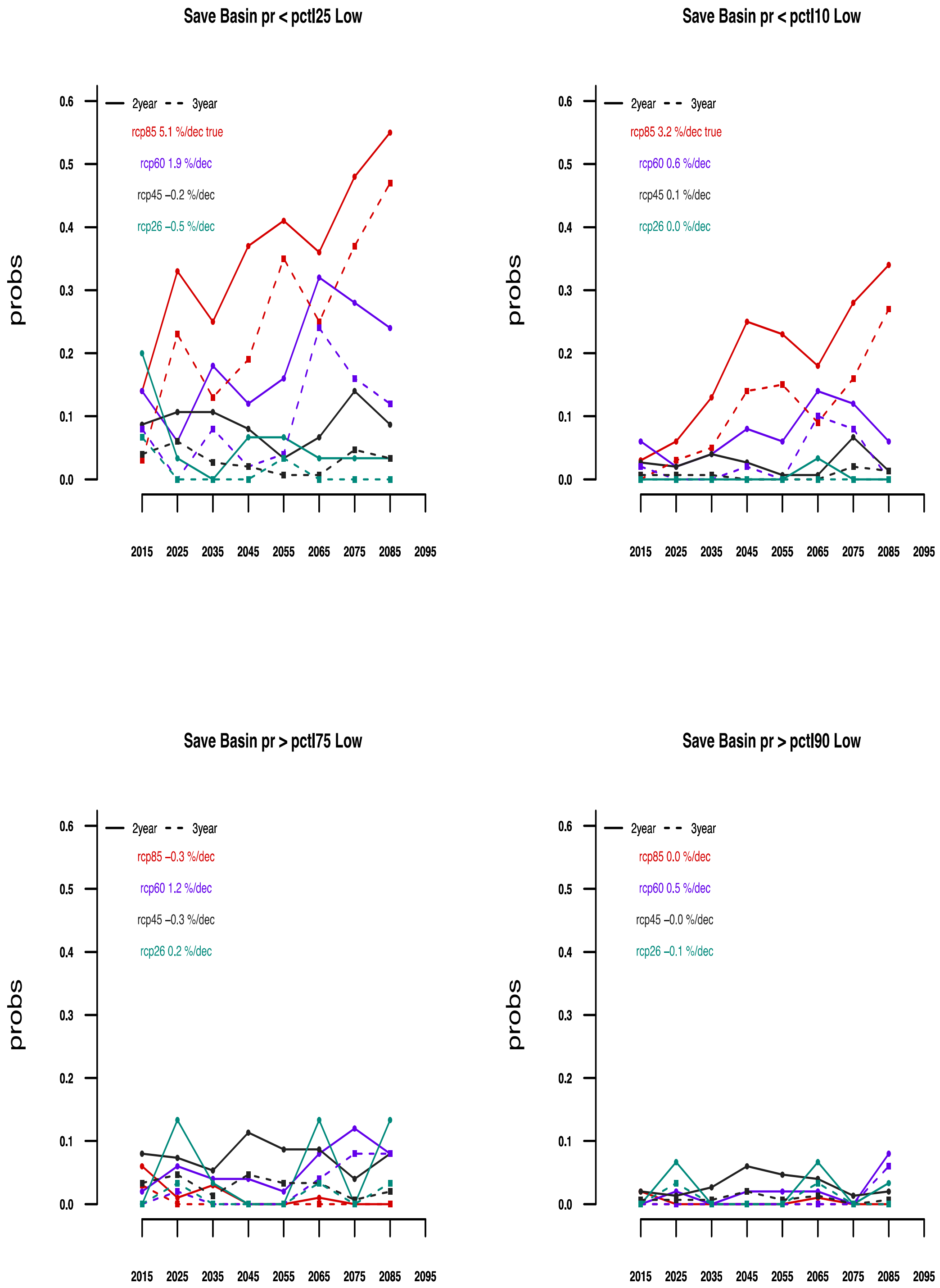


Figure 12. Decadal likelihoods for the lower likelihood scenarios in Table 1 of annual rainfall totals being below the 25th (top left) and 10th (top right) or above the 75th (bottom left) or 90th (bottom right) percentiles (calculated over 1979 to 2005) over future consecutive two (solid lines) and three (dotted lines) year periods. Green: RCP2.6; black: RCP4.5; blue: RCP6.0; red: RCP8.5.

Table 3. Linear trends in probabilities of two-year sequences of annual temperatures exceeding 2 and 3 standard deviations (calculated over the base period) based on Figures 9 to 12. Columns are for the higher, medium and lower likelihood scenarios in Table 1. Values given are only for two standard

deviations/three standard deviations. Only two-year trends are presented as those for three years are similar. Values are in % per decade according to Mann-Kendall. Figures in bold are significant at the 5% level.

	Temperature		
Likelihood	Higher	Medium	Lower
RCP2.6	5.1/2.4	2.3/1.8	0.6/0.0
RCP4.5	12.4/7.1	13.2/8.9	14.3/9.8
RCP6.0	12.7/10.2		15.5/9.5
RCP8.5	16.1/17.4		16.2/17.4

Trends in probabilities of warm events increase with RCP (Table 3), and all are significant at the 5% level according to the Mann-Kendall statistic except for some under RCP2.6. Note that the calculations have not taken into consideration the plateauing of some these curves later in the century and hence trends may be underestimated across the main periods of change.

Table 4. Linear trends in probabilities of two-year sequences of annual rainfall totals based on Figures 9 to 12. Columns are for the higher, medium and lower likelihood scenarios in Table 1. In each box the top-left figures refer to events below the 25th percentile (calculated across the base period), the top-right figure to events below the 10th percentile, the bottom-left figure to events above the 75th percentile, and the bottom-right figure to events above the 90th percentile. Hence the top rows refer to possible drought conditions and the bottom rows to possible flooding conditions. Only two-year trends are presented as those for three years tend to be similar. Values are in % per decade according to Mann-Kendall. Figures in bold are significant at the 5% level.

	Rainfall		
Likelihood	Higher	Medium	Lower
RCP2.6	**3.8** 1.4	-0.5 -0.1	-0.5 0.0
	-0.1 0.0	0.1 -0.1	0.2 -0.1
RCP4.5	1.7 0.9	-0.6 0.0	-0.2 0.1
	0.0 0.0	-0.3 0.0	-0.3 0.0
RCP6.0	0.9 0.6		1.9 0.6
	-0.1 0.0		1.2 0.5
RCP8.5	0.1 0.0		5.1 3.2
	-0.1 0.2		-0.3 0.0

Few trends in probabilities of dry or wet events are significant according to the Mann-Kendall statistic (Table 4); in general, the curves are somewhat noisy. Those that are significant, for RCP2.6 and RCP4.5 (higher likelihood scenarios) and for RCP8.5 (lower likelihood scenario), all indicate an increase in future dry events. More of the trends might have been assigned significance at the 5% level had parametric statistics been calculated.

3 Maize Cultivation

The discussion on maize is separated into four sections:

2. A discussion of climate conditions suitable for the cultivation of maize according to various sources. This section has not been updated. The examples given illustrate the uncertainties associated with specifying appropriate climatic conditions.

3. Potential ranges of maize cultivation according to various sources. This section has not been updated. Illustrated clearly are the differences in cultivation ranges according to the different analyses. “Ground truth” is assumed, as is common in this field, from the FAO GAEZ (Global Agro-Ecological Zones) project. The GAEZ work has been updated since the basis of this report was prepared, although there are unlikely to have been major adjustments in the areas illustrated below, with any adjustments lying within the bounds of uncertainties. Note that work following with the CMIP5 projections incorporates climate conditions only, whereas GAEZ incorporates additional considerations such as soil suitability. Nevertheless none of the charts should be taken to indicate either the *actual* or the *potential* ranges of cultivation unless stated, but only estimates, complete with inherent, but unquantified, uncertainties. Note also that some crops are cultivated currently in areas unsuitable from a climatic perspective, relying or otherwise on irrigation.

4. Calibration of the CMIP5 assessments of crop ranges. Charts to be contrasted with those in the second section illustrating the simulated potential range of cultivation based on a calibration of the models across a base period of 1979 to 2005.

5. Distribution charts of simulated adjustments in crop range for each of RCP2.6, RCP4.5, RCP6.0 and RCP8.5 for the periods 2025 to 2049, 2050 to 2074 and 2075 to 2099. The charts are presented for Africa south of the Equator, as it is unreasonable to provide them for the Save Basin alone.

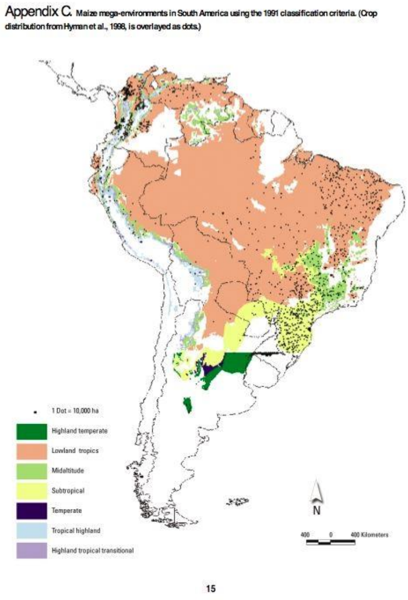
3.1 Climate Conditions for Cultivation for Maize

Source	Details
Wikipedia – http://en.wikipedia.org/wiki/Maize	**Temperature.** Maize is a facultative long-night plant and flowers in a certain number of growing degree days > 50 °F (10 °C) in the environment to which it is adapted.
Naural History Museum – http://www.nhm.ac.uk/jdsml/nature-online/seeds-of-trade/page.dsml?section=crops&ref=maize&page=agriculture	**Climate.** Maize is an annual crop requiring 110-140 frost-free days

Source	Details
FAO GAEZ	**Climate and Temperature.** Four independent sets of temperature conditions for maize cultivation are specified: 1. Lowland Maize in tropical climates: growing season of 3 to 4.5 months; temperatures of 15-20ºC for less than 16% of the season (ideally never); temperature sum during season > 2200 (ideally > 2500) 2. Highland maize in tropical climates: growing season lengthens with ambient temperature from 3.5 months @ 20ºC to 10 months at 15ºC; no average temperatures above 25ºC or below 10ºC; temperatures 10-15ºC for less than 50% of season (ideally < 33% of season); temperatures 20-25ºC for < 33% of season; temperature sum during growing season > 2200 (ideally > 2500) 3. Maize for grain in the subtropics (with both summer and winter rains) and at temperate latitudes: growing season of 3.5 to 6 months; temperatures of 10-15ºC for < 50% of season and never < 10ºC; temperature sum during growing season > 1900 (ideally > 2400) 4. Maize for silage in temperate latitudes: growing season of 3.5 to 6 months; temperatures of 10-15ºC for < 66% of season and never < 10ºC; temperature sum during growing season > 1700 (ideally > 1900); no permafrost
Consultant Agro-meteorologist	**Climate.** Non-climatic influences, and the range of responses to climate, mean that the particular variety grown can play a key role in determining yields. Basic requirements: 500-800 mm rain over 4-5 months; maximum temperature 30-32ºC, minimum 13-17ºC. More complex option: reaches photosynthetic peak at 30-40ºC, but negligible growth at 44-50ºC; optimal daytime leaf temperatures of 30-33ºC with cool nights (i.e. favours seasonally-arid, as opposed to humid, tropics); radiation use efficiency for photosynthetically active radiation (PAR) 5-7%; APAR 3-4g/MJ, i.e. approximately 4-6g?MJ PAR; maximum grains per plant with temperature maximum in range 27-32ºC and minimum 13-17ºC; sensitive to water stress during flowering; development slows with temperatures < 20ºC; water requirement 500-800 mm with water use efficiency 11g/kg; 2100-3200 growing degree days with threshold temperature of 10ºC or 1000-1800 with threshold of 8ºC; duration 80-100 days for early growth, total 110-140 days

3.2 Current Potential Cultivation Range for Maize

To illustrate the generic manner in which different methodologies can produce dissimilar potential cultivation areas given the same input data the following two diagrams for Latin America have been reproduced from two International Maize and Wheat Improvement Centre (CIMMYT – an expert international research organisation regarding maize and wheat cultivation) Reports. In both cases the objective was to define the variety of climate regimes under which maize could be produced, the only differences being in the methodology employed for treating the data.



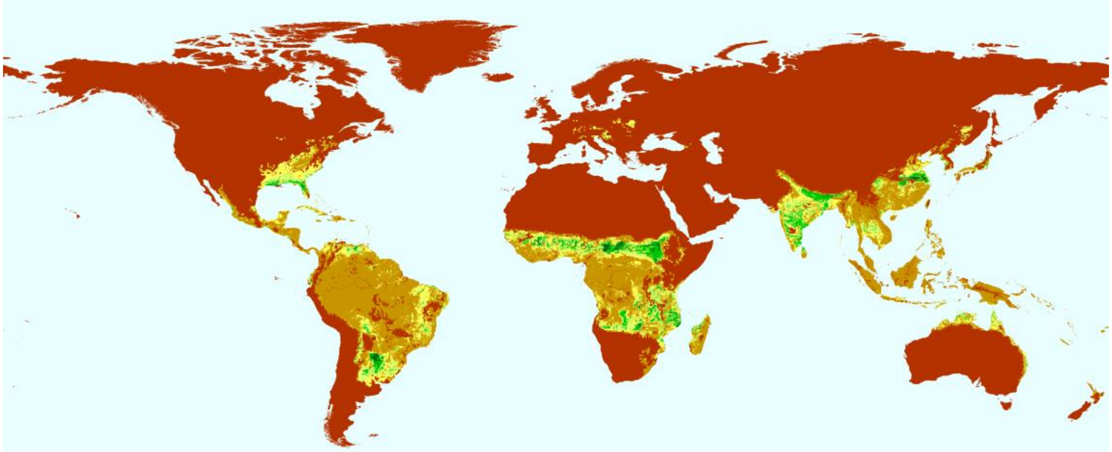
Maize 1. Potential current cultivation range of maize in South America according to a 1991 CIMMYT analysis

Maize 2. Potential current cultivation range of maize in South America according to a 2000 CIMMYT analysis

First (Maize 1) are results from a 1991 analysis, following those from a 2000 analysis (Maize 2). Not only are there differences between the "mega-environments" (outlined in colours on both diagrams), but also, more critically, the extents of the potential cropping areas differ by substantial amounts. On the 1991 analysis diagram small black dots indicate where known cultivation locations of maize were in 1996; encouragingly, the majority of these are included within the areas predicted by the 1991 analysis.

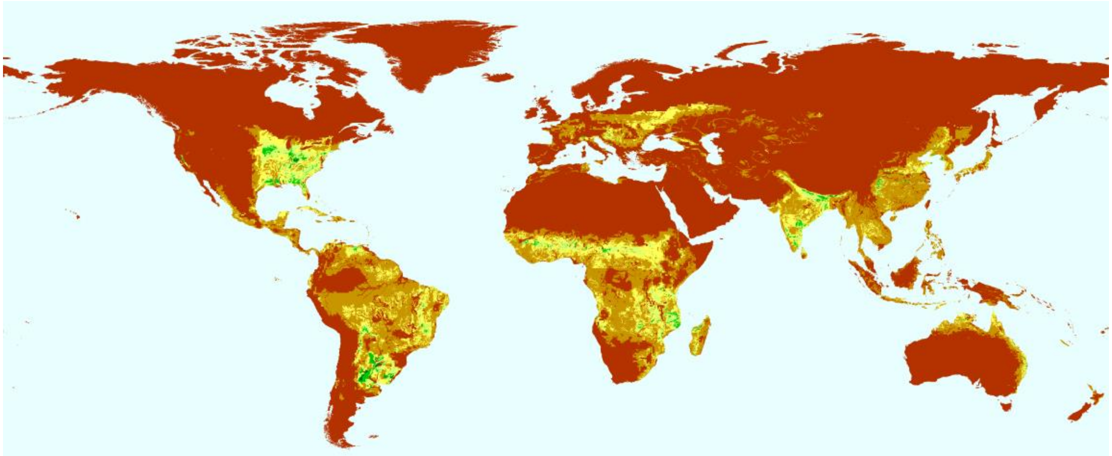
GAEZ ranges for high inputs (top = e.g. use of fertiliser) and low inputs (bottom) are:

High input



Maize 3. High input GAEZ Field - Green is most suitable, red least suitable

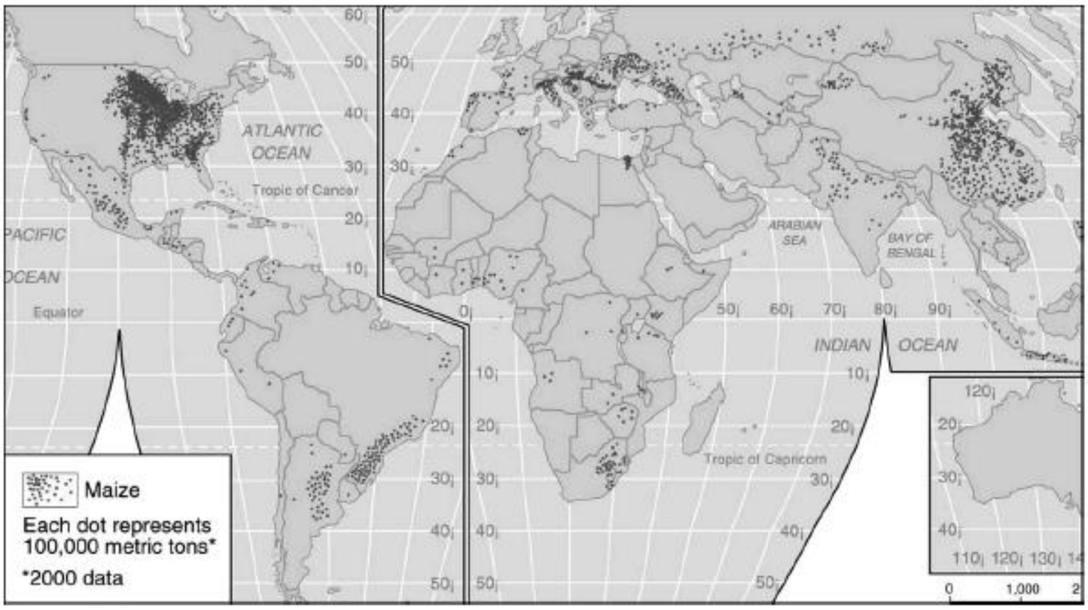
Low input



Maize 4. Low input GAEZ Field - Green is most suitable, red least suitable

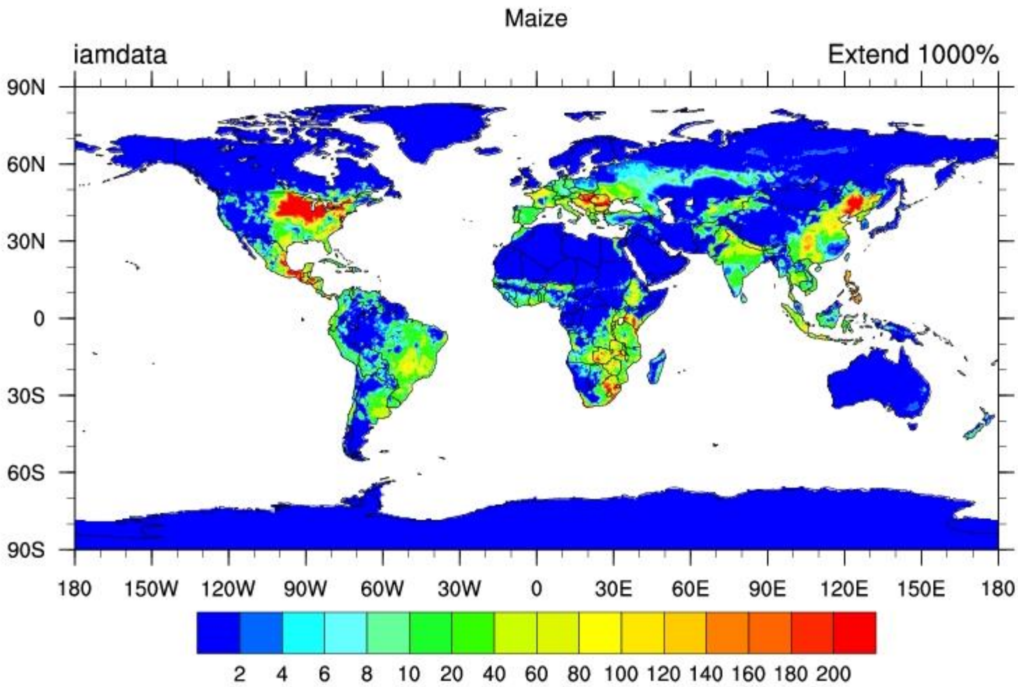
There are substantial differences in distributions between the two GAEZ charts in Maize 3 and Maize 4, particularly, but not exclusively, at temperate latitudes. There is no absolute agreement on potential cultivation ranges over Latin America from any of the four above charts, the two from CIMMYT and the two from GAEZ.

Following is a map of recent (2000) locations of maize cultivation (Maize 5), obtained from the State University of New York at http://myhome.sunyocc.edu/~wheelemi/GEG101/class_notes/09-Agriculture.pdf. There is reasonable agreement with the GAEZ projections over much of the globe, but there are certainly areas in parts of Central America and northern Asia over which maize is cultivated according to this analysis but which are not selected by GAEZ. Cultivated locations in Latin America do not necessarily accord between Figures Maize 1 and Maize 5.



Maize 5. Cultivation range of maize in 2000 according to the State University of New York

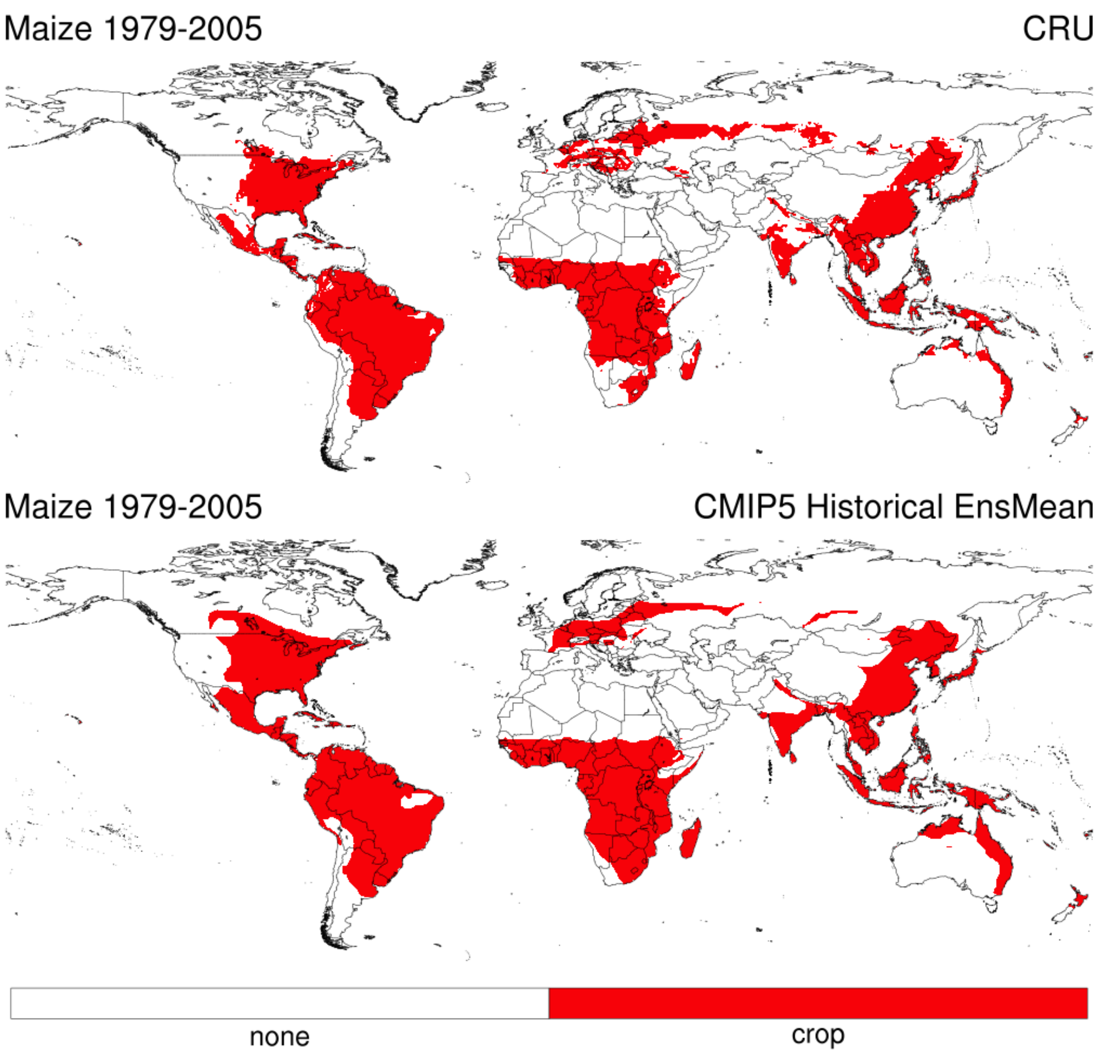
Finally the following distribution for 2000 (Maize 6) comes from the Global Land Use Data Set of the Center for Sustainability and the Global Environment of the Gaylord Nelson Institute for Environmental Studies, University of Wisconsin-Madison, USA - http://www.sage.wisc.edu/iamdata/. This chart suggests rather more extensive cultivation in a number of locations than indicated in general by the other approaches.



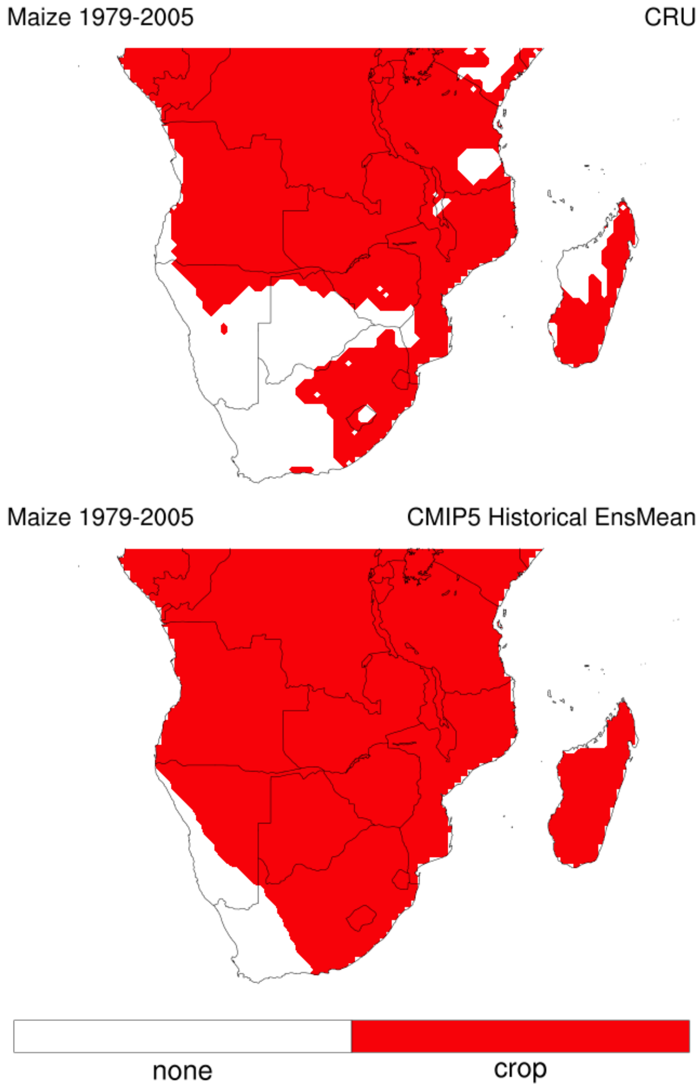
Maize 6. Distribution of maize cultivation in 2000 according to the University of Wisconsin-Madison

3.3 Calibration of the CMIP5 assessments of crop ranges

Given the diversity of information in the previous sections the tuning of the climate conditions used in this assessment has focussed on the low-input GAEZ chart (Maize 4), which captures in the broad sense the distributions shown in the remaining charts above. For maize an excellent reproduction has been achieved using a growing season of 3 months in which the average temperatures lie between 15°C and 30°C with contemporaneous monthly rainfall in the range 60-350mm (Maize 7 and Maize 8) using both observed climate values in the CRU data set and the CMIP5 ensemble mean, in both cases across 1979 to 2005 (cf. Maize 4):

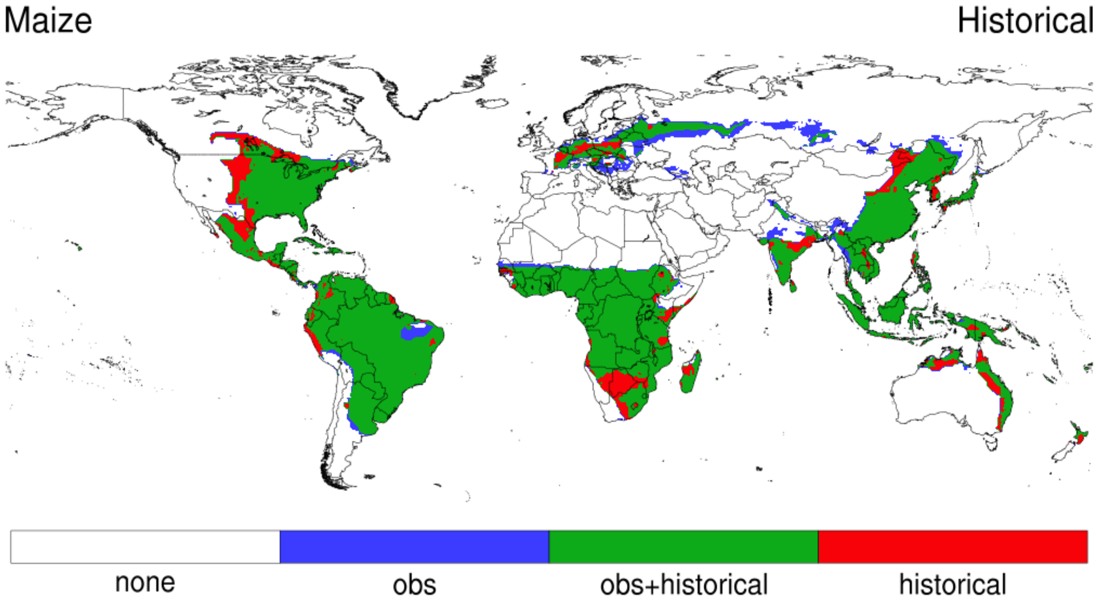


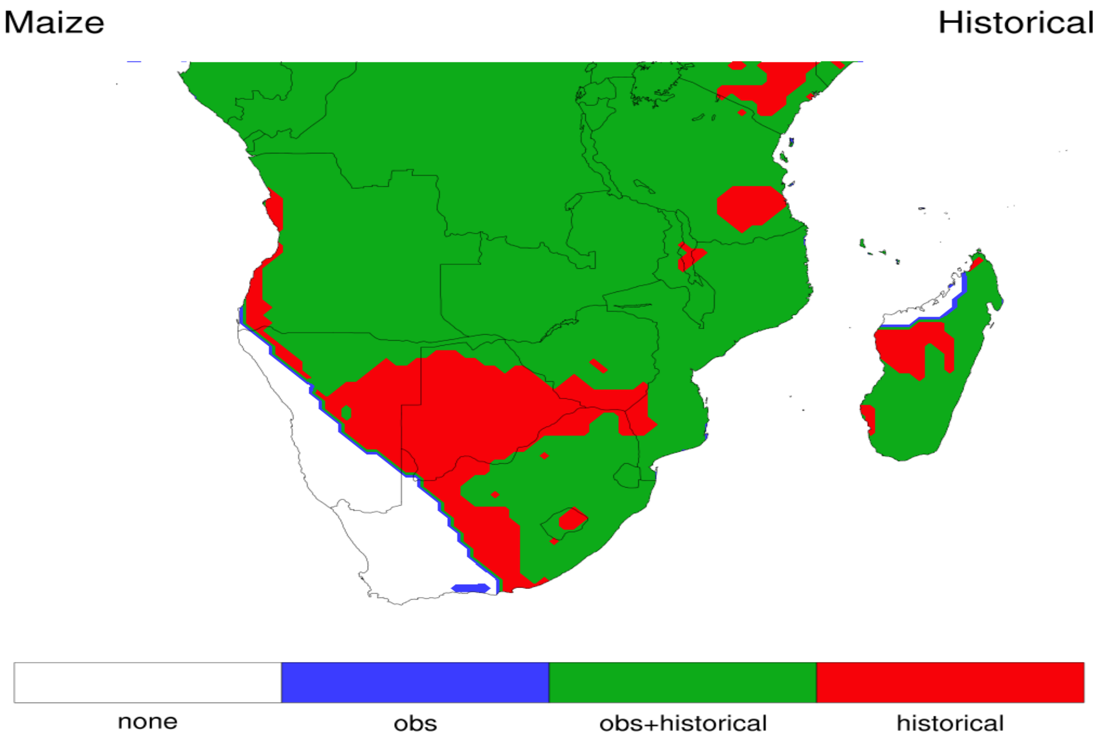
Maize 7. Potential range of maize cultivation under observed climate given a requirement of 3 months with average temperatures in the range 15 to 30°C and contemporaneous monthly rainfall in the range 60 to 350mm based on CRU data (top) and based on the CMIP5 ensemble mean (bottom), in both cases for 1979-2005.



Maize 8. As Maize 7 but in detail for southern Africa.

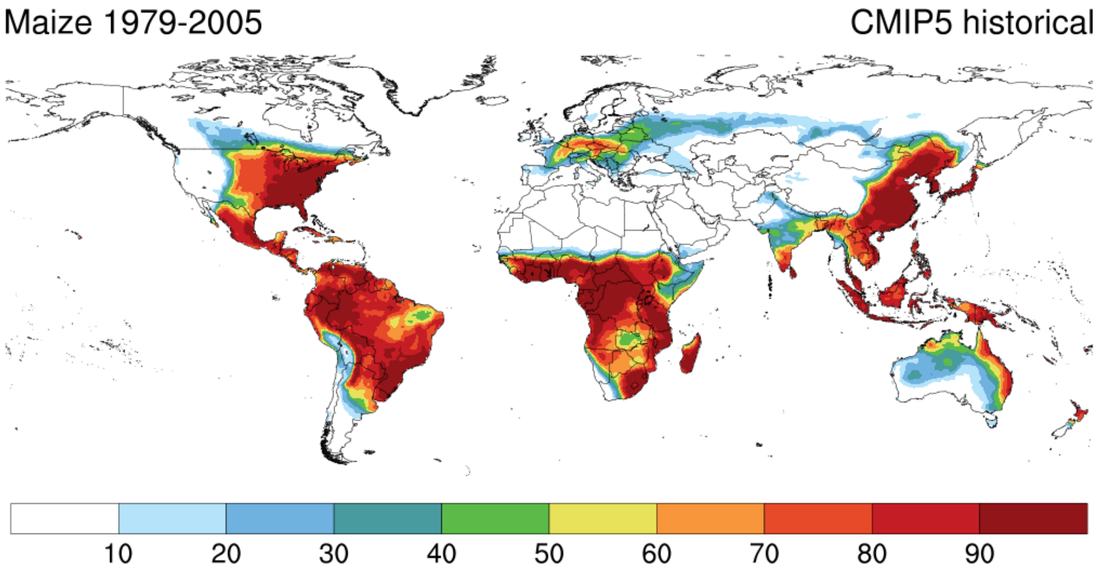
Results in Maize 7, and in more detail in Maize 8, reveal an important issue for southern Africa. Most of the analyses discussed above suggest that maize cultivation is not possible over much of Botswana and into the Limpopo Valley whereas the ensemble mean suggests, incorrectly assuming no irrigation, that cultivation is possible. This characterises an issue with the abilities of the models to simulate adequately the climate of this area, something that can be ascribed mainly to problems with simulating rainfall.

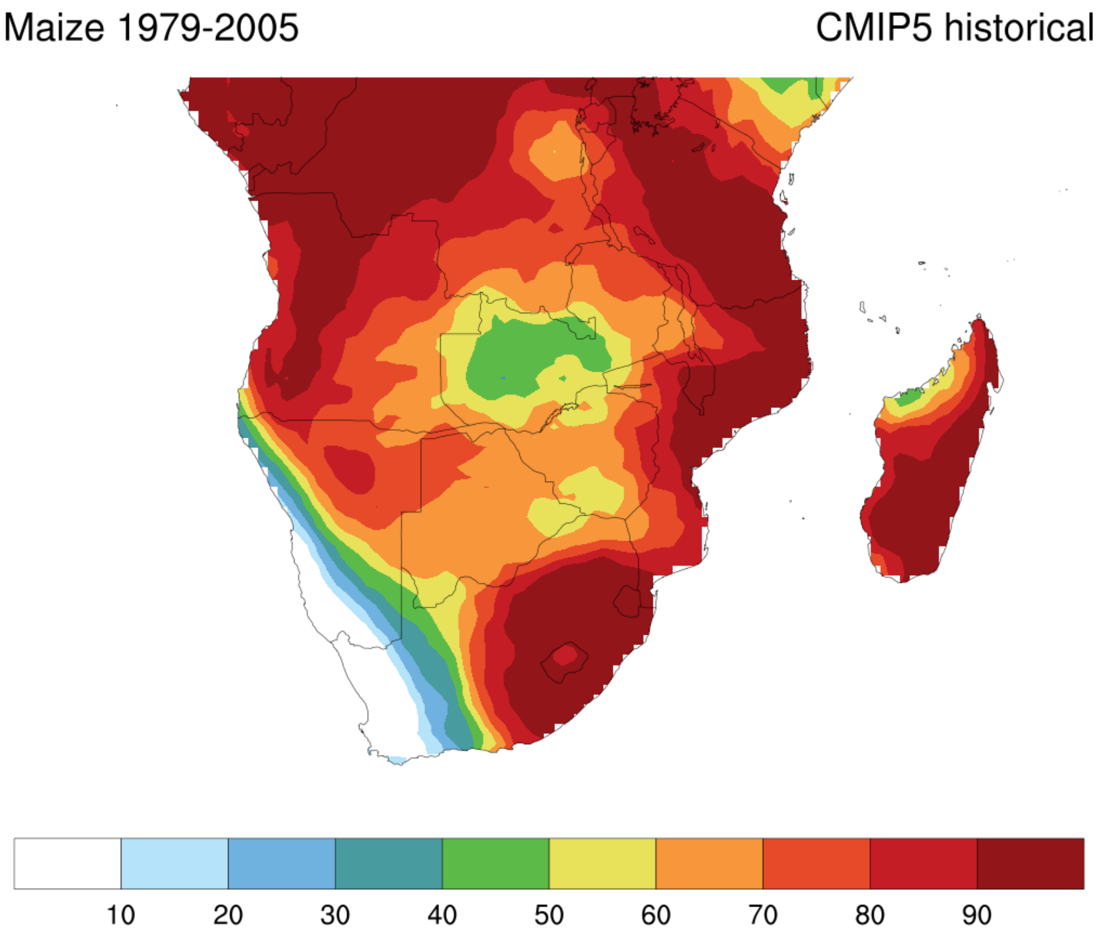




Maize 9. Differences between potential ranges of maize cultivation for 1979 to 2005 between calculations given a requirement of 3 months with average temperatures in the range 15 to 30°C and contemporaneous monthly rainfall in the range 60 to 350mm under observed climate (CRU) and as simulated by the ensemble mean of the CMIP5 models; for the globe (top) and in detail for southern Africa (bottom). White areas are unsuitable for cultivation according to this analysis; green areas are suitable according to both the observations and the ensemble mean (indicated as "historical"); blue areas are suitable only according to the observations; red areas are suitable only according to the ("historical") ensemble mean.

The difficulties noted above of the models in simulating adequately the rainfall climate over Botswana are amplified in Maize 9 (bottom). Equivalent difficulties of the models in simulating rainfall in certain other areas of the globe, such as in Europe and Asia where the models are too dry and in Australia where they are two wet over arid regions, might also be noted (Maize 9, top).





Maize 10. Distribution of potential ranges of maize cultivation for 1979 to 2005 according to the CMIP5 ensemble given a requirement of 3 months with average temperatures in the range 15 to 30°C and contemporaneous monthly rainfall in the range 60 to 350mm: for the World (top) and for southern Africa (bottom). The redder the colour the more models indicate suitability for cultivation, the bluer the fewer models; the scale is in % of models.

The distribution of climate model simulations indicating that maize cultivation is possible reaches maxima of over 90% along many coastal areas and in the north of southern Africa (Maize 10). Over Botswana, where the ensemble mean suggests cultivation to be possible (Maize 8), the number of supporting simulations reduces to between 60% and 70%, and over parts of the Limpopo Valley, including southern Zimbabwe, to below 60%. Across much of Zambia the supporting simulations drop below 50% (Maize 10) even though the ensemble mean suggestions possible cultivation (Maize 8); there is likely to be a relatively highly skewed distribution of simulated rainfalls across this area.

Most simulations support the possibility of maize cultivation throughout the Save River Basin, although perhaps less so in the higher reaches in Zimbabwe.

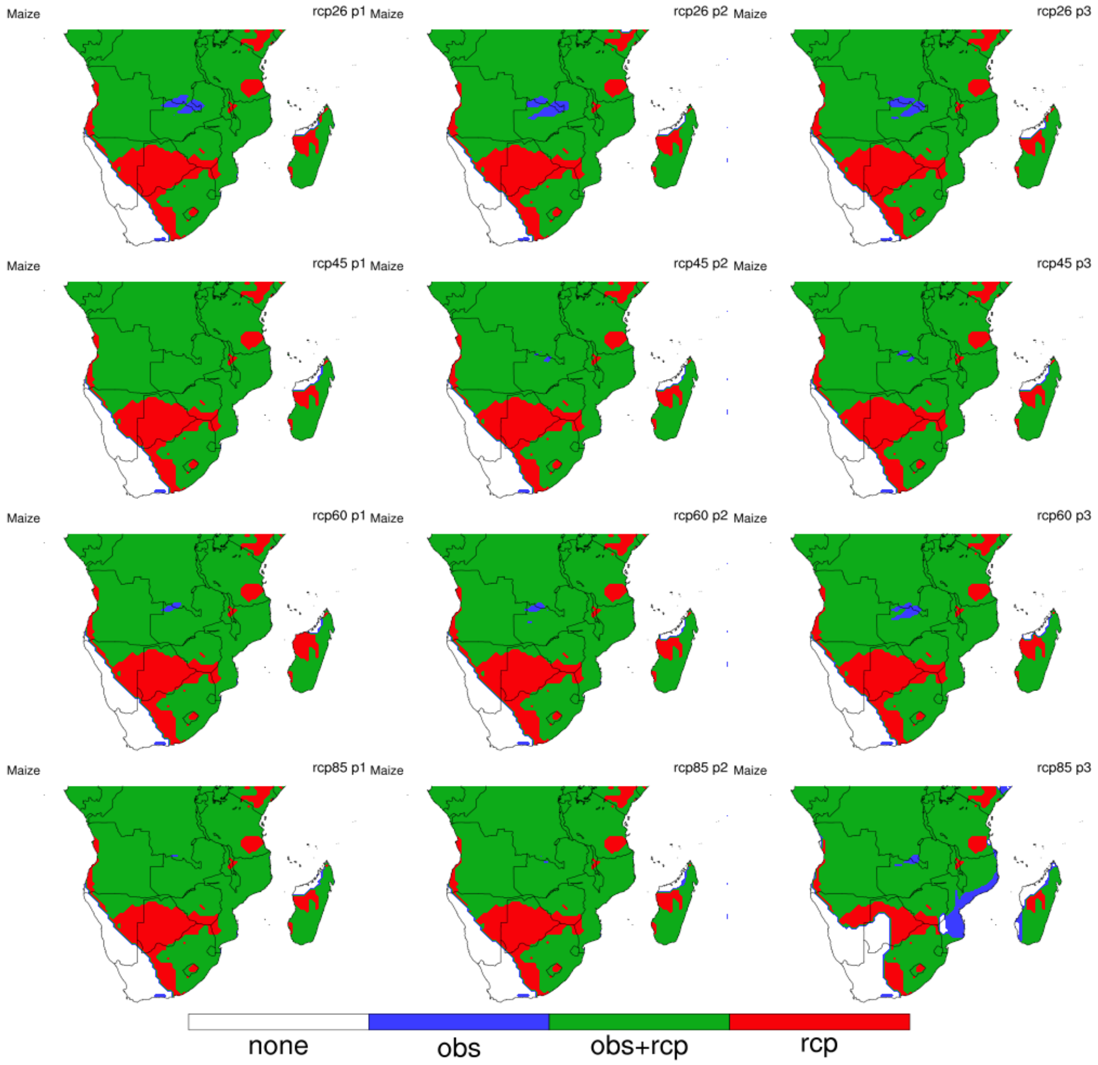
For interest, distributions of potential cropping areas according to individual models are shown in Maize 11. Inherent in this diagram are the possible dangers of planning adaptation based on a single model, or a small group of models. For individual models the proportion of model grid points differing between the observed and the modelled simulated distributions (i.e. the distribution based on CRU data in Maize 8 and those based on CMIP5 in that and subsequent diagrams) varies from over 9% to over 18%, whereas for the ensemble mean the equivalent figure is 8.7%, i.e. the ensemble mean has the best agreement with cultivation ranges based on observed climate data. Some of the models individually simulate no cropping potential over much of Botswana roughly correctly, but none capture the full details indicated in Maize 1 to Maize 6.

Maize 11. As Maize 8 but for individual CMIP5 model simulations.

3.4 Projected Cultivation Ranges for Maize

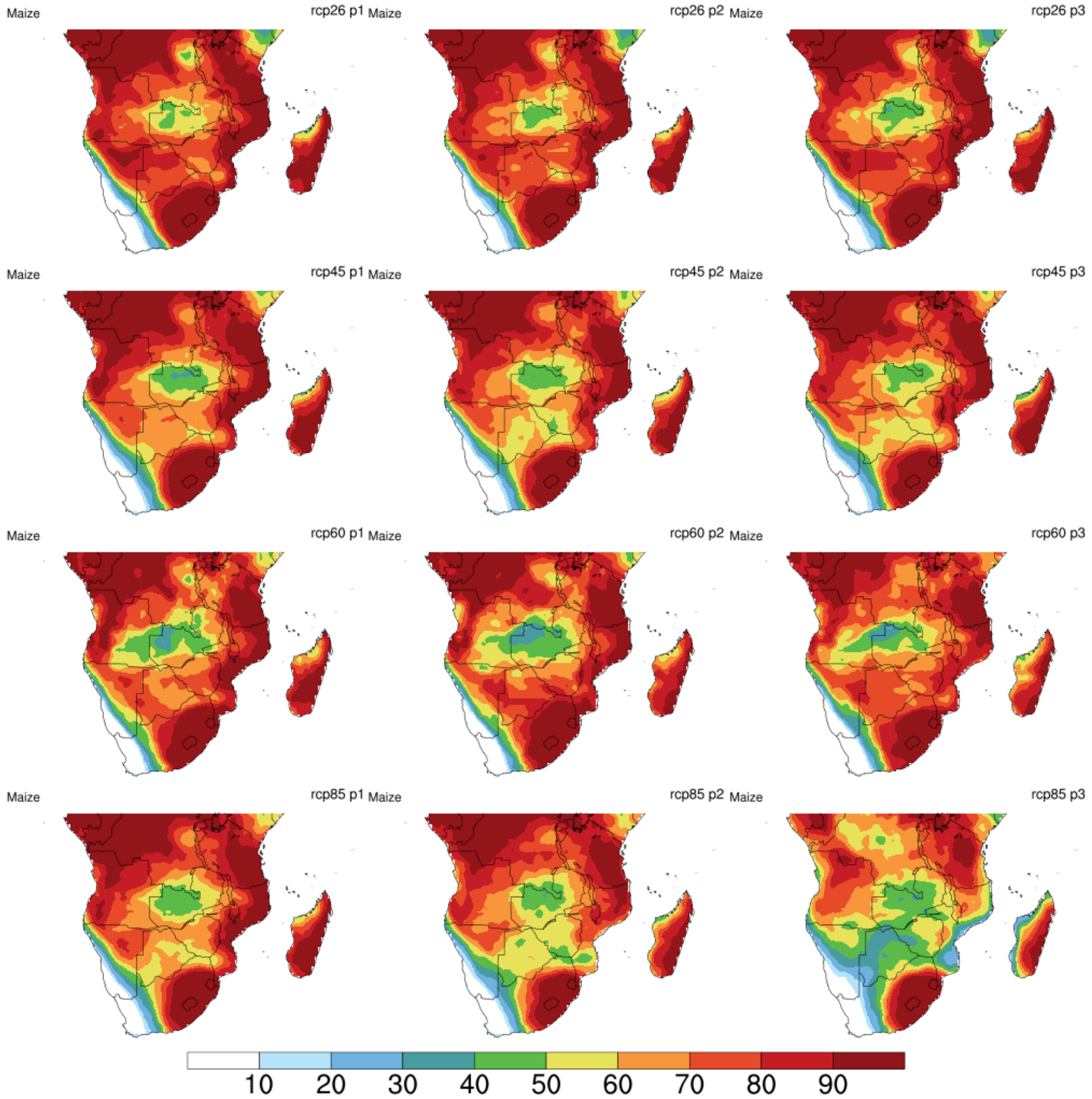
Results are presented here for:

a. Projected cultivation ranges using simulations for the periods 2025 to 2049, 2050 to 2074 and 2075 to 2099; climate conditions are as before (three months with average temperatures in the range 15-30°C and monthly rainfall in the range 60-350mm). This assumes that climate conditions required for cultivation do not change.
b. Scenarios RCP2.6, RCP4.6, RCP6.0 and RCP8.5.
c. All available simulations for each RCP.



Maize 12. Distributions of simulated future areas over which maize might be cultivated according to ensembles means from CMIP5 given a requirement of 3 months with average temperatures in the range 15 to 30°C and contemporaneous monthly rainfall in the range 60 to 350mm. Left-hand column for 2025-2049 (p1), central column for 2050-2074 (p2), right-hand column for 2075-2099 (p3). Top row for RCP2.6, second row for RCP4.5, third row for RCP6.0, bottom row for RCP8.5. Areas over which maize cannot be cultivated at any time according to this analysis in white, where it can be cultivated only during the historical period of 1979-2005 according to the ensemble mean in blue, where it can be cultivated only according to the CMIP5 simulated future climate in red, and where it can be cultivated continuously through the historical period and the 21st Century according to the ensemble means in green.

Some regional details are revealed in Maize 12, such as the late extension of the non-cultivable range across Botswana under RCP8.5 (but see earlier comments on model performance over this region) and an apparent loss of cultivation potential over northern central Zambia. Over the Save Basin Maize 12 suggests that cultivation of maize will continue to be possible throughout the 21st Century regardless of CO_2 emissions.



Maize 13. Distribution of potential ranges of maize cultivation given a requirement of 3 months with average temperatures in the range 15 to 30°C and contemporaneous monthly rainfall in the range 60 to 350mm for 2025 to 2049 (p1 – left-hand column), 2050 to 2074 (p2 – central column) and 2075 to 2099 (p3 – right-hand column) under RCP2.6 (top row), RCP4.5 (second row), RCP6.0 (third row) and RCP8.5 (Bottom row) according to the CMIP5 ensemble. The redder the colour the more models indicate suitability for cultivation, the bluer the fewer models; the scale is in % of models. Note that the available number of projections varies by RCP, with most in RCP8.5, and least in RCP6.0 and then RCP2.6.

The relatively low likelihoods of future maize cultivation over parts of Zambia are emphasised in Maize 13, whereas over Botswana and the Limpopo valley there appears to be a likelihood increasing in time of loss of cultivation potential (this appears to be more prevalent under RCP4.5 and, especially, RCP8.5, and may be a reflection of the greater numbers of models available under these two RCPs). Over the Save Basin there is a distinct reduction in likelihoods of continuing cultivation, again particularly under RCP4.5 and RCP8.5 but given the caveats noted above.