Climate Change Impacts on African Agriculture

July 12, 2000

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Figuers 1 and 2 are taken from: Mendelsohn, Schlesinger, and Williams, 2000. We would like to thank Nagaraja Rao Harshadeep for producing figures 3-11.

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Background

Many scientists, economists and policy makers now agree that the world is facing a threat from climate warming. The degree of the impact and its distribution is still debated. The current evidence suggests that countries in temperate and polar locations may benefit from small economic advantages because additional warming will benefit their agricultural sectors. Many countries in tropical and sub-tropical regions are expected to be more vulnerable to warming because additional warming will affect their marginal water balance and harm their agricultural sectors. However, little research has been done on tropical countries, so that little is known about the extent of these damages. The problem is expected to be most severe in Africa where current information is the poorest, technological change has been the slowest, and the domestic economies depend the most heavily on agriculture. African farmers have adapted to a certain amount of climate variability, but climate change may well force large regions of marginal agriculture out of production in Africa.

The agriculture sector is a major contributor to the current economy of most African countries, averaging 21% and ranging from 10% to 70% of the GDP (Mendelsohn et al., 2000a). Future development is likely to reduce agriculture's share of GDP. With an optimistic forecast of future development, the agriculture's share of GDP could shrink to as little as 4% by 2100. Even with this scenario, several countries will still have large agricultural sectors of over 10% of GDP. Africa's future development path remains uncertain so that it is not clear what fraction of GDP will remain in agriculture.

Even without climate change, there are serious concerns about agriculture in Africa because of water supply variability, soil degradation, and recurring drought events. A number of countries face semi-arid conditions that make agriculture challenging. Further, development efforts have been particularly difficult to sustain. African agriculture has the slowest record of productivity increase in the world.

Experts are concerned that the agriculture sector in Africa will be especially sensitive to future climate change and any increase in climate variability. The current climate is already marginal with respect to precipitation in many parts of Africa. Further warming in these semi-arid locations is likely to be devastating to agriculture there. Even in the moist tropics, increased heat is expected to reduce crop yields. Agronomic studies suggest that yields could fall quite dramatically in the absence of costly adaptation measures. The current farming technology is basic, and incomes low, suggesting that farmers will have few options to adapt. Presently, public infrastructure such as roads, long-term weather forecasts, and agricultural research and extension are inadequate to secure appropriate adaptation. Unfortunately, none of the empirical studies of climate impacts in Africa have explored what adaptations would be efficient for either African farmers or African governments. This is a serious deficiency in African impact research, given the importance of efficient adaptation (Mendelsohn 2000).

Although there are well-established concerns about climate change effects in Africa, there is little quantitative information concerning how serious these effects will be. Existing studies cover only a small fraction of Africa, and few of the African studies include data of actual farmer behavior (adaptation includes responses such as planting dates, harvest dates, use of fertilizer, and crop choice). Existing studies mostly examine how individual crops behave in controlled experiments, addressing largely grain crops.

The Analytical Framework

In order to better understand the magnitude of the potential effects of climate change on African agriculture, we develop a simulation. The simulation uses an IPCC forecast of future atmospheric carbon dioxide levels by 2100. Fourteen alternative climate models were then used to predict the climates in each country using COSMIC (Schlesinger and Williams, 1997). The results were then evaluated with an impact model, GIM (Global Impact Model) (Mendelsohn et al 2000b). GIM begins with the climate forecasts made by COSMIC and calculates impacts in each market sector using two alternative climate response functions (Mendelsohn and Schlesinger, 1999). The climate sensitivity of agriculture in Africa has not yet been measured. This analysis consequently had to rely on studies about climate sensitivity that have been done in the United States (Mendelsohn, Nordhaus and Shaw, 1994 and Mendelsohn and Neumann, 1998). Because local African studies have not yet calibrated climate sensitivity, these initial estimates are highly tentative. We present them to give a sense of the uncertainty surrounding African forecasts.

The response functions are calibrated from experimental and cross-sectional models in the US. GIM produces two alternative forecasts of agricultural impacts in billions of dollars by 2100 for each sub-region and country (Mendelsohn et al., 2000b). Figures 1 and 2 present the results for the world, using 14 different climate models in terms of % of GDP. Both response functions are hill-shaped implying that warming in the high latitudes will be beneficial and warming in the low-latitudes will be harmful. Figure 1 shows the experimental results and Figure 2 shows the cross sectional results. The experimental response function is more climate sensitive and leads to larger benefits in the polar region and larger damages in the low-latitudes compared to the cross sectional results. The figures contain a picture of the average effect across all 14 General Circulation Models (GCM's) as well as the most optimistic and the most pessimistic results. The most optimistic climate model, GENESIS with dynamic sea-ice (POLD), predicts a modest increase in temperature near the equator and a larger increase in the temperate zones and near the poles (Thompson and Pollard, 1995). The most pessimistic climate model, University of Illinois at Urbana-Champaign (UIUC), predicts significant warming near the equator and moderate warming near the poles (Schlesinger and Zhao, 1989). These different temperature and precipitation forecasts have important implications for the climate in Africa as seen in both figures. However, all the models show that Africa is the most vulnerable continent in the world to climate change.

Results

The results (Table 1) indicate that the climate sensitivity of agriculture is an important factor. Even relying upon a single climate model, UIUC, the impacts in Africa as a continent can range from a potential loss of $25 billion to a loss of $194 billion per year, depending on the climate sensitivity used. The most pessimistic forecast comes from the experimental simulation data that suggests that African countries may lose 47% of their agricultural revenue because of global warming. However, this forecast is possibly extreme because only limited adaptation is included in the model, and the theoretical models in this case do not contain any tropical crops. The cross-sectional forecast was less pessimistic, suggesting losses of only 6% of agricultural GDP. These numbers are more moderate because cross-sectional models automatically include a comprehensive set of adaptation measures. It is likely that the correct estimates for Africa are bounded by these two US-based estimates. However, even this is uncertain because the US results are calibrated to a temperate climate and US farmers use more capital-intensive agricultural technologies than farmers in Africa.

Despite the large size of these climate impacts, it should be noted that the impacts are expected to be a small fraction of future GDP. With the expected growth in other sectors of the economy, agriculture should be a small fraction of GDP in Africa by 2100. The damage from climate change to African agriculture is expected to range from 0.13% to 2% of GDP by 2100. The larger effects (1.4% to 2%) come from the predictions of the experimental response function and the smaller effects (0.13% to .25%) come from the predictions of the cross sectional response function.

Regional Results

One of the important results from the simulation is that effects are likely to be different across the African continent. The initial climate conditions are quite different as precipitation varies a great deal across sub-regions. West Africa is in broad terms very moist as are parts of central Africa, whereas the rest of Africa is mostly semi-arid to arid. Initial temperatures also vary with West Africa, the Sahara, and East Africa being the warmest regions, while North Africa, Kenya, and Southern Africa are more temperate. The climate models forecast larger temperature changes in North Africa and the Sahara, with reductions in precipitation in the semi-arid regions of Africa and a precipitation increase only in Western Africa. Finally, economic conditions vary significantly across Africa. In northern and southern Africa, agriculture represents only 11-15% of GDP whereas in the rest of Africa, agriculture counts for 35-40% of GDP. The results by geographical regions are presented in Table 1 as well.

The result of all these factors suggest that every region in Africa will experience some negative climate change impacts, but that some regions will be more vulnerable to warming than others. As a fraction of GDP, the Sahara and EGAD regions are the most vulnerable. Examining only the experimental results, these two regions are expected to suffer losses between 2% and 7%. West Africa and Central Africa are also vulnerable with effects ranging from 2% to 4%. In contrast, Northern and Southern Africa are expected to have losses from 0.4% to 1.3%.

With the experimental climate response function, West Africa suffers the greatest losses amounting to between 36% and 44% of the losses for the entire continent. These damages represent losses between 42% and 60% of agricultural GDP in this region. The Sahara suffers the lowest absolute damages because agriculture in the Sahara has low value. However, the Sahara consistently loses the highest fraction of remaining agricultural value between 68% and 80%. The EGAD region also suffers high losses as a fraction of agricultural GDP between 48% and 73%. The other regions split the remaining damages depending upon the climate model. The other regions experience losses between 13% and 45% of their agriculture. With the cross-sectional climate response function, West Africa suffers about half of the damages in Africa even though the losses are less than 10% of the value of their agriculture. EGAD suffers the same percentage losses as West Africa. The Sahara suffers the greatest percentage loss of agriculture (10-20%) although the absolute amount of the loss is small. The losses in the remaining agricultural regions are in the neighborhood of 1-3% of agricultural GDP.

Country-level Results

The impacts on individual countries vary over an even wider range (Appendix 1, 2 and 3). Appendix 1 measures the absolute value of the impacts in billions on dollars in 2100. Appendix 2 expresses these same impacts as a fraction of 2100 GDP. Appendix 3 presents the results by country as a fraction of 2100 agricultural GDP. With the experimental climate response function and the 14 climate predictions, 7 countries are predicted to suffer the largest average losses in the agricultural sector in descending order (Nigeria, Sudan, Algeria, Cameroon, South Africa, Morocco, and Zaire). Together, these 7 countries account for 47% of the damages in Africa. All of these countries have large agricultural sectors. Examining impacts as a fraction of agricultural GDP consequently gives a different perspective. In descending order, the following countries were most severely impacted (Zambia, Niger, Chad, Burkina Faso, Togo, Botswana, Guinea Bissau, and Gambia). All 8 countries suffered losses greater than 70% of their agricultural sectors, the first three countries practically losing their entire farming sector. Average continental effects do hide dramatic national impacts. Even with the cross-sectional climate response functions, national impacts may be significant although only Chad, Niger, Burkina Faso, and Togo had effects greater than 10% of agricultural GDP. A visual representation of selected variables from Appendixes 1-3 are presented in Figures 3-10.

Conclusion

As of today there is sufficient evidence to conclude that African agriculture is very vulnerable to climate change. The modeling results presented here indicate that the potential damages may be large both in absolute terms and as a fraction of agricultural GDP. However, even these impact estimates may be optimistic because they were based on US climate response functions. It is likely that these US functions are too optimistic because they are based on a capital-intensive agricultural system with significant adaptive capacity. It is consequently urgent that studies be undertaken in Africa to estimate the likely magnitude of these effects and to begin to understand adaptation options for Africa.

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Table 1: Regional climate change impact estimates in 2100 (billions USD)

Region	Observed Temp C°	Observed Precip cm	UIUC Forecasted Temp	UIUC Forecasted Precip	UIUC Δ Temp	UIUC Δ Precip	UIUC Exp[a] (USD)	UIUC CRS (USD)	POLD Exp (USD)	POLD CRS (USD)	Average Exp (14 models) (USD)
SADC	20.98	8.82	23.36	8.40	2.37	-0.43	-31.5	-2.1	-17.7	+0.1	-21.1
North	20.39	1.06	23.60	0.96	3.22	-0.10	-27.0	-2.9	-14.9	-1.1	-19.7
Sahara	27.19	2.34	29.98	2.17	2.79	-0.18	-10.6	-2.9	-9.2	-1.4	-9.0
Egad	25.39	7.79	27.87	7.46	2.48	-0.33	-31.2	-3.9	-8.4	-2.4	-20.4
Central	23.13	11.25	25.38	10.86	2.25	-0.40	-20.6	-1.8	-22.2	-1.2	-12.1
West	26.05	13.20	28.39	13.50	2.35	0.09	-74.7	-11.2	-51.1	-6.4	-51.8
Total	23.67	9.16	26.13	8.96	2.47	-0.21	194.1	24.6	142.4	12.3	133.0

[a]Exp=Experimental-based climate sensitivity function.

[b]CRS=Cross sectional Ricardian climate sensitivity function.

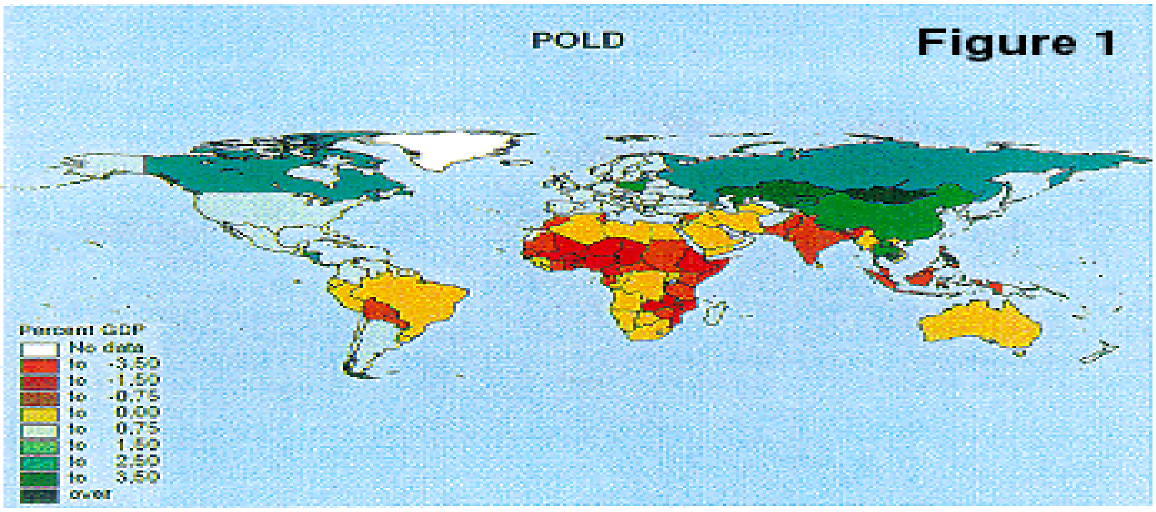
Table 1: Cont'd

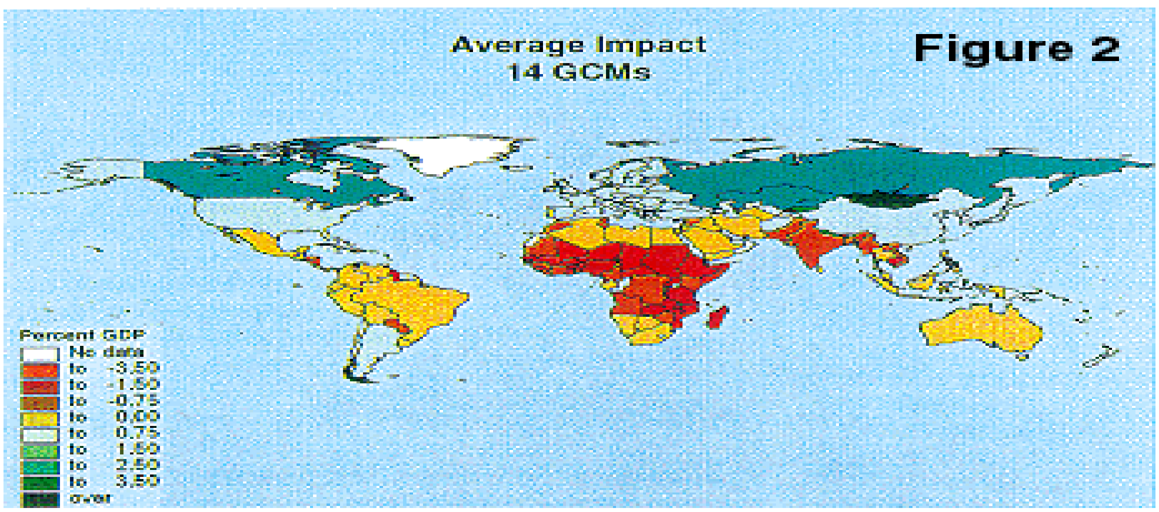
Region	Average CRS (14 mo dels) (USD)	GDP in 1990 (USD)	GDP in 2100 (USD)	UIUC Exp %GDP	POLD Exp %GDP	AVG Exp %GDP	UIUC CRS %GDP	POLD CRS %GDP	AVG CRS %GDP
SADC	-0.4	127.0	3085.3	-1.1	-0.2	-0.5	-0.503	-0.119	-0.236
North	-1.3	146.9	3569.8	-0.8	-0.2	-0.3	-0.258	-0.059	-0.125
Sahara	-1.7	6.6	159.7	-1.3	-2.5	-0.1	-0.159	-0.310	-0.008
egad	-2.1	21.7	528.5	-6.1	-1.4	-0.6	-0.768	-0.186	-0.080
central	-0.7	29.3	711.3	-3.4	-0.6	-0.4	-0.423	-0.079	-0.046
west	-6.9	70.9	1725.8	-4.4	-1.1	0	-0.650	-0.162	0
Total	13.0	402.4	9780.4	-2.0	-1.5	-1.4	-0.3	-0.1	-0.1

Table 1: Continued

Region	POLD Exp %Ag GDP	UIUC Exp %Ag GDP	AVG Exp %Ag GDP	POLD CRS %Ag GDP	UIUC CRS %Ag GDP	AVG CRS %Ag GDP
SADC	-25.1	-44.7	-29.9	+0.1	-3.0	-0.6
North	-13.1	-23.7	-17.3	-1.0	-2.6	-1.1
Sahara	-69.8	-80.3	-68.3	-10.5	-21.8	-13.1
egad	-67.3	-73.5	-48.2	-5.6	-9.1	-4.9
central	-38.5	-35.8	-21.0	-2.0	-3.1	-1.3
west	-41.5	-60.6	-42.0	-5.2	-9.1	-5.6
Total	-34.2	-46.7	-32.0	-3.0	-5.9	-3.1

Figure 1: Range of impacts calculated using Experimental (EXP) climate response functions





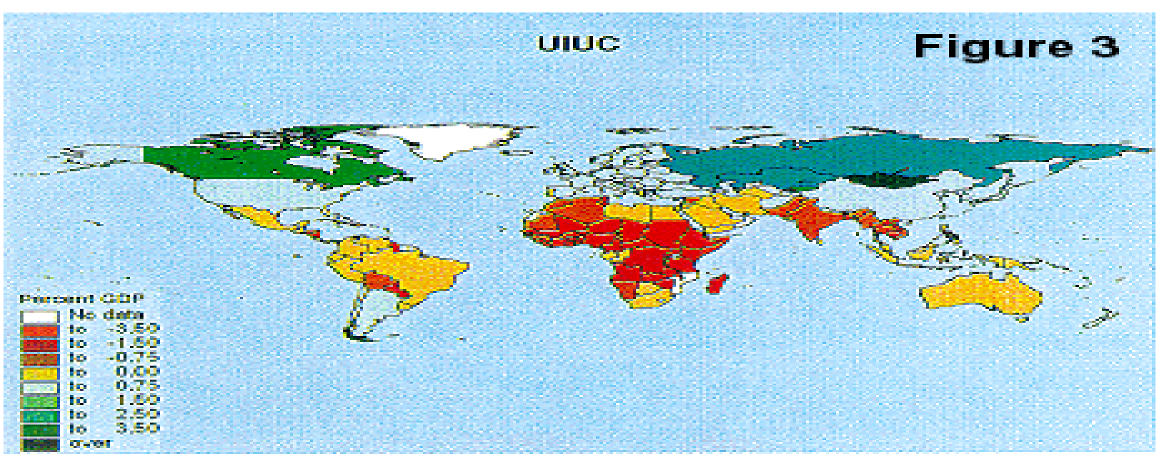
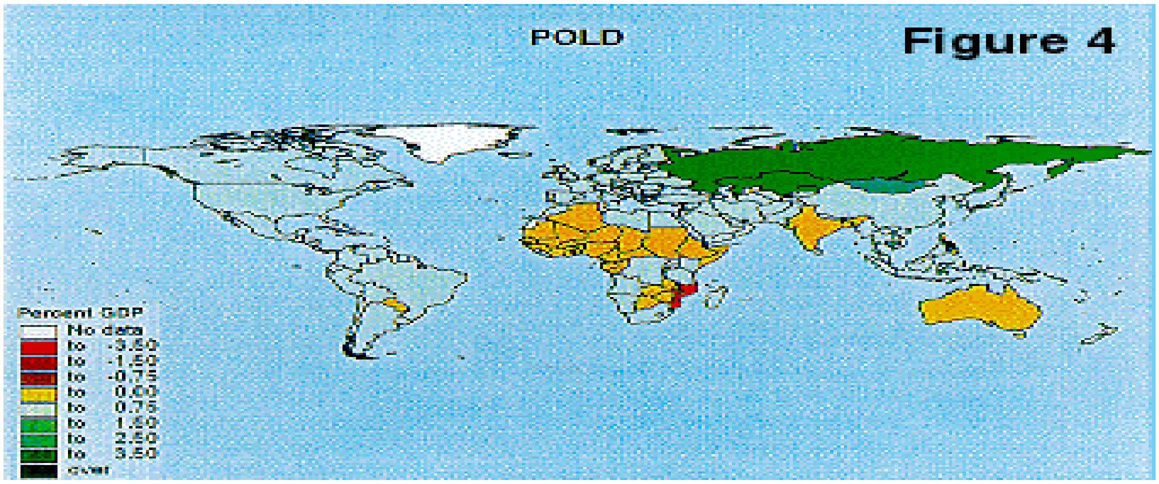
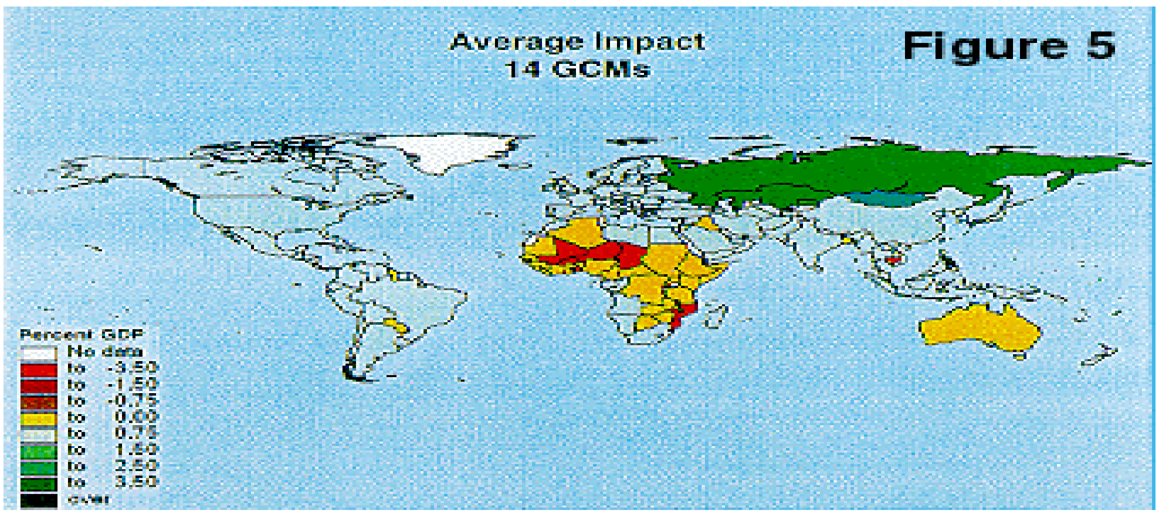


Figure 2: Range of impacts calculated using Cross Sectional (CRS) climate response functions





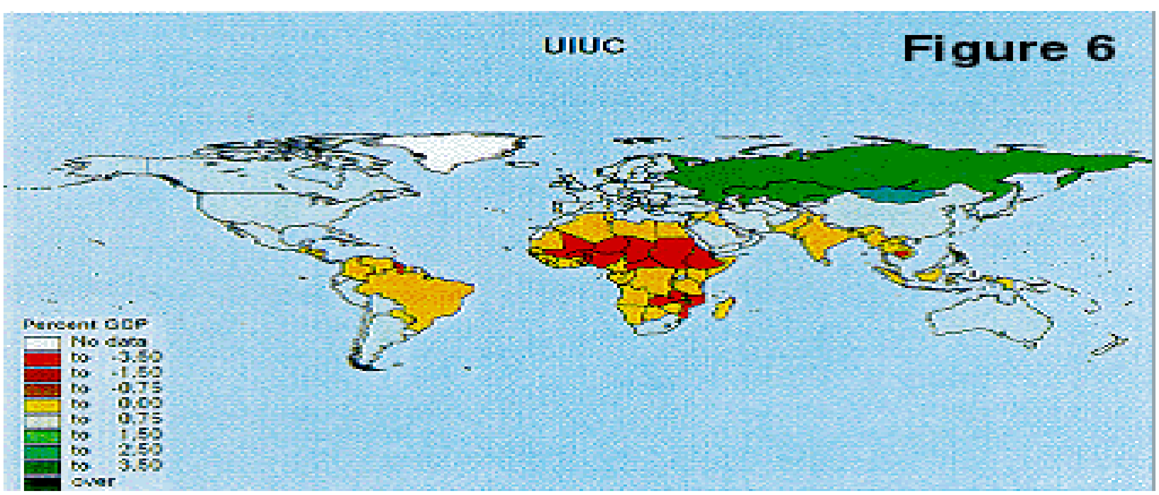


Figure 3: Agricultural Gross National Product of African countries in 1990 (AG_GDP_1990) in billions of 1990 $US

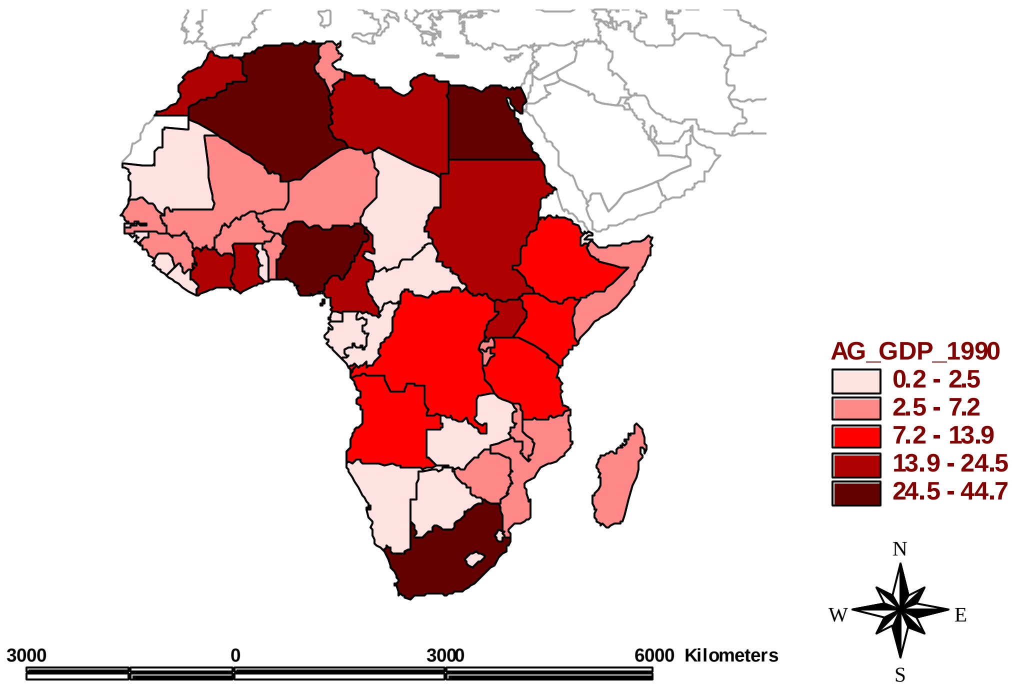


Figure 4: Agricultural Gross National Product of African countries in 2100 (AG_GDP_2100) in billions of 1990 $US

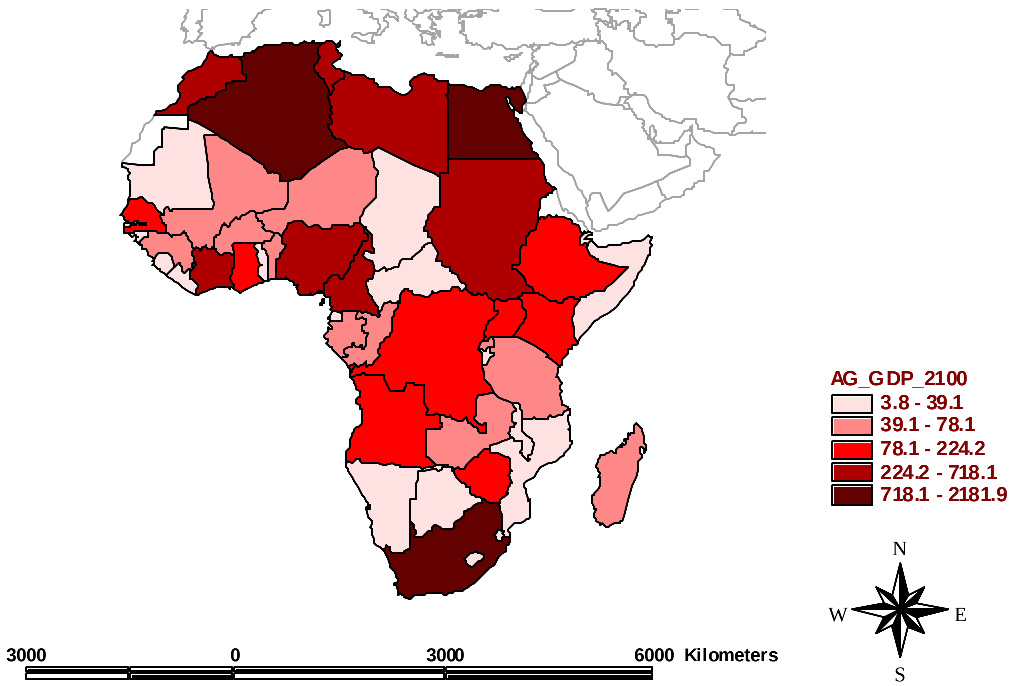


Figure 5: Percentage change in Agricultural GDP (PAG) in 2100 in African countries due to climate change using the average values (AVG) of 14 global climate change models and cross sectional (CRS) coefficients (CRS_AVG_PAG)

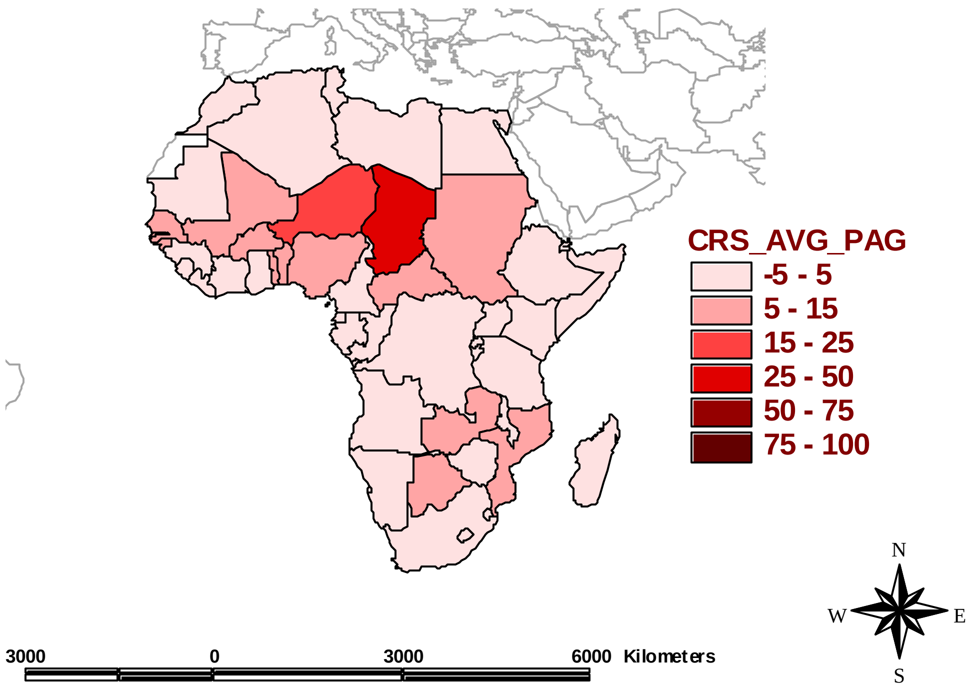


Figure 6: Percentage change in Agricultural GDP (PAG) in 2100 in African countries due to climate change using the values produced by the POLD global climate change model and cross sectional (CRS) coefficients (CRS_AVG_PAG)

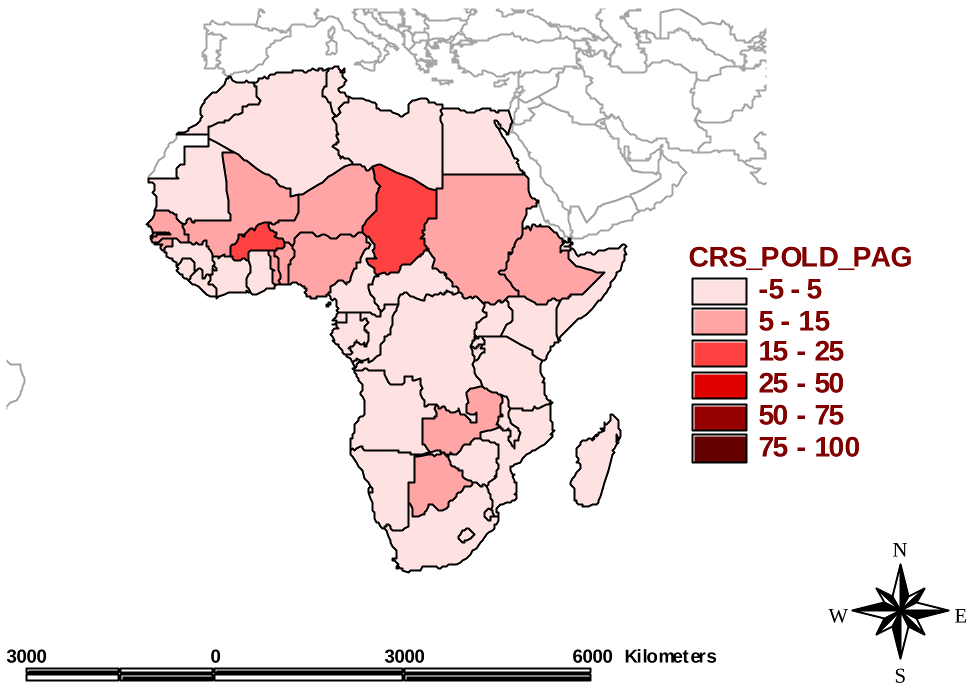


Figure 7: Percentage change in Agricultural GDP (PAG) in 2100 in African countries due to climate change using the values produced by the UIUC global climate change model and cross sectional (CRS) coefficients (CRS_AVG_PAG)

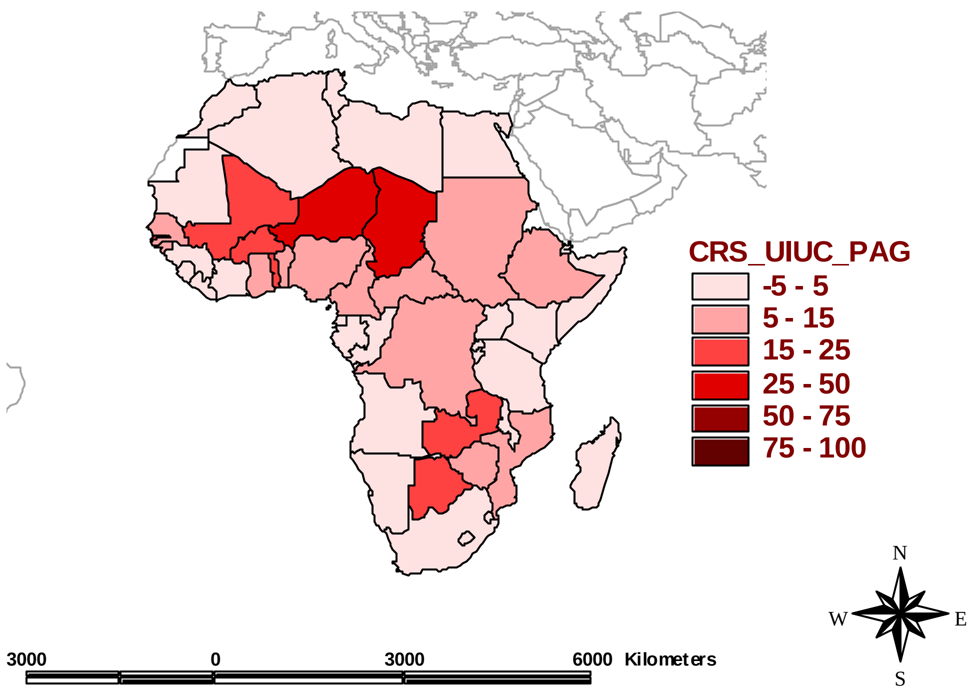


Figure 8: Percentage change in Agricultural GDP (PAG) in 2100 in African countries due to climate change using the average values (AVG) of 14 global climate change models and experimental (EXP) co-efficients (EXP_AVG_PAG)

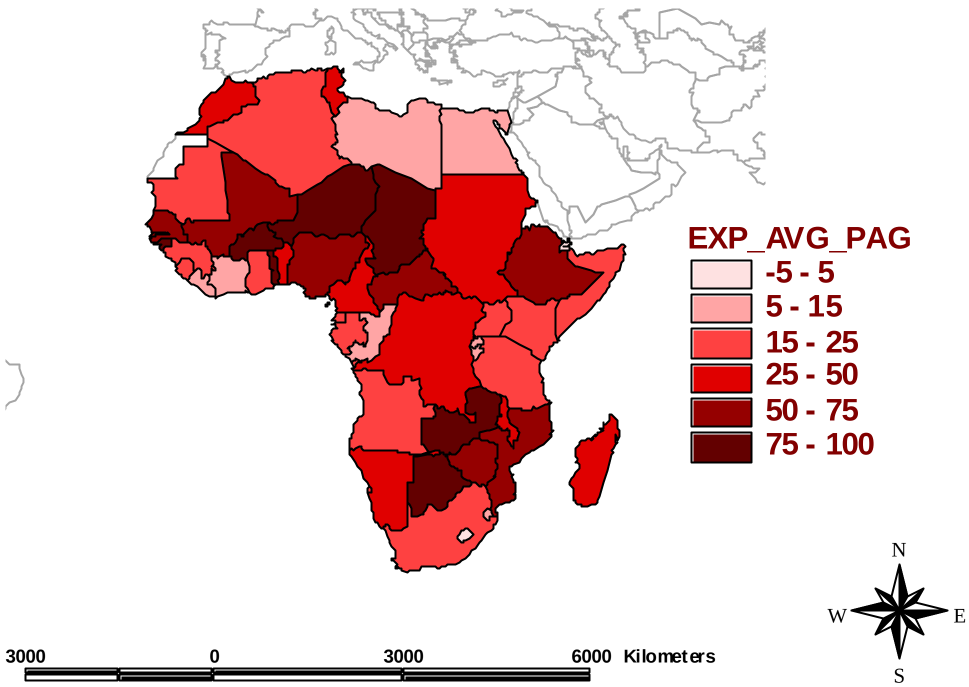


Figure 9: Percentage change in Agricultural GDP (PAG) in 2100 in African countries due to climate change using the values produced by the POLD global climate change model and experimental (EXP) co-efficients (EXP_AVG_PAG)

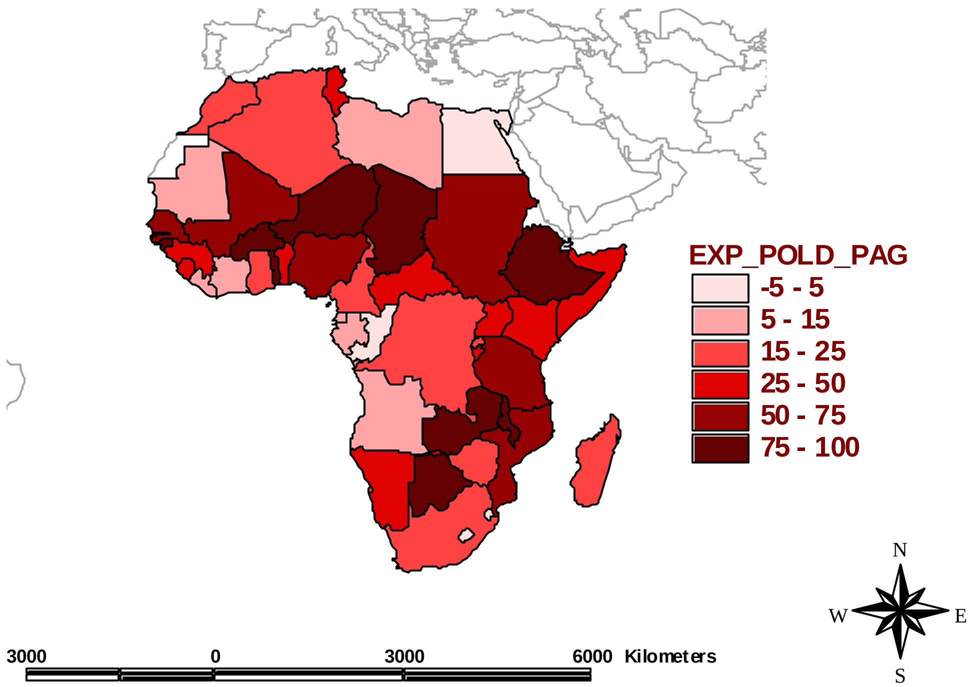
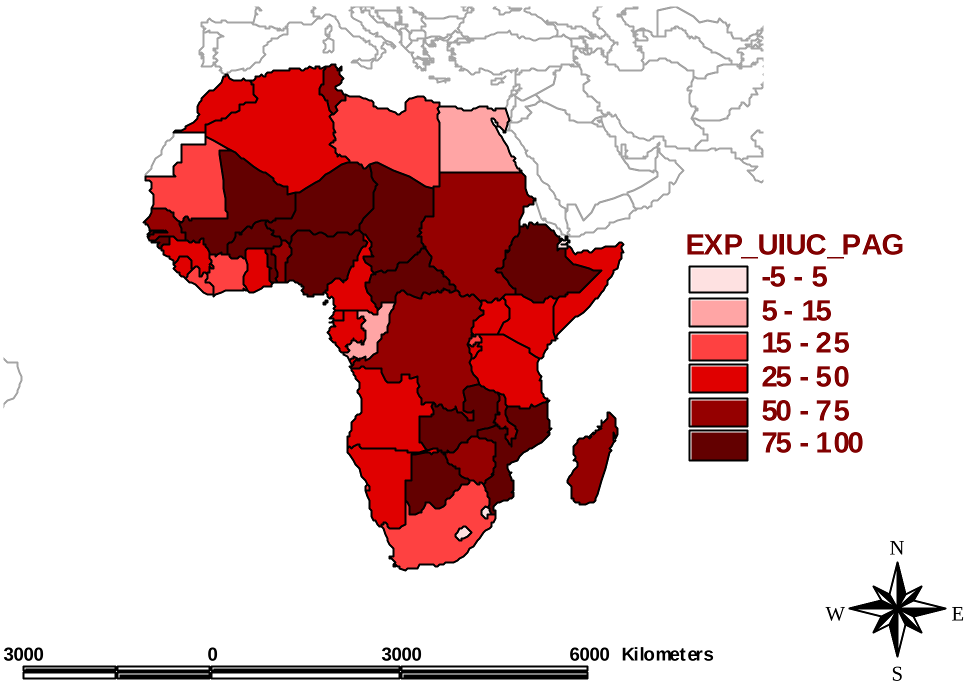


Figure 10: Percentage change in Agricultural GDP (PAG) in 2100 in African countries due to climate change using the values produced by the UIUC global climate change model and experimental (EXP) co-efficients (EXP_AVG_PAG)



Appendix 1: Country-level Estimates of Impacts in 2100 (billions USD)

Country	AGR GDP USD	GDP USD	AGR% of GDP %	exp POLD USD	exp UIUC USD	exp AVG USD	crs POLD USD	crs UIUC USD	crs AVG USD
Algeria	36.1	1347.2	2.68	6.57	11.04	8.24	0.57	1.75	1.07
Angola	9.6	152.4	6.30	1.12	2.76	1.84	0.06	0.22	0.08
Benin	4.1	44.5	9.21	1.99	2.63	1.85	0.27	0.41	0.26
Botswana	0.2	28	0.71	0.17	0.17	0.17	0.02	0.04	0.02
Burkina Faso	4.4	68.9	6.39	4.4	4.4	3.93	0.69	1.03	0.66
Burundi	3.3	29.1	11.34	0.92	1.12	0.39	-0.04	0.03	-0.03
Cameroon	16.2	295.8	5.48	3.31	7.66	5.09	0.24	0.91	0.49
Cape Verde	0.2	7.1	2.82	0	0	0	0	0	0
Central African Rep.	2.5	29	8.62	1.08	2.36	1.53	0.11	0.28	0.17
Chad	1.9	26.3	7.22	1.9	1.9	1.8	0.41	0.82	0.52
Comoros	0.4	5.3	7.55	0.05	0.08	0.06	0	0.01	0.01
Congo	1.4	51.9	2.70	-0.02	0.19	0.13	0	0.03	0.01
Cote d'Ivoire	22	236	9.32	1.88	4.47	3.1	0.28	0.61	0.37
Djibouti	0.6	8.4	7.14	0	0	0	0	0	0
Egypt	35.5	824.3	4.31	1.35	3.31	2.08	0	0.48	0.19
Equatorial Guinea	0.5	3.8	13.16	0.05	0.17	0.12	0	0.02	0.01
Ethiopia	13.2	151	8.74	13.2	12.35	7.7	0.67	1	0.31
Gabon	1.6	77.6	2.06	0.09	0.45	0.35	0	0.06	0.03
Gambia	0.3	5	6.00	0.28	0.3	0.22	0.03	0.05	0.03
Ghana	14.2	139.6	10.17	2.89	5.39	2.8	0.43	0.81	0.49
Guinea	4.5	60.2	7.48	0.00	0.00	0.00	0.00	0.00	0.00
Guinea-Bissau	0.4	4.4	9.09	0.4	0.39	0.31	0.04	0.06	0.04
Kenya	13.9	222.8	6.24	5.43	4.1	2.91	0.45	0.49	0.26
Lesotho	1	20.7	4.83	0.04	0	0	-0.05	-0.04	-0.05
Liberia	2	26.7	7.49	0.15	0.45	0.29	0.02	0.05	0.03
Libya	17.2	582.7	2.95	1.23	2.8	1.75	0.04	0.41	0.18
Madagascar	4.1	64.5	6.36	0.93	2.58	1.26	-0.02	0.12	0.03
Malawi	2.6	37.4	6.95	1.96	1.6	0.99	0.06	0.1	0.04
Mali	5.4	53.5	10.09	2.96	4.24	2.94	0.41	0.82	0.5
Mauritania	1.8	24.2	7.44	0.25	0.36	0.28	0.03	0.07	0.05
Mauritius	1.3	52.5	2.48	-0.04	0.07	0.05	0	0	0
Morocco	17.6	559.7	3.14	3.61	5.62	4.59	0.61	-0.06	-0.25
Mozambique	4	30.3	13.20	2.44	3.64	2.43	0.15	0.33	0.21
Namibia	1.1	39.1	2.81	0.49	0.51	0.34	0	0.02	-0.01
Niger	4.1	55.7	7.36	4.1	4.1	3.99	0.54	1.17	0.66
Nigeria	44.7	718.1	6.22	28.77	40.94	27.78	3.64	5.94	3.64
Rwanda	4.1	54.7	7.50	0.74	0.97	0.25	-0.06	-0.01	-0.06
Sao Tome/Principe	0.1	1.1	9.09	0	0	0	0	0	0

Senegal	5.3	119.6	4.43	3.23	3.57	2.71	0.38	0.61	0.4
Seychelles	0.6	7.4	8.11	0	0	0	0	0	0
Sierra Leone	1.9	20.6	9.22	0.49	0.57	0.45	0.04	0.07	0.05
Somalia	3.5	26.3	13.31	1.1	1.1	0.74	0.08	0.15	0.08
South Africa	25.7	2181.9	1.18	5.29	6.33	4.91	-0.77	-0.27	-0.61
Sudan	24.5	335.4	7.30	14.12	17.71	12	1.61	2.71	1.69
Swaziland	0.8	17.3	4.62	0.03	0.01	0.1	-0.01	0	0
Togo	2.4	34.6	6.94	2.14	2.38	2.06	0.27	0.47	0.29
Tunisia	7.2	255.9	2.81	2.13	4.19	3	-0.11	0.34	0.07
Uganda	15.9	107.9	14.74	6.97	6.58	3.28	0.39	0.47	0.15
United Rep.Tanzania	10.4	78.1	13.32	5.81	3.47	2.17	0.22	0.25	0.09
Zaire	13.5	224.2	6.02	2.35	8.57	4.7	0.23	0.91	0.43
Zambia	2.2	77.6	2.84	2.2	2.2	2.16	0.14	0.41	0.15
Zimbabwe	4	154.1	2.60	0.68	2.97	2.05	0.11	0.23	0.14
Total	416.00	9780.40	4.25	141.23	192.77	131.89	12.18	24.38	12.89

There are two climate response functions: experimental (exp) and cross-sectional (crs). There are three climate forecasts: POLD, UIUC, and the average of 14 models (avg).

Appendix 2: Climate impacts in Africa as a fraction of GDP in 2100

Country	exp pold %GDP	exp uiuc %GDP	exp AVG %GDP	crs pold %GDP	crs uiuc %GDP	crs AVG %GDP
Algeria	0.49	0.82	0.61	0.04	0.13	0.08
Angola	0.73	1.81	1.21	0.04	0.14	0.05
Benin	4.47	5.91	4.16	0.61	0.92	0.58
Botswana	0.61	0.61	0.61	0.07	0.14	0.07
Burkina Faso	6.39	6.39	5.70	1.00	1.49	0.96
Burundi	3.16	3.85	1.34	-0.14	0.10	-0.10
Cameroon	1.12	2.59	1.72	0.08	0.31	0.17
Cape Verde	0.00	0.00	0.00	0.00	0.00	0.00
Central African Rep.	3.72	8.14	5.28	0.38	0.97	0.59
Chad	7.22	7.22	6.84	1.56	3.12	1.98
Comoros	0.94	1.51	1.13	0.00	0.19	0.19
Congo	-0.04	0.37	0.25	0.00	0.06	0.02
Cote d'Ivoire	0.80	1.89	1.31	0.12	0.26	0.16
Djibouti	0.00	0.00	0.00	0.00	0.00	0.00
Egypt	0.16	0.40	0.25	0.00	0.06	0.02
Equatorial Guinea	1.32	4.47	3.16	0.00	0.53	0.26
Ethiopia	8.74	8.18	5.10	0.44	0.66	0.21
Gabon	0.12	0.58	0.45	0.00	0.08	0.04
Gambia	5.60	6.00	4.40	0.60	1.00	0.60
Ghana	2.07	3.86	2.01	0.31	0.58	0.35
Guinea	1.93	2.24	1.77	0.16	0.28	0.20
Guinea-Bissau	9.09	8.86	7.05	0.91	1.36	0.91
Kenya	2.44	1.84	1.31	0.20	0.22	0.12
Lesotho	0.19	0.00	0.00	-0.24	-0.19	-0.24
Liberia	0.56	1.69	1.09	0.07	0.19	0.11
Libya	0.21	0.48	0.30	0.01	0.07	0.03
Madagascar	1.44	4.00	1.95	-0.03	0.19	0.05
Malawi	5.24	4.28	2.65	0.16	0.27	0.11
Mali	5.53	7.93	5.50	0.77	1.53	0.93
Mauritania	1.03	1.49	1.16	0.12	0.29	0.21
Mauritius	-0.08	0.13	0.10	0.00	0.00	0.00
Morocco	0.64	1.00	0.82	0.11	-0.01	-0.04
Mozambique	8.05	12.01	8.02	0.50	1.09	0.69
Namibia	1.25	1.30	0.87	0.00	0.05	-0.03
Niger	7.36	7.36	7.16	0.97	2.10	1.18
Nigeria	4.01	5.70	3.87	0.51	0.83	0.51
Rwanda	1.35	1.77	0.46	-0.11	-0.02	-0.11
Sao Tome/Principe	0.00	0.00	0.00	0.00	0.00	0.00

Senegal	2.70	2.98	2.27	0.32	0.51	0.33
Seychelles	0.00	0.00	0.00	0.00	0.00	0.00
Sierra Leone	2.38	2.77	2.18	0.19	0.34	0.24
Somalia	4.18	4.18	2.81	0.30	0.57	0.30
South Africa	0.24	0.29	0.23	-0.04	-0.01	-0.03
Sudan	4.21	5.28	3.58	0.48	0.81	0.50
Swaziland	0.17	0.06	0.58	-0.06	0.00	0.00
Togo	6.18	6.88	5.95	0.78	1.36	0.84
Tunisia	0.83	1.64	1.17	-0.04	0.13	0.03
Uganda	6.46	6.10	3.04	0.36	0.44	0.14
United Rep.Tanzania	7.44	4.44	2.78	0.28	0.32	0.12
Zaire	1.05	3.82	2.10	0.10	0.41	0.19
Zambia	2.84	2.84	2.78	0.18	0.53	0.19
Zimbabwe	0.44	1.93	1.33	0.07	0.15	0.09
Total	1.46	1.98	1.36	0.13	0.25	0.13

There are two climate response functions: experimental (exp) and cross-sectional (crs). There are three climate forecasts: POLD, UIUC, and the average of 14 models (avg).

Appendix 3: Climate Impacts in Africa as a fraction of Agricultural GDP in 2100

Country	exp pold %AG GDP	exp uiuc %AG GDP	exp AVG %AG GDP	CRS pold %AG GDP	CRS uiuc %AG GDP	CRS AVG %AG GDP
Algeria	18.20	30.58	22.83	1.58	4.85	2.96
Angola	11.67	28.75	19.17	0.63	2.29	0.83
Benin	48.54	64.15	45.12	6.59	10.00	6.34
Botswana	85.00	85.00	85.00	10.00	20.00	10.00
Burkina Faso	100.0	100.0	89.32	15.68	23.41	15.00
Burundi	27.88	33.94	11.82	-1.21	0.91	-0.91
Cameroon	20.43	47.28	31.42	1.48	5.62	3.02
Cape Verde	0.00	0.00	0.00	0.00	0.00	0.00
Central African .	43.20	94.40	61.20	4.40	11.20	6.80
Chad	100.0	100.0	94.74	21.58	43.16	27.37
Comoros	12.50	20.00	15.00	0.00	2.50	2.50
Congo	-1.43	13.57	9.29	0.00	2.14	0.71
Cote d'Ivoire	8.55	20.32	14.09	1.27	2.77	1.68
Djibouti	0.00	0.00	0.00	0.00	0.00	0.00
Egypt	3.80	9.32	5.86	0.00	1.35	0.54
Equatorial Guinea	10.00	34.00	24.00	0.00	4.00	2.00
Ethiopia	100.0	93.56	58.33	5.08	7.58	2.35
Gabon	5.63	28.13	21.88	0.00	3.75	1.88
Gambia	93.33	100.0	73.33	10.00	16.67	10.00
Ghana	20.35	37.96	19.72	3.03	5.70	3.45
Guinea	25.79	30.00	23.68	2.11	3.68	2.63
Guinea-Bissau	100.0	97.50	77.50	10.00	15.00	10.00
Kenya	39.06	29.50	20.94	3.24	3.53	1.87
Lesotho	4.00	0.00	0.00	-5.00	-4.00	-5.00
Liberia	7.50	22.50	14.50	1.00	2.50	1.50
Libya	7.15	16.28	10.17	0.23	2.38	1.05
Madagascar	22.68	62.93	30.73	-0.49	2.93	0.73
Malawi	75.38	61.54	38.08	2.31	3.85	1.54
Mali	54.81	78.52	54.44	7.59	15.19	9.26
Mauritania	13.89	20.00	15.56	1.67	3.89	2.78
Mauritius	-3.08	5.38	3.85	0.00	0.00	0.00
Morocco	20.51	31.93	26.08	3.47	-0.34	-1.42
Mozambique	61.00	91.00	60.75	3.75	8.25	5.25
Namibia	44.55	46.36	30.91	0.00	1.82	-0.91
Niger	100.0	100.0	97.32	13.17	28.54	16.10
Nigeria	64.36	91.59	62.15	8.14	13.29	8.14
Rwanda	18.05	23.66	6.10	-1.46	-0.24	-1.46
Sao Tome/Pr.	0.00	0.00	0.00	0.00	0.00	0.00
Senegal	60.94	67.36	51.13	7.17	11.51	7.55

Seychelles	0.00	0.00	0.00	0.00	0.00	0.00
Sierra Leone	25.79	30.00	23.68	2.11	3.68	2.63
Somalia	31.43	31.43	21.14	2.29	4.29	2.29
South Africa	20.58	24.63	19.11	-3.00	-1.05	-2.37
Sudan	57.63	72.29	48.98	6.57	11.06	6.90
Swaziland	3.75	1.25	12.50	-1.25	0.00	0.00
Togo	89.17	99.17	85.83	11.25	19.58	12.08
Tunisia	29.58	58.19	41.67	-1.53	4.72	0.97
Uganda	43.84	41.38	20.63	2.45	2.96	0.94
U. Rep.Tanzania	55.87	33.37	20.87	2.12	2.40	0.87
Zaire	17.41	63.48	34.81	1.70	6.74	3.19
Zambia	100.0	100.0	98.18	6.36	18.64	6.82
Zimbabwe	17.00	74.25	51.25	2.75	5.75	3.50
Total	34.23	46.66	31.96	2.95	5.90	3.13

There are two climate response functions: experimental (exp) and cross-sectional (crs). There are three climate forecasts: POLD, UIUC, and the average of 14 models (avg).