ON THE IMPLICATIONS OF CLIMATE CHANGE FOR AGRICULTURE-LED DEVELOPMENT STRATEGIES IN SUB-SAHARAN AFRICA

by

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ABSTRACT

Climate change is presenting challenges for agriculture-led development. Historically, increased agricultural productivity has been essential to poverty reduction and development, particularly for agriculture-based countries. In several countries of Sub-Saharan Africa, present and future climate change will negatively affect agricultural productivity. Adaptation strategies can dampen these effects, but many are prohibitively expensive without sustained economic growth or international assistance. In countries that are projected to experience positive or minimally negative effects from climate change, such as Burundi, Cameroon, Côte d'Ivoire, Ethiopia, Ghana, Kenya, Madagascar, Niger, and Uganda, agriculture-led development strategies remain advisable. Those countries that are projected to experience significantly negative consequences, such as Benin, Burkina Faso, Chad, Guinea, Malawi, Mali, Mozambique, Nigeria, Rwanda, Sudan, Togo, and Zambia, may wish to consider alternative strategies. In these cases, explicit efforts to distribute the benefits of other strategies to the poor (especially the rural poor) will be required to achieve widespread poverty reduction.

Keywords: Climate Change; Agriculture; Development; Sub-Saharan Africa

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For those who strive to improve the world

May we succeed

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PREFACE

The interconnected aspects of interest here are climatic systems, human development, ecosystems, and the future. These are all highly complex and uncertain, and, when combined, the complexity and uncertainty compound. Nevertheless, given the scale of potential changes, the extreme poverty experienced by many, and humanity's conscious awareness and free will, we must strive to understand the probable effects of our actions and incorporate this knowledge into our future choices. This is an effort to do so.

1. INTRODUCTION

Throughout human history, agriculture has played a central role in development. Recently, the results of our emergent development path have presented a significant challenge to future development in the form of global climate change. Of particular interest, are the projected effects of climate change on agricultural systems and whether these effects will render agriculture-led development strategies unviable for the less developed countries of Sub-Saharan Africa.

Much research and historical evidence has shown that agricultural[1] progress is an important engine for development[2]. While it is clear that there is no simple formula to induce economic growth (Easterly, 2001), growth in the agricultural sector has been shown to have significant effects on decreasing poverty in less developed countries (LDCs) and instigating economic activity in other sectors (Christiaensen et al., 2006; Mellor, 1998; Ruttan & Hayami, 1998; etc.). Recently, agriculture-led development has resurfaced as a promising focus in the international community (World Bank, 2007a), especially for Sub-Saharan Africa, as this region continues to struggle with low agricultural productivity and poor food security.

Global climate change presents a challenge for development in general, and for agriculture-led development, specifically. The Intergovernmental Panel on Climate

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[1] See appendix 2 for a definition of agriculture

[2] See appendix 3 for a definition of development

Change (IPCC) has documented a steady increase in the global average temperature due to increased atmospheric concentrations of greenhouse gases (GHGs) (2007). This warming trend is expected to continue, even under various stabilization scenarios, as the effects of past emissions take decades to fully materialize (ibid). In addition to temperature increases, the IPCC has observed changes in global precipitation patterns and rising sea levels; trends that are also expected to continue (ibid). These climatic changes will have varying effects on the Earth's biosphere, including the organization of human civilizations and ecosystems (ibid, p.33). Of particular interest are the projected effects of climate change on Sub-Saharan Africa, a region that already suffers from high temperatures and frequent droughts.

Sub-Saharan Africa[3] (appendix 1) remains one of the least developed regions of the world. All 22 of the countries listed under "Low Human Development" by the United Nations Development Programme's Human Development Index[4] and 70% of the lowest 60 countries are in Sub-Saharan Africa (UNDP, 2007a). While there are many complex reasons for this, it is likely that persistently low agricultural productivity is one (Challinor et al., 2007). Despite this low productivity, agriculture, specifically small-scale rain-fed farming, remains a vitally important sector throughout the region. According to the International Labour Organization, nearly 70% of the region's employed work in

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[3] Following the definition used by the Canadian International Development Agency (CIDA), when speaking of Sub-Saharan Africa, I am referring to countries south of, and including, Senegal, Mali, Niger, Chad, Sudan, Eritrea, and Somalia (see appendix 1 for a complete list and map).

[4] The United Nations Development Programme calculates the Human Development Index which "is a summary composite index that measures a country's average achievements in three basic aspects of human development: health, knowledge, and a decent standard of living. Health is measured by life expectancy at birth; knowledge is measured by a combination of the adult literacy rate and the combined primary, secondary, and tertiary gross enrollment ratio; and standard of living by GDP per capita (PPP US$)" (UNDP, 2007b).

agriculture (ILO, 2007, p.4). Furthermore, although it has declined in recent years, the added value to Sub-Saharan African Gross Domestic Product from agriculture in 2006 averaged 15% overall and was as high as 40% to 60% in the agriculture-based countries[5] (World Bank, 2007b).

The region receives substantial international development assistance in the form of aid and loans from governmental and non-governmental organizations. According to the World Bank, approximately 36%[6] of the population in Sub-Saharan Africa is living below the poverty line of $1 (PPP) per day (2007c, p.48). In addition, approximately 25% of children under 5 years of age are malnourished (as measured by prevalence of children underweight) and 30% of the population is considered below the minimum dietary energy consumption level (ibid, p.49). Agriculture-led development strategies present possibilities to improve this situation.

Given the developmental importance of agriculture, especially in Sub-Saharan Africa, the projected effects of climate change on this sector are of particular interest. In the literature, the link between agriculture and development is well established, as are the projected effects of climate change on agricultural systems. The bridge I wish to build is between these two realms: given the projected effects of global climate change, will agriculture-led development strategies remain viable for the agriculture-based countries of Sub-Saharan Africa?

[5] There will be a special focus on Benin, Burkina Faso, Burundi, Cameroon, Chad, Côte d'Ivoire, Ethiopia, Ghana, Guinea, Kenya, Madagascar, Malawi, Mali, Mozambique, Niger, Nigeria, Rwanda, Sudan, Togo, Uganda, and Zambia, the agriculture-based countries as defined by the World Bank (2007a, p.5), because these countries appear most likely to benefit from agriculture-led development strategies.

[6] This is a rough approximation based on available data from 16 countries. It is likely that the number is greater as there may be a correlation between poverty and a lack of reporting.

2. GLOBAL CLIMATE CHANGE

Human activity since the industrial revolution has increased atmospheric concentrations of greenhouse gases (GHGs), including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (IPCC, 2007, p.37). These gases capture infrared radiation reflected off the Earth's surface and reemit it in all directions, warming the air and returning some to the surface. Increasing levels of GHGs in the atmosphere prevent an increasing amount of radiation from escaping into space. As a result, the Earth's average surface temperature rises. (IPCC, 2007; Pallant, 2007)

Over the history of the Earth (roughly 4.5 billion years), there have been very significant climatic changes (Emanuel, 2007, p.7). The Earth's environment is fragile and unstable, varying significantly with, for example, small changes in its orbit, which "change the distribution of sunlight with latitude" (ibid, p.8). As a result of human activity, "the atmospheric concentrations of CO_2 and CH_4 in 2005 exceed[ed] by far the natural range over the last 650,000 years" (IPCC, 2007, p.37). In addition, "there is *very high confidence*[7] that the global average net effect of human activities since 1750 has been one of warming, with a radiative forcing of +1.6 [+0.6 to +2.4] W/m^2" (ibid). It is likely that this rate of change is the fastest experienced on Earth in the past 10,000 years (Houghton, 2004, p.139-40). This is particularly significant, because ice core data show that, in the past, the climate has reacted unpredictably to slow, steady changes in radiative forcing

[7] The IPCC has various methods to speak of uncertainty. Here, "*very high confidence*" refers to confidence levels of "expert judgment of the correctness of underlying data, models or analyses" of "at least 9 out of 10" (IPCC, 2007, p.27).

(Emanuel, 2007, p.53). "Far from changing smoothly, it remains close to one state for a long time and then suddenly jumps to another state" (ibid).

Small climatic changes since the last ice age were debilitating to early civilizations in Mesopotamia and the Americas (ibid, p.52). It is an understatement to say that things are different in modern civilizations, most notably astonishing technological advances. However, we are still reliant on oxygen, agricultural products, and freshwater for sustenance. It is, therefore, necessary to understand the projected impact of these climatic changes. For a more complete description of the science of climate change and the projected effects, please see appendix 4.

2.1. Projected Effects of Climate Change

The effects of climate change are expected to be significant for the biosphere, including the organization of human civilization. With the observed and projected increases in global average temperatures and changes in precipitation patterns will come a continued rise in sea levels, declining freshwater availability, loss of biodiversity, and increased disease burden. These, in turn, may cause migration, changes in agricultural yields, increased sensitivity to future changes, and, in some cases, increased risk of conflict.

The IPCC has identified four primary storylines to project the magnitude and effects of climate change under various possible future states. The four families of scenarios (called SRES scenarios for the Special Report on Emissions Scenarios (IPCC, 2000)) are A1[8],

[8] The letter (A or B) denotes the relative future emphasis on global integration or regionalization with A implying greater integration and B implying greater regionalization. The number (1 or 2) denotes the relative future emphasis on economic or environmental priorities with 1 implying an environmental emphasis and 2 implying an economic emphasis. (IPCC WGII, 2007, p.32)

A2, B1, and B2 (IPCC WGII, 2007, p.32). These scenarios are simplified categories of possible future paths of social, economic, and technological development. However, they do provide a means of examining a range of plausible future states and the relative impact of variables such as population growth, the speed and direction of technological innovation, the level of economic integration, etc. (ibid). Some scenarios have variations; for example, the A1 family contains three possibilities for the direction of technological change with respect to the source of energy: A1FI assumes a continuation of a "fossil fuel intensive" energy path; A1T assumes broad use of "non-fossil fuel energy sources"; and A1B assumes the source of energy is "balanced across all sources" (ibid).

Since the 1960s, observed and modelled temperatures have diverged from the temperature range projected with only natural forcing models, which means that the observed warming is "*very likely*[9]" a result of human activity (ibid, p.39-40; appendix 5). This warming trend would continue, albeit at a slower pace, even if atmospheric GHG concentrations were immediately stabilized at year 2000 levels, as the effects of existing emissions take decades to fully materialize (ibid, p.46).

Under SRES projections, the range of temperature change by 2100 is 1°C to >6°C relative to the 1980-1999 average (ibid). Best estimates range from 1.8°C for the B1 scenario, 2.4°C for the A1T and B2 scenarios, 2.8°C for the A1B scenario, 3.4°C for the A2 scenario, and 4.0°C for the A1FI scenario (ibid; appendix 6). The effect of increasing temperatures is, and will be, important, especially in polar regions and semi-arid climates on the threshold of desertification such as Africa's Sahel region.

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[9] "*Very likely*" here refers to a likelihood of greater than 90% (IPCC, 2007, p.27).

The effects of warming on ecosystems will be amplified by related changes in global hydrological patterns and cycles. "The twin perils of flood and drought actually both increase substantially in a warmer world" (Emanuel, 2007, p.52). Precipitation patterns are expected to change significantly with some regions experiencing decreases and others experiencing increases (IPCC, 2007, p.47; see appendix 7). In addition to projected changes, there is likely to be an increase in variability and an increase in the frequency of heavy precipitation events, which can be detrimental to crops, cause flooding, contaminate groundwater, increase the risk of respiratory and skin diseases, and obstruct transportation infrastructure (ibid, p.53). Under low to moderate warming, higher latitudes may experience an increase in agricultural yields and arable land (Parry et al., 2004 & 2005). However, at lower latitudes (where most LDCs are located) yields are projected to decrease, especially where crops are rain-fed (ibid). Under higher warming projections, global yields are expected to fall, with negative implications for poverty and global food security (ibid). The projected effects of climate change on agriculture will be discussed in further detail below.

With rising temperatures, extreme events are also expected to occur related to the hydrological cycle. Tropical cyclones are expected to increase in frequency and intensity, as are heat waves, heavy precipitation events, and extended droughts (IPCC, 2007, p.53). These events are expected to have primarily negative effects on agriculture, freshwater resources, human health, and society in general (ibid). Please see appendix 4 for more information on the projected effects of climate change on sea levels, freshwater availability, ecosystems and biodiversity, disease, and the risk of conflict.

2.2. The Interrelationship between Climate Change and Agriculture

In 2004, 13.5% of total anthropogenic GHG emissions occurred because of agricultural activity (IPCC, 2007, p.36). This does not include emissions from deforestation due to agricultural encroachment (considered by the World Bank to be the primary reason for deforestation (2007a, p.17)) as this is included under the forestry sector, which accounted for 17.4% of global anthropogenic GHG emissions (IPCC, 2007, p.36). More specifically, agricultural activity is predominantly responsible for the rise in atmospheric concentrations of CH_4 and N_2O, two of the most potent GHGs (ibid, p.37; World Bank, 2007a, p.201). In addition, deforestation associated with agriculture is a leading cause of reduced CO_2 sequestration (World Bank, 2007a, p.201). Approximately 80% of emissions from agriculture, including deforestation, occur in developing countries (ibid). Therefore, decreasing emissions associated with agriculture provides the most scope for mitigation in developing countries. Ascribing a price to carbon emissions will be particularly helpful in preventing deforestation for agriculture, a very low return activity (ibid). According to the World Bank's *Agriculture for Development* report, "a price of around $27 per ton of CO_2 in carbon markets (comparable to the May 2007 trading price in the European Climate Exchange for 2008-10 carbon allowances) could deter conversion of 5 million square kilometres of forest by 2050" (ibid). This land area is about the size of the Southern Cone[10] region of South America (including Paraguay and Bolivia). In addition to pricing emissions, the World Bank outlines various strategies for decreasing agriculture's footprint, including "agricultural land management (conservation tillage, agroforestry, and rehabilitation of degraded crop and pasture land), overall

[10] The Southern Cone of South America generally refers to Argentina, Chile, Uruguay, and sometimes Paraguay.

improvement of nutrition and genetics of ruminant livestock, storage and capture technologies for manure, and conversions of emissions into biogas" (ibid). Some of these strategies can be implemented with minimal investment, but others will require large-scale investment and research.

In addition to being a major contributor to increasing atmospheric GHG concentrations, global agricultural production will be significantly affected by the result of these emissions, namely global climate change. The net effect on agricultural yields remains uncertain because it depends largely on the extent to which the CO_2 fertilization effect occurs in reality. Under simulated conditions of increased CO_2 concentrations, many plants display "increased rates of photosynthesis" and a reduction in the size of stomatal openings thus reducing "transpiration per unit leaf area while enhancing photosynthesis" and improving "water-use efficiency" (Parry et al., 2004, p.55).

While these simulated results may be encouraging, further research has shown that the degree to which these changes occur depends also on water and nutrient availability (ibid). Furthermore, simulations often do not take into account changes in pest and disease vectors associated with warming, problems of soil salination associated with sea level rise, or crop damage due to extreme weather events (ibid, p.57; Parry et al., 2005, p.2126). Also, most of these studies have been performed on the most common global crops, so the CO_2 fertilization effects on common African crops, such as sorghum, millets, banana, and yam, are poorly understood (Challinor et al., 2007, p.384).

Nevertheless, in models where CO_2 fertilization effects are fully realized, yield reductions due to climate change "diminish by about two-thirds" (Parry et al., 2005, p.2135). However, due to the various factors discussed above, it is expected that the effects of increased concentrations of atmospheric CO_2 will be somewhere between the full-CO_2-fertilization projections and the no-CO_2-fertilization projections (ibid). According to the IPCC, small amounts of warming can increase the CO_2 fertilization effect, but with greater warming, the benefits diminish rapidly (IPCC WGII, 2007, p.276). Their models show yield decreases with even "minimal warming in the tropics"; "mid- to high-latitude crops benefit from a small amount of warming (+2°C) but plant health declines with additional warming" (ibid).

Even with full CO_2 fertilization effects, the percentage difference in yield changes in more versus less developed countries runs from 7.0 (B1a scenario) to 10.4 (A1FI scenario) (Parry et al., 2004, p.64). Broadly speaking, "the world, for the most part, appears to be able to continue to feed itself under the SRES scenarios during the rest of this century. However, this outcome is achieved through production in the developed countries" (ibid, p.53). As we ponder the implications for agriculture-led development in Sub-Saharan Africa, and given the importance of agriculture for the economies of LDCs, the poorest people in LDCs, and the development prospects of LDCs, these findings are very important.

Part of agriculture-led development strategies will be improving the efficiency of agricultural practices (while increasing productivity) to minimize the sector's impact. This is the area where LDCs have the most scope for mitigation, as they are not responsible for the majority of other emissions. While these mitigation strategies are highly important, the more developed countries (MDCs) have much greater scope for mitigation across all sectors with potential for a much greater impact. In addition, one could argue that not only do the MDCs have more scope for impact, but they also face the greatest responsibility, for increases in atmospheric GHG concentrations to date are largely a result of activity in MDCs. Furthermore, "all the world's countries and all the world's leading development institutions" have committed to the millennium development goals (MDGs), two of which are to "eradicate extreme poverty and hunger" and "ensure environmental sustainability" by 2015 (UN, 2008). Unmitigated climate change will render these impossible to achieve. Therefore, in principle, 'all the world's countries' have already committed to combating the worst effects of climate change. Whether this commitment will materialize as action remains to be seen. After examining the role played by agriculture in development, I will focus on the projected implications of climate change for agriculture in Sub-Saharan Africa.

3. AGRICULTURE AND DEVELOPMENT

3.1. History

The advent of agriculture played a key role in the transition between nomadic social organizations, where most members of society were involved in hunting and gathering for sustenance, and more complex civilizations with diversified activities. Agriculture made it so that a portion of the population could manage food production while others were free to pursue other activities. This is thought to have first taken place in the fertile crescent with the town of Jericho (around 7000 B.C.E[11]) and, later, the more complex Sumerian civilization (around 3200 B.C.E) (Kagan, 2006, p.17-24). This key transition was central to the development of what we understand today to be modern civilizations.

More recently, agriculture played a role in the advent of modern nation states. According to Robert Bates, urbanization and an increase in agricultural profitability were central to the formation of states in early modern Europe (Bates, 2001). With the growth of urban centres, farming became more profitable which, in turn, increased the incentive for rural families to invest further in their farms (ibid, p.52-3). In addition to increasing the incentive to invest, the new profitability also increased the incentive to protect them, leading to the "militarization of households" (ibid, p.54). This, however, was expensive which meant that only rural elites could afford to do so (ibid). Eventually this system led to Feudalism (ibid, p.56).

[11] Following the author's notation, B.C.E. refers to before the Common Era. "B.C.E. refers to the same time period as B.C. (before Christ), and C.E. refers to the same time period as A.D. (anno Domini, a Latin phrase meaning 'in the year of the Lord')" (Kagan, 2006, p.12).

Ruling lineages that succeeded in defending and expanding their lands produced monarchs who targeted towns as sources of funds to fuel expansion (ibid). Initially this end was often achieved through plunder and theft; however, this proved less profitable than cooperation (ibid, p.56-7). "Rather than plundering wealth, [the monarchs] had to elicit its creation" by employing the tactics of protection, procurement, and empowerment (ibid, p.58-60). These strategies achieved many things, but most importantly, they (1) increased the profitability of urban manufacturers (ibid), which likely increased the demand for agricultural products; and (2) they exposed the rural farmers to foreign competition (ibid), which likely increased the efficiency of agricultural practices. Subsequently, "in response to demands for peace, monarchs transformed the local order, demilitarizing kinship, co-opting elites, and incorporating local communities into a system that terminated, rather than exacerbated, conflict" (ibid, p.68). The increase in productivity of farms encouraged (and was encouraged by) the rise of urban centres in early modern Europe. This was a key step in the development of kingdoms and, later, states. High agricultural productivity, in terms of high yields per worker or high yields per hectare, is essential to the profitability of farming, the sustainability of rural livelihoods, the wellbeing of urban areas, and the development of societies.

3.2. The Role of Agriculture in Economic Development

Economic development, and development in general, is highly complex. Yet, theoretical and practical research has identified various important factors. For example, according to John Mellor, "the basics of achieving sustainable growth have included … a policy environment that fosters competitive private firms and markets, infrastructure development, broad participation in education, and getting agriculture moving on a broad base" (1998, p.55). Nevertheless, in the mid 20th century, agriculture-led development strategies were questioned because of the observed declining relative importance of the sector as countries developed and because rural life was sometimes seen as traditional or 'backwards' (Timmer, 1998, p.122-3). However, as time progressed, it became clear that, while agriculture is likely not a 'panacea for development' (a phrase used frequently by William Easterly (2001)), it can play a vital role, particularly where agricultural productivity is a limiting developmental factor, as is the case in much of Sub-Saharan Africa. In the mid-1990s, a series of studies by Martin Ravallion and his colleagues showed that, while urban growth brings benefits to the urban poor, it does not have an effect on rural poverty (Ravallion & Datt, 1996 in Mellor, 1998, p.61). Conversely, "rural consumption growth" reduced "poverty in both rural and urban areas" (ibid). While these results were from a study in India, further studies in other locations have substantiated these results (Mellor, 1998, p.61). If growth and increased productivity of the agricultural sector can increase rural consumption, these studies suggest that the benefits, in terms of poverty alleviation, will be felt across rural and urban populations.

According to an important article by Johnston and Mellor (1961) (as referenced by Timmer), agriculture can play a role in economic development in five key areas: "(1) increase the supply of food for domestic consumption, (2) release labor for industrial employment, (3) enlarge the size of the market for industrial output, (4) increase the supply of domestic savings; and (5) earn foreign exchange" (Timmer, 1998, p.123). Growth in agricultural production (via increased land use and/or improved productivity) plays a key role in increasing the supply of food which means more people are free to pursue other activities and thus contribute to general economic growth. In addition, agricultural products can move beyond domestic consumption and become key exports if the global market is receptive to the particular products at their particular prices. Perhaps the key feature that differentiates agriculture from other sectors is the simple fact that we all need to eat. The poor are often required to produce a portion of their own food in order to sustain themselves due to a lack of alternative income sources. Therefore, an increase in agricultural productivity can increase a family's disposable income, which, in turn, can enable them to pursue other income generating activities. I discuss these effects in detail in the next section.

3.2.1. Direct, Indirect, and Participation Effects

According to a World Bank Policy Research Working Paper by Christiaensen et al., "the relative contribution of a sector to poverty reduction" depends on "its direct and indirect 'growth effects' as well as its 'participation effect'" (2006, p.1). Investment in agriculture appears to display both 'direct growth effects' for the agricultural sector and 'indirect growth effects' for other sectors. Furthermore, especially for a region with a high proportion of the poor employed in agriculture, such as Sub-Saharan Africa, it also displays a high 'participation effect', thus increasing the potential for poverty reduction.

There is some evidence to suggest that the agricultural sector grows more slowly than non-agricultural sectors (ibid, p.7-8). As a result, some policymakers have assumed that agricultural development may not be the most effective growth strategy. However, despite slower growth rates, "total factor productivity (TFP) growth in agriculture does not lag behind total factor productivity growth in non-agriculture" (ibid, p.10). Although this conclusion holds for Sub-Saharan Africa, agricultural productivity in this region remains among the lowest in the world. This reinforces the suggestion agricultural productivity may be a limiting factor in Sub-Saharan African development and that investment to increase it may be an effective engine for growth and poverty reduction in the region (ibid, p.11). That said, the agricultural sector also suffers low productivity because of a high disease burden (malaria and HIV/AIDS), population pressure, and limited access to inputs such as fertilizers, irrigation, and improved seed varieties.

In addition to the direct growth effects of agriculture, Christiaensen and his colleagues cited three indirect mechanisms by which growth in agriculture can spur growth in other sectors of the economy from Johnston and Mellor (1961) and Schultz (1964): "inter-sectoral linkages", "final demand effects", and "wage-good effects" (Christiaensen et al., 2006, p.12). To paraphrase, 'inter-sectoral linkages' refers to an increase in up- and down-stream economic activity induced by growth in agriculture; 'final demand effects' refers to the increase in demand for general goods resulting from a prosperous agricultural sector; and 'wage-good effects' refers to the downward pressure on wages due to less expensive agricultural products which, in turn, increases the profitability of other sectors and thus investment (ibid). "Much of this literature argued that the stronger links were from agriculture to non-agriculture rather than the other way around" (ibid). Although these indirect effects were found to be higher in LDCs, they were found to be lower for Sub-Saharan Africa than for other regions, but still positive and significant (ibid, p.17).

Finally, the participation effect suggests that, the more people who participate in the particular sector, the more people will benefit from its growth. This is expected to occur as a result of spatial proximity, direct employment, and growth in value of related assets (ibid, p.20). Echoing the definition of development (appendix 3), various studies show that landlessness, low levels of education, poor access to services, and inequality, in general, depress the ability of the poor to gain from agricultural growth (ibid, p.21-2).

Christiaensen et al.'s statistical analysis confirmed that growth in the agricultural sector has a greater impact on poverty reduction than does growth in non-agricultural sectors when poverty is measured by the headcount index (9 times greater) and the poverty gap index (7 times greater) (ibid, p.23-4). Although the squared poverty gap index produces a similar result (6 times greater), these results are not statistically significant (ibid). They conclude that, "while both agricultural and non-agricultural growth offer scope for extreme poverty reduction in middle-income countries, it is only agricultural growth that appears to affect the poorest in the low-income countries" and that "in [Sub-Saharan Africa] two thirds of the predicted poverty change could be attributed to agriculture" (ibid, p.27-32). The participation effect alone appears to cause agriculture to effect poverty reduction 2.2 times more than from non-agriculture (ibid, p.34). While these results suggest that investment in agriculture is an effective means of poverty reduction, a goal closely associated with development in Sub-Saharan Africa, there are also concerns that with recent trade liberalization, the full indirect and participation effects may not be realized because products can be imported more readily (ibid, p.31).

3.2.2. Agriculture-Based Countries

According to the World Bank's *Agriculture for Development* report, increased productivity in the agriculture sector has the most scope for development and poverty alleviation among 'agriculture-based countries', defined as those countries with high contributions to growth from agriculture and high levels of rural poverty (World Bank, 2007a, p.5). As well as those agriculture-based countries in Sub-Saharan Africa listed above, other examples include Nepal, Papua New Guinea, Paraguay, and Syria (ibid). For reference, 'transforming countries'[12] are those with low contributions to growth from agriculture and high levels of rural poverty; 'urbanized countries'[13] are those with lower contributions to growth from agriculture and lower rates of rural poverty (ibid).

In Sub-Saharan Africa, 82% of the rural population lives in agriculture-based countries (ibid, p.4). The *Agriculture for Development* report identified two arguments for why agriculture-led development strategies are important and viable, particularly for agriculture-based countries, besides simply the number of people involved in the sector and its relative size in the economy (ibid, p.6). The first is that because of poor access to markets and high transaction costs, much of the food produced in these countries is for domestic consumption (ibid, p.7). "Agricultural productivity determines the price of food, which in turn determines wage costs and competitiveness of the tradable sectors" (ibid). Therefore, growth in agricultural productivity is "key to growth" (ibid). The second argument is that agriculture-based countries are likely to have a competitive advantage in primary production and extractive activity, such as agriculture, for some time to come (ibid). As a result of "multiplier effects", growth in agriculture "induces strong growth in other sectors of the economy" (ibid). This pattern was witnessed in early modern Europe, as discussed above, and, more recently, in countries that have moved from agriculture-

[12] Examples of transforming countries are China, Egypt, Vietnam, and Tunisia (World Bank, 2007a, p.5).

[13] Examples of urbanized countries are Brazil, Hungary, Malaysia, Mexico, Philippines, Poland, South Africa, and Venezuela (World Bank, 2007a, p.5).

based to transition, such as China, India, and Vietnam (ibid). Increased agricultural productivity played a key role in inducing growth in the manufacturing and industrial sectors (ibid).

3.2.3. Using Agriculture for Development

In addition to showing that growth and productivity in agriculture can be an effective approach to development, especially for agriculture-based countries, the *Agriculture for Development* report also identified specific tools or strategies for how to do so. In line with the finding by Christiaensen and his colleagues that investment and growth in agriculture decreases poverty more effectively in more equal societies (2006), the first strategy suggested by the World Bank is to improve the asset position of the rural poor, in terms of real assets (land), resource assets (water), and human assets (education, skills) (2007a, p.9). The report identifies Sub-Saharan Africa as the region with the most severe asset deficiencies such as small farm size from high populations, significant environmental degradation, low technology agricultural production (most often without irrigation), and considerable challenges for health and education (ibid). Markets are required to facilitate the transfer of land to the most efficient users while enabling a diversification of livelihood activities (ibid). In addition, a key constraint to increased yields and yield stability is the availability of water for irrigation (ibid). The vast majority (96%) of land under production in Sub-Saharan Africa is rain-fed which means it is highly vulnerable (ibid), especially to increasing rainfall volatility from climate change. Furthermore, education is vitally important to enable farmers to also engage in non-farm market activities and eventually migrate away from agriculture; rural education remains very low across the world (ibid). Finally, poor health indicators from malnutrition and disease negatively impact productivity across the entire economy, and especially in agriculture. In fact, "the majority of people affected by HIV work in farming" (ibid, p.10) and malaria is correlated with lower economic growth (Gallup & Sachs, 2001). However, widespread epidemics like HIV/AIDS may, in the long run, have a positive effect on agricultural productivity (Pereira, 2008). In areas with very high prevalence rates, populations may decrease which could increase the average farm size, a potential limiting factor. This will certainly not be without difficulty as the majority of people affected are working age adults. However, as prevention strategies and orphan care increase in effectiveness, a new generation of farmers may grow up to cultivate larger plots.

The second major strategy is to improve the productivity and sustainability of small farms (World Bank, 2007a, p.10). The key ways to do this are increasing the incentive to invest, improving access to markets and credit, encouraging organization and cooperation, and inducing scientific innovation (ibid). An important way to encourage investment is through the liberalization of markets, particularly in the MDCs of North America and the European Union (ibid, p.11). This would allow something closer to true competition, for currently, those LDCs that have reduced trade barriers for agricultural products are challenged by subsidized products from MDCs. In addition, improving access to markets through infrastructure and exchange fora for common agricultural goods as well as higher-value products can bring important benefits to the rural poor (ibid, p.12). Furthermore, financial, insurance, and credit markets have the power to increase investment in inputs such as fertilizer or irrigation, smooth rural consumption to cope with volatility, and mitigate the risk of shock (ibid, p.13-4). Producer organizations can be an effective way for smallholder farmers to advance common interests, reduce transaction costs, and call for political and institutional change (ibid, p.14). Finally, investment in technological innovation specific to local conditions is of vital importance in increasing agricultural productivity (ibid).

The third strategy is to enable the diversification of livelihoods and even the transition into non-agricultural economic activities (ibid, p.18). "With rapidly growing rural populations and declining farm sizes [in Sub-Saharan Africa], the rural employment problem will need to be addressed" in the near future (ibid, p.17). Encouraging non-farm rural economic activities is an important way to diversify the income sources of the rural poor. In addition, social programs designed to mitigate risk can increase efficiency and wellbeing (ibid). Guarding against shocks and supporting the elderly while not decreasing the incentive to work can be key strategies for improving the wellbeing of the poor.

3.3. The State of Agriculture in Sub-Saharan Africa

Sub-Saharan Africa remains one of the few regions of the world where significant advances in agricultural productivity have yet to occur. Although the sector accounts for at least an average of 15% of the region's GDP (much more in several countries) and employs approximately 70% of the region's workers, it has received relatively little attention since the 1960s. "Small-scale farmers predominate in a climate of increasing population pressure, food insecurity, very low (and declining) levels of agricultural productivity and rapid natural resource degradation" (Beintema & Stads, 2004, p.239). Following independence, many Sub-Saharan African countries invested significantly in agricultural research in order to address these challenges. However, since the end of the 1960s, there has been very little growth in research funding (ibid, p.245). In fact, research expenditure decreased from 2% in the 1970s to 0.8% in the 1990s (and to only 0.3% if the two largest investors, South Africa and Nigeria, are omitted) (ibid, p.241).

Governments and international development agencies have failed to resolve this issue. According to John Mellor, although food production is a "first-generation problem," development efforts in Sub-Saharan Africa bypassed agricultural development for other necessary, but second-generation, problems such as poverty alleviation, environmental protection, and the empowerment of women (1998, p.65). This is particularly apparent when comparing Sub-Saharan Africa to Asia where the agricultural sector got moving before attention was diverted to other issues. "The laggard countries are still largely agricultural, with weak institutional structures for agricultural growth and limited human resources" (ibid, p.62). Nevertheless, recent years have seen the re-emergence of agricultural investment as a recognized priority by some in the international development community (World Bank, 2007a). It remains to be seen whether this renewed focus will improve the situation, especially given the increasing challenges of climate change.

4. IMPLICATIONS OF CLIMATE CHANGE FOR AGRICULTURE

4.1. Projected Impacts in Sub-Saharan Africa

Agriculture in Sub-Saharan Africa is a sensitive and vulnerable sector, even without global climate change. The region suffers from poor soil quality, periods of prolonged droughts and floods, pest and disease stress, and limited access to inputs such as irrigation, fertilizer, and improved seed varieties (IPCC WGII, 2007, p.439). Based on data since the 1980s, despite recent increases, rain-fed cereal yields in Africa "are 0.8 tons/ha, which is 0.4 tons/ha below the lowest figure for any other region" (Cooper, 2004 in Challinor et al., 2007, p.387). Combined with poor access to markets due to limited infrastructure and insufficient institutional arrangements, this means that the population is generally reliant on domestic production, which is often inadequate to ensure food security. In general, climate change is expected to exacerbate this situation with rising temperatures, changing precipitation patterns, increased climatic variability, increased frequency and intensity of extreme events, and rising sea levels.

According to the IPCC scenario A1B[14], it is clear that Sub-Saharan Africa will experience a general warming trend across the West, East, and Southern regions (IPCC WGI, 2007, p.854). By the end of this century, West Africa is likely to warm an annual average of 1.8 to 4.7°C, East Africa by 1.8 to 4.3°C, and Southern Africa by 1.9 to 4.8°C

[14] The A1 scenario "assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies" (IPCC, 2007, p.44). The A1B scenario follows the same assumption, but also assumes that technological advancement is balanced across fossil-based and alternative energy sources (ibid).

(ibid; IPCC Table 11.1). Much less certain are the changes in rainfall. West Africa is projected to experience a change in precipitation of -9% to +13%, East Africa -3% to +25%, and Southern Africa -12% to +6% (ibid). Areas of more certainty are significant wetting in East Africa from September to May and significant drying in Southern Africa from June to November (ibid). Other seasons in these two regions remain variable, as do projections for West Africa (ibid).

Maize, wheat, and rice yields at low latitudes are all expected to decrease sharply with warming. Without adaptation, maize yields will drop by 5 to 30% with 1 to 3°C of warming, and 50% or more with 5°C of warming (IPCC WGII, 2007, p.286). With adaptation strategies, including irrigation, these yield losses can be greatly minimized (ibid); however, the capacity of farmers to implement irrigation under conditions of increasing water stress[15] is unknown. Wheat yields at low latitudes will also drop by 0 to 40% with 1 to 3°C of warming, and 50% with 5°C of warming (ibid). Again, adaptation strategies can decrease, and in some cases overcome, these decreases with 1 to 3°C of warming, but, even with adaptation, above 3°C, yields drop sharply (ibid). Finally, rice yields are more stable under warming scenarios, but without adaptation, are likely to drop by 10% with 1 to 3°C of warming, and 10 to 40% with 5°C of warming (ibid). Adaptation appears to overcome the most significant decreases under less than 3°C of warming (ibid). At higher warming projections, the range with adaptation is from a decrease of 25% to an increase of 40% (ibid), suggesting significant variability, which can be as harmful as, or more harmful than, steady decreases.

[15] See appendix 4 for more information on projected freshwater stress.

These changes will have significant implications for smallholder livelihoods and country-level economies. In a preliminary analysis, Mendelsohn and his colleagues estimated agricultural losses in the Saharan region to be 2 to 7% of GDP by 2100, 2 to 4% in Western and Central Africa, and 0.4 to 1.3% in Northern and Southern Africa (in IPCC WGII, 2007, p.447). These losses are significant, yet not devastating in magnitude, especially given the uncertainty of future growth and development. Nevertheless, the majority of projections use steady changes and do not consider the projected increase in volatility and extreme events. In addition, by the 2080s, the land area considered arid and semi-arid "could increase by 5-8% (60-90 million hectares)" which will have significant implications for agricultural production in currently marginal areas (IPCC WGII, 2007, p.448). "Wheat production is likely to disappear from Africa by the 2080s" and "Southern Africa would be likely to experience notable reductions in maize production" (ibid). In terms of percentage of arable land, wheat production is particularly important in Eritrea (7%), Ethiopia (14%), Lesotho (9%), Rwanda (1%), and Tanzania (2%) (FAO, 2008). Similarly, in Southern Africa, Angola, Lesotho, Mozambique, Swaziland, and Zimbabwe all cultivate maize on over 20% of their arable land (up to 40% in the smaller countries and 30 to 35% in Zimbabwe and Mozambique, respectively) (ibid). South Africa and Botswana also cultivate significant areas of maize (6 and 13% respectively) (ibid). Projected yield decreases will have significant consequences for rural livelihoods and national GDP in these countries.

Other studies that include existing risk factors that are likely to be exacerbated by climate change project yield deficiencies from rain-fed agriculture to be up to 50% between 2000 and 2020 (IPCC WGII, 2007, p.448). Nevertheless, some areas may experience increased cereal yield potential under low and short-term warming projections and full CO_2 fertilization effects, such as Kenya (Parry et al., 2005, p.58-61) and "parts of the Ethiopian highlands and parts of southern Africa such as Mozambique" (IPCC WGII, 2007, p.448). On the other hand, some areas, such as Nigeria, may experience significant cereal yield decreases, even under limited warming and full CO_2 fertilization effects (Parry et al., 2005, p.58-61).

Using the IPCC's A2[16] scenario and different climate models, Günther Fischer and his colleagues developed projections for the percentage change in "potentially attainable cereal output… in the 2080s" (Fischer et al., 2005, p.2077). The results vary with the climate model used. The CGCM2[17] model, projects yield decreases of 25% to >50% in the Sahel region along the southern edge of the Sahara Desert, in eastern and southern Ethiopia, northern Kenya, parts of Tanzania and Uganda, southern Angola and Zambia, northern Namibia and Botswana, much of Zimbabwe, southern Mozambique, and eastern South Africa (ibid). Yield changes of +5% to -5% are expected for much of West Africa while increases of 5% to >50% are expected for much of the Democratic Republic of the Congo (DRC), northern Zambia, eastern Madagascar, central Angola, western Ethiopia, northern Mali, and along the southern border of the Sahara through the south of Niger, the middle of Chad, and into eastern central Sudan (ibid).

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[16] "The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines." (IPCC, 2000, p.5)

[17] Version 2 of the Canadian Global Coupled Model, described in Flato et al. (2000).

The CSIRO[18] model, projects cereal output to decrease by 25% to >50% along the entire southern edge of the Sahara (with no sliver of increase as projected in the CGCM2 model), in southern and western DRC, much of Mozambique and Malawi, parts of central Angola, north-eastern Namibia and northern Botswana, northern Zimbabwe, parts of central Zambia, and eastern South Africa (ibid). Areas of output increase in the range of 5% to >50% include much of Cameroon, Gabon, Congo, northern and central DRC, western Ethiopia, Kenya, northern Tanzania, north western and central Angola, and parts of Guinea, Liberia, and the Côte d'Ivoire (ibid).

The HADCM3[19] model projects output decreases of 5% to >50% along the western part of the southern edge of the Sahara, western and southern Angola, northern Namibia and Botswana, much of Zimbabwe, southern Mozambique, eastern South Africa, and south western Madagascar (ibid). Output changes of +5% to -5% are projected to occur through much of west and central Africa (ibid). Increases of 5% to >50% are projected to occur in much of Angola, Congo, Gabon, southern Cameroon, parts of central DRC, central Kenya, much of Tanzania, and the central part of the southern edge of the Sahara (ibid).

Finally, the ECHAM4[20] model projects output changes of +5% to -25% through much of western and central Africa (ibid). Decreases of 25% to >50% are projected for western Angola, northern Namibia and Botswana and central Mozambique (ibid). Increases of 5% to >50% are projected for northern Mali, the central region along the southern edge of the

[18] Australia's Commonwealth Scientific and Industrial Research Organization
[19] Version 3 of the Hadley Centre Coupled Model
[20] From the European Centre for Medium Range Weather Forecasts; described in Roeckner et al. (1996)

Sahara, central Angola, southern Mozambique and Zimbabwe, northern Tanzania, parts of Kenya, and eastern Madagascar (ibid).

In an important study regarding the effects of climate change on maize production in Africa (and Latin America) in 2055, Peter Jones and Philip Thornton found that, in aggregate, the region can expect a 10% decrease in production by 2055 (2003, p.57). While this is certainly significant, they suggested that "it can reasonably be expected that this level of decrease will be compensated for by plant breeding and technological interventions in the intervening period, given the history of cereal yield increases since 1950" (ibid). On the other hand, these aggregate findings mask significant regional variation implying farmers in some regions may increase production while others may be forced out of agriculture all together (ibid). In addition, the maize crop is "remarkably tolerant of high temperatures", yet other important products, such as beans, are more sensitive to temperature increases (ibid). While farmers can shift production to more heat tolerant crops, this may lead to a decrease in nutrient variety available, especially in regions not well connected to regional and international markets. Finally, many studies show that the impact of climate change on crop yields is moderate through mid-century, but becomes more significant and negative towards the latter part of the 21st century (Parry et al., 2005).

In general, countries expected to lose cereal production by the 2080s, regardless of emissions scenario, are Angola, Burkina Faso, Chad, Ethiopia, Mali, Mozambique, Niger, Nigeria, Senegal, Sierra Leone, Somalia, Sudan, and Zimbabwe (Fischer et al., 2005, p.2075). This is particularly concerning as these countries are home to approximately

45% of the total number of undernourished people in Sub-Saharan Africa (ibid). In contrast, Benin, Côte d'Ivoire, DRC, Ghana, Guinea, Kenya, Madagascar, Tanzania, Togo, and Uganda are expected to experience increases in cereal production under all scenarios (ibid). These countries are home to approximately 38% of the undernourished people in Sub-Saharan Africa (ibid). More specifically, under the A1FI climate model, with the highest warming projection, Fischer and his colleagues found that in Southern Africa, 55% of land is in 'impact classes' of -50% to -100% and 76% of land is in negative impact classes (ibid, p.2076). Global emissions are currently higher than the A1FI (highest) scenario (Raupach et al., 2007, p.10289).

The majority of these studies do not consider the effects of increased pest activity, changes in plant (and human) disease vectors, increased occurrence of extreme weather events, raised sea levels, and increased climatic variability (as opposed to change). These factors will be more or less important in different areas; however, it is important to keep them in mind as they are likely to further decrease agricultural productivity in some regions and may prevent increases in others.

Changes in production potential across Sub-Saharan Africa will have significant implications for the development of the region. That said, various adaptation strategies have been suggested to dampen the effects of climatic change on agricultural production.

4.2. Adaptation Strategies

In the past, farmers have shown remarkable adaptability to climatic challenges (Challinor et al., 2007, p.381). However, the rate of climatic change is expected to be faster than any other experienced in the past 10,000 years (Houghton, 2004, p.139). Furthermore, the atmospheric concentration of GHGs (closely associated with temperature) is already higher than any other time in at least the past 650,000 years, and is growing rapidly (Emanuel, 2007, p.60). Finally, "past emissions of greenhouse gases have already committed the globe to further warming of ~0.1°C per decade for several decades" (Howden et al., 2007, p.19691). Therefore, it is unlikely that historical adaptation strategies will be sufficient to avert the worst effects of climate change.

There is significant scope for advancement in current agricultural practices in Sub-Saharan Africa. As stated above, the region displays the lowest yields in the world, relies on rainfall for 96% of land in production (World Bank, 2007a, p.9), struggles with small farm sizes, and suffers from insufficient access to irrigation, fertilizers, pesticides, herbicides, and improved seed varieties. In fact, a study of three regions: Mangondi village South Africa, Gireigikh rural council in Sudan, and Chingowa village in Nigeria, noted that current "climate variability alone does not determine vulnerability to climate change" (Ziervogel et al., 2008, p.189). Other socio-economic and livelihood factors, such as "input price, household income, income diversification, belonging to local community institutions, and disintegration of social fabric", play very important roles as well, as do "the size of landholding cultivated, the labour per hectare of farm land, poor health services, and participation in off-farm employment" (ibid, p.190). Furthermore, "household factors played a more dominant role" among all case studies and "appeared to have the largest influence on vulnerability to food insecurity" (ibid). This may change as climate change progresses, yet agriculture-led development strategies will work to address these constraints in order to improve productivity and move towards poverty reduction.

Drawing on Ellis (2000), Challinor and his colleagues identified three main threats to which rural livelihoods are vulnerable: "shocks", "seasonal variations", and "long term trends" (2007, p.388). The above analysis regarding the projected effects of climate change suggests that all three are likely to increase. Extreme events, or 'shocks', such as tropical storms and disease, 'seasonal variations', including droughts and floods, and 'long term trends', such as increases in average temperature and changes in average rainfall, are all expected to increase in frequency and intensity.

Parry and his colleagues identified two levels of adaptation (2005, p.2128). The first does not require "major changes in agricultural practices" and includes "changes in planting date, amounts of irrigation and the choice of crop varieties that are currently available" (ibid). The second level includes, in addition to the above adaptations, "major changes in agricultural practices, such as large shifts of planting date, the availability of new cultivars, extensive expansion of irrigation and increased fertilizer application" (ibid). I include in these more significant adaptation strategies substantial changes in formal and informal institutional arrangements that allow improved access to regional and global markets, changes in land tenure norms and farm sizes, diversification (in whole or in part) into non-agricultural livelihoods, and increased access to insurance and social services. As many level 1 adaptation practices are already being implemented, most of the strategies suggested below are level 2.

4.2.1. Adapting to Shocks

Shocks can be weather-related or otherwise. Examples of weather-related shocks include droughts, floods, cyclones, and heat waves. Examples of other shocks include illness or death of primary income generator, political or social unrest, and violent conflict. Adaptation strategies designed to guard against one type of shock will often be effective against other types, given the nature of a shock's effect: usually a decrease in earning capability and/or a loss of livelihood or food production. Generally, level 2 adaptation strategies are required to guard against such shocks. Insurance and social safety nets can be effective in dampening the impact of a shock at the household level, if these services are available and accessible. These services can prevent stochastic poverty from becoming structural (Carter & Barrett, 2006). In other words, if a household must liquidate their asset base in order to compensate for a loss in income (shock), poverty can become structural because the household has, in effect, been forced to consume their asset base. However, if insurance or social services can compensate for the loss in income, the household may experience a period of stochastic (or temporary) poverty, but will more likely be able to maintain its asset base, and thus have a better chance of recovering.

In addition to insurance and social services, and perhaps more easily implemented, "community management of natural resources" can also be an effective means to dampen the effects of a shock (Challinor et al., 2007, p.390). This can strengthen community networks, which can act as a social safety net in the event of a shock while "retaining the resilience of the underpinning resources and ecological systems" (Tompkins & Adger, 2004 in ibid).

Although these community-based adaptation strategies may be effective under certain circumstances, evidence from drought shocks in the 1970s and 1980s "have shown that the adaptation abilities of many individual farmers and communities do not extend to coping with such extreme events in absence of outside support" (ibid, p.389). As a result, public, private, and international investment in insurance and social services will be an important aspect in coping with current and future climate (and other) shocks.

4.2.2. Adapting to Variability

Increasing climatic variability can often pose a more significant threat to agriculture than steady changes. Of particular importance to agriculture in Sub-Saharan Africa is variability in rainfall. Nearly all crops in the region are rain-fed and so yields are at the weather's mercy. One of the best ways to mitigate this increased risk is the irrigation, which can occur on small (level 1) or large (level 2) scales. Shocks, such as floods, can still be detrimental for soil quality, yields, and disease; however, erratic seasonal rainfall patterns will have less effect with irrigation.

Despite the clear benefits of irrigation, it has been, and will continue to be, difficult to implement broadly in Sub-Saharan Africa due to limited state resources, small farm sizes, and pressure on freshwater sources (appendix 4). Due to projected effects of climate change and population pressure, Sub-Saharan Africa is expected to experience an "alarming increase in water scarcity" with 20 countries[21] expected to experience water scarcity or stress by 2025 (UNEP, 2000, ch.2, Africa, freshwater). UN-Water identified

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[21] The 20 countries identified as likely to experience water scarcity or stress by 2025 are Burkina Faso, Burundi, Cape Verde, Comoros, Eritrea, Ethiopia, Ghana, Kenya, Lesotho, Malawi, Mauritius, Niger, Nigeria, Rwanda, Somalia, South Africa, Tanzania, Togo, Uganda, and Zimbabwe (UNEP, 2000, ch.2, Africa, freshwater).

"markets, commodity selection, ownership, land tenure, water storage for reliable supply, and international agreements on water allocations within river basins" as important for increasing the irrigation potential for African agriculture (2007, p.19).

In general, and especially for areas where barriers to irrigation are preventive, Howden et al. suggested "wider use of technologies to 'harvest' water, conserve soil moisture, and use and transport water more effectively where rainfall decreases" and "managing water to prevent water logging, erosion, and nutrient leaching where rainfall increases" (2007, p.19693). In addition, Challinor et al. identified "cropping practices that are often used to mitigate the effects of variable rainfall" such as mixing crops with different climate sensitivities, using local varieties adapted to variability, using left-over plant matter to bolster the soil's water retention capacity, planting "starvation-reserve crops", and employing water conservation tactics such as those described above (2007, p.388). While these strategies will dampen the effects of climatic variability, they are unlikely to be sufficient to guard against prolonged droughts or other extreme weather events, especially when these damage biodiversity and seed reserves (ibid).

4.2.3. Adapting to Long-Term Trends

In addition to adapting to shocks and increased variability, households and countries of Sub-Saharan Africa will need to adapt to long-term climate trends that have been set in motion and will continue, even after stabilization of atmospheric concentrations of GHGs. Long-term adaptation strategies will include improving the capacity of regions and nations to trade so that those with increased production potential can export to those with decreased potential, developing climate forecasting capacity, improving access to inputs, diversification of livelihoods away from the agricultural sector, and migration.

It is clear that future trends in trade liberalization, especially of agricultural products, will play a significant role in the course and rate of global development. Of particular importance, given the projected effects of climate change for agricultural production, will be improving the infrastructure and institutions required to connect rural Africans to regional and global markets. In order for trade in foodstuffs to enable regional and global redistribution of production, these markets must be well functioning and efficient. Although, many African nations rely on domestic farming, this does not have to be so (ibid, p.390). Trade in agricultural products can play a role in increasing food security under appropriate policy and where those negatively affected have options for income generation to enable the purchase of food in place of subsistence production. However, "a downturn in prices due to liberalisation of markets makes it even harder for farmers who are already trying to cope with climate variability and change to maintain their farms and their livelihoods" (ibid).

Developing and improving short- and long-term climate forecasting capacity can also play a role in helping farmers adapt to future climate trends. While some progress has been made on this front, much is yet to be improved (Archer et al., 2007). Archer and her colleagues studied various climate prediction programs in Southern Africa and surveyed local farmers to determine whether these programs were useful and how they might be improved. They discovered two primary areas for improvement to increase the effectiveness of climate projection: "forecast improvement" and "increased national and non-traditional investment in outreach and applications" (ibid, p.295-7). Ways to improve forecasts included increasing spatial resolution, improving timeliness, and tailoring forecasts to local needs (ibid, p.295-6). Increasing investment and outreach can be accomplished by including "non-traditional" stakeholders in regional and national meetings to determine forecast-related policy and direction (ibid, p.297). These improvements in forecasting are particularly important for tropical areas like Sub-Saharan Africa, as correlations between simulated and actual crop yields (based on climate models) are lowest in tropical regions (Parry et al., 2004, p.54).

Improving access to inputs is also an important strategy for improving agricultural productivity in the long-term. This is primarily a problem of household and national poverty as fertilizers, pesticides, herbicides, and improved seed varieties can be expensive. In addition, African smallholders do not provide a sufficient level of market demand for most private enterprise to develop products tailored to their needs. As a result, public and not-for-profit investment at the national and international level will play a vital role in this process. However, developing tailored products is limited in its capacity to assist with adaptation because "there is at least a twenty-year lag between initiating strategic research and any resulting significant increases in production in farmers' fields" (McCalla, 1998, p.53). In order for these strategies to be effective, they must be undertaken with anticipation of projected future conditions, for the rate of change is such that 20 years may render improved inputs obsolete before they can be implemented.

A long-term adaptation strategy for many rural smallholders may be to diversify their livelihoods away from agricultural activity, in whole or in part. According to Deborah Bryceson, "diversification out of agriculture has become the norm among African rural populations" (2000). While this will likely continue to be an important adaptation strategy, especially as countries industrialize, it is highly unlikely that agricultural activity will stop being vital to rural livelihoods and food security "for some time to come as the population in Africa undergoes a three-fold increase this century" (Challinor et al., 2007, p.390). I will discuss this further in the *Agriculture-led Development* section.

Finally, another long-term adaptation strategy for families that do not wish to migrate to urban centres may be to migrate to rural areas in other countries that have not experienced devastation from climate change or that have even increased productivity. This will be more viable in areas with more liberal migration policies and where areas negatively affected are in close proximity to areas minimally or positively affected.

4.2.4. Development as Adaptation?

In an important piece by Richard Tol, he suggested that "there are two ways of reducing vulnerability to climate change: economic growth and greenhouse gas emission reduction" (Tol, 2005, p.615). As discussed above, part of the reason Sub-Saharan Africa is particularly vulnerable to the effects of climate change is because of low development indicators. It therefore appeals to reason that spending on development efforts may rival climate change mitigation in effectiveness. Using econometric analysis, Tol finds that, only in Africa, "a dollar invested in emission reduction is worth less than a dollar invested in development" between 2000 and 2009 (ibid, p.622). As we are already nearing the end of the period studied, we must be careful in assuming that these results will hold for the coming decades as the effects of climate change increase in magnitude. In addition, while spending on development is important for increasing the adaptive capacity of less developed regions, emission abatement is a long political process. We have seen that, despite considerable effort, global emissions continue to exceed the worst SRES scenarios (Raupach et al., 2007, p.10289). In other words, waiting until emission abatement is more cost effective than development may forgo the opportunity to mitigate emissions on a sufficient scale to avert the worst impacts of climate change that we are unlikely able to adapt to.

In addition, if the focus is to be on development as a means of adaptation, these development efforts will have to include the projected effects of climate change. In a recent report for the OECD[22], Shardul Agrawala and his colleagues found that much development spending is "directed at activities potentially affected by climate risks" – 50-65% in Nepal and 12-26% in Tanzania, for example (2005, p.16). Therefore, adaptation must be integrated into "the development mainstream" by "making climate change information more useful and easier to use, focusing more on implementing climate change and development strategies, and increasing co-ordination between development and climate change policies" (OECD, 2006, p.5). A key component of improving the relevancy and usability of climate change information is in the conveyance of uncertainty (ibid). A reduction in uncertainty is not necessarily feasible, but the parameters can be conveyed so as to be easily incorporated into specific development

[22] *Bridge Over Troubled Waters: Linking Climate Change and Development*, for the Organization for Economic Co-operation and Development (OECD)

projects (ibid). In addition, methods for screening development projects for climate change sensitivity must be developed so development agencies can accurately analyze their projects and determine what level of climate sensitivity they must account for (ibid). Environmental assessments need to be broadened to include the potential environmental effects on a project as well as vice versa (ibid). Methods required to implement these strategies already exist, and it is critical that they be incorporated into development activities (ibid, p.6). Finally, encouraging coordination to share discoveries and best practices among climate researchers and development institutions can make a significant contribution to successfully incorporating adaptation into development efforts (ibid).

4.2.5. Technological Innovation

A significant area of uncertainty regarding the adaptation potential of agriculture in Sub-Saharan Africa is technological innovation. Notwithstanding the 20 year lag between research initiation and improvements on the ground (as mentioned above), in the past, technological innovation has enabled vast increases in production capacity. Vernon Ruttan and Yujiro Hayami have developed an "induced innovation model of agriculture development" in which technological innovation "is treated as endogenous to the development process, rather than as an exogenous factor that operates independently of other development processes" (1998, p.163). They identified two types of innovations common to agriculture: "mechanical technology" (labour saving) and "biological and chemical technology" (land saving) (ibid, p.164). Essentially, they suggested that, similar to the Hicksian *Theory of Wages* (Hicks, 1932, p.124-5), the factor of constraint (land or labour) will determine the direction of technological innovation (Ruttan & Hayami, 1998, p.164). The examples they used are Japan and Taiwan, where the factor of constraint was land, so land-saving technology was developed in the form of fertilizers, and high-yield crop varieties; and Canada and the United States, where the factor of constraint was labour, so mechanical technology was developed to allow fewer people to cultivate more land (ibid).

Ruttan & Hayami are quick to assert that, although the factor of constraint determines the direction of technological innovation, state policies also play a central role (ibid, p.172-3). In particular, the allocation of resources to innovation, input production capacity, market linkages, and the organization of agricultural production all "must be consistent with national (or regional) resource endowments if they are to lead to an 'efficient' growth path" (ibid). In addition, both the private and public spheres have important roles to play in these technological innovations that are so vital to the sector's growth (ibid, p.174). "Economic growth ultimately depends on the flexibility and efficiency of society in transforming itself in response to technical and economic opportunities" (ibid, p.172).

Under the projected effects of climate change for agriculture in Sub-Saharan Africa, and given these opportunities for and constraints to various adaptation strategies, what is the prognosis for agriculture-led development in Sub-Saharan Africa?

5. AGRICULTURE-LED DEVELOPMENT?

As discussed above, agriculture has unique direct, indirect, and participation effects on poverty reduction, which is a primary goal of development. For this reason, in recent years there has been a renewed focus on agriculture as an especially important sector in which to invest, increase productivity, and encourage innovation. However, given the implications of climate change and the possible adaptation techniques discussed above, will these strategies remain viable for Sub-Saharan Africa's agriculture-based countries?

Using a survey of over 9,000 farm households in 11 African countries[23], Pradeep Kurukulasuriya and his colleagues determined the revenue elasticities of temperature and precipitation changes for rain-fed crops, irrigated crops, and livestock (2006, p.367). They found that "dryland crop revenue falls an average of $27 per hectare per 1° Celsius increase in temperature, whereas irrigated crop revenue increases an average of $30 per hectare per 1° Celsius" (ibid, p.378). This is a strong argument for increasing irrigated land area where access to water is sufficient. Yet, changes in precipitation patterns and extreme events associated with temperature increases must also be considered.

Very significantly, "livestock net revenue falls by an average of $379 per farm per 1° Celsius" (ibid, p.379). This poses a particular challenge for smallholders who rely on their livestock asset base to prevent changes in income generating capacity from pushing them into structural poverty (Little et al., 2006).

[23] The 11 countries in which surveys were conducted were Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Niger, Senegal, South Africa, Zambia, and Zimbabwe (Kurukulasuriya et al., 2006, p.374).

A marginal change in average monthly precipitation of 1 millimetre increased farm revenue by $1.66 per hectare for rain-fed crops and $2.98 for irrigated crops (Kurukulasuriya et al., 2006, p.379). Livestock revenue per month increases by $15 with a 1 millimetre increase in average monthly precipitation (ibid). These results do not consider the increase in rainfall variability and extreme weather events projected with climate change. Nevertheless, where increases in precipitation can be harnessed to the benefit of agriculture and where precipitation extremes do not decrease soil nutrients and increase pest and disease prevalence, there may be agricultural benefits.

In general, "the temperature elasticity is -1.9 for dryland crops and 0.5 for irrigated crops" and -5.4 for livestock (ibid)[24]. "Precipitation elasticity is 0.1 for irrigated crops, 0.4 for dryland crops, and 0.8 for livestock" (ibid, p.380). Irrigated crops are already more productive and so experience a smaller marginal increase in revenue with increased precipitation. Rain-fed crops, on the other hand, generally display low productivity, hence, the larger marginal increases with precipitation. From these results, we see that revenue is generally more sensitive to changes in temperature than precipitation.

5.1. Projected Changes in Agriculture-based Countries

According to a range of IPCC scenarios[25], by 2029, most of Sub-Saharan Africa will experience warming of 0.5 to 1°C, with patches in the Sahara and Southern Africa experiencing warming of 1 to 1.5°C (IPCC, 2007, p.46; appendix 6). Later in the century (years 2090 to 2099), the region will experience warming of around 2 to 5.5°C,

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[24] Elasticity refers to the ratio of one variable's change resulting from a given change in another variable. For example, if the temperature changes by one unit, unirrigated crop yields decrease by 1.9 units

[25] The scenarios considered are A2 (second largest warming), A1B (mid-range warming), and B1 (lowest warming) (IPCC, 2007, p.46).

depending on the scenario, with A2 projecting 3.5 to 5.5°C, A1B 2.5 to 4.5°C, and B1 1.5 to 3°C (ibid). Areas of highest warming risk are the Sahel and Southern Africa (ibid).

For the months of December to February, the A1B (mid range warming) scenario projects decreases in rainfall for 2090 to 2099 (relative to 1980-1999) of 10 to >20% for the Sahel and parts of northern Central Africa and increases of 5 to >20% for Eastern and Central Africa (ibid, p.47; appendix 7). Projections for Southern Africa are inconclusive due to lack of consistency in modelled projections, except for decreases of 5 to 20% along the western coast of Southern Africa (ibid). For the months of June to August, the same scenario projects decreases of 10 to >20% for all of Southern Africa and small patches of 5 to 20% increase through Central and Eastern Africa (ibid). However, projections for much of Central, Eastern, and especially Western Africa are largely inconclusive (ibid), which may suggest increased variability.

Based on these projections and the revenue elasticities calculated by Kurukulasuriya et al. (2006), the agriculture-based countries of the Sahel region, including Mali, Burkina Faso, Niger, Chad, Sudan, and Ethiopia, are very likely to experience temperature increases of 0.5 to 1.5°C in the next two decades, and 2 to 5°C by the end of the century (IPCC, 2007, p.46). These countries are also projected to experience significant rainfall decreases through the winter months, and uncertain changes through the summer months (ibid, p.47). As a result, farmers in these countries are very likely to see significant decreases in farm revenue, especially given the small percentage of arable land under irrigation (5% in Mali, 11% in Sudan, 3% in Ethiopia, and 1% in the others) (FAO, 2007).

The agriculture-based countries of West Africa (Guinea, Côte d'Ivoire, Ghana, Togo, Benin, Nigeria, and Cameroon), East Africa (Uganda, Kenya, Rwanda, and Burundi), and Southern Africa (Zambia, Malawi, Mozambique, and Madagascar) all have similar warming projections of 1.5 to 4.5°C by the end of the century (IPCC, 2007, p.46). Large increases in these countries are not as certain, depending on emissions scenarios. They will experience losses due to temperature increase, but they may not be so detrimental as to negate agriculture-led development strategies, especially where improvements in irrigation are possible. Currently, these countries display extremely low irrigation rates (0 to 3% in all but Guinea (6%) and Madagascar (31%)) (FAO, 2007). Precipitation in December to February is expected to increase in Ethiopia, Uganda, Kenya, Rwanda, and Burundi, so if these countries are able to harness and effectively use this, the negative effect of warming may be dampened. Conversely, Zambia, Malawi, Mozambique, and Madagascar are expected to experience significantly decreased precipitation in June to August (IPCC, 2007, p.47) which will, combined with temperature increases, likely have severe consequences for agricultural production in these countries (except perhaps Madagascar due to higher levels of irrigation). Precipitation projections for other regions are uncertain (ibid).

In addition to temperature and precipitation changes, various studies have projected the effects of climate change on agricultural yields. The climate and GHG emission scenarios used, as well as the degree to which CO_2 fertilization effects are assumed to function, create significant uncertainty in cereal yield projections. Drawing on three major studies of various scenarios at the country level by Parry et al. (2005 & 2004) and Rosenzweig et al. (2001), the majority of agriculture-based countries[26] are expected to experience cereal yield decreases of 0 or 2.5 to 30%. Projections for the remaining countries[27] vary significantly from yield changes of +10 or even +20 to -30%. Most countries with very wide projected changes are in areas where models disagree on projected precipitation changes (IPCC, 2007, p.47). However, Kenya (yield changes of +20 to -30%) is projected to experience significant precipitation increases from December to February, while Zambia (yield changes of +20 to -30%) is projected to experience significant precipitation decreases from June to August (ibid). Other than these uncertain findings, the consensus among these studies is that agriculture-based countries will experience decreases in cereal yields that increase in intensity with higher warming projections and less CO_2 fertilization effectiveness.

A study by Fischer et al. (2005) which projects changes in cereal output under the A2 scenario with four different climate models on a much finer scale than the above studies may shed some light on these broad uncertainty ranges. Zambia displays areas of high increase in the north and areas of decrease in the south (ibid, p.2077). Similarly, Kenya is projected to experience increases through the centre of the country, but decreases on the east and west sides (ibid). Depending on the climate model, Cameroon is projected to experience significant increases or decreases across much of its territory (ibid). Côte d'Ivoire and Ghana, on the other hand, both show decreases across much of their area,

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[26] The countries projected to experience cereal yield decreases of 0 to 30% are Burundi, Chad, Ethiopia, Guinea, Madagascar, Mali, Niger, Nigeria, and Sudan. The countries projected to experience cereal yield decreases of 2.5 to 30% are Benin, Burkina Faso, Malawi, Mozambique, Rwanda, Togo, and Uganda.

[27] The countries projected to experience cereal yield changes of +10 to -30% are Cameroon, Côte d'Ivoire, and Ghana. The countries projected to experience cereal yield changes of +20 to -30% are Kenya and Zambia.

except for the northern and western borders of Côte d'Ivoire which show increases under some climate scenarios (ibid).

5.2. Implications for Development Strategies

According to Paul Collier, low-income countries with significant natural resources (such as Chad, Sudan, Nigeria, Angola, and Cameroon) face the best prospect for obtaining middle-income status by efficiently using the revenues from these resources (Collier in ODI, 2005). This is, of course, easier said than done, given the dismal development history of natural resource rich countries (Collier, 2007, ch.3). Nevertheless, progress is being made and Collier is of the opinion that this is the best opportunity for these countries (Collier in ODI, 2005). This is, perhaps, particularly true for Chad and Sudan, which are mostly landlocked (and so have poor access to global markets) and are projected to experience large temperature increases. The studies by Parry et al. (2004 & 2005) singled out Nigeria as likely to see significant cereal yield decreases earlier than most other countries; therefore, Collier's strategy may also be particularly important for Nigeria. Cameroon is a more interesting case because some studies show significant increases in cereal yield potential (ibid). In this case, a strategy that channels some of the natural resource revenues into agricultural development and adaptation may be best.

Collier identified a second group of countries, which are poor in natural resources, but are coastal (Collier in ODI, 2005). These countries include Benin, Côte d'Ivoire, Ghana, Guinea, Kenya, Madagascar, Mozambique, and Togo. For this group, Collier suggested a strategy that includes "breaking into global markets for labour-intensive manufacturing exports" (ibid). This is perhaps an especially good strategy for those agriculture-based countries that are likely to experience significant challenges from climate change, such as Benin, Guinea, Mozambique, and Togo. However, this strategy may rely on trade policy in MDCs because of significant competition from Asia (ibid; Collier, 2007, ch.10). The projections are more uncertain for Côte d'Ivoire, Ghana, Kenya, and Madagascar. Agriculture-led development strategies may very well remain viable for these countries under some emissions scenarios and climate models, especially for Madagascar with its large irrigated area that will be more shielded from temperature increases.

The third group of countries is comprised of those with few natural resources and no coastal access; these countries will face significant challenges for development (Collier in ODI, 2005). In the Sub-Saharan African agriculture-based country category, these include Burkina Faso, Burundi, Ethiopia, Malawi, Mali, Niger, Rwanda, Uganda, and Zambia. According to the A2 scenario studied by Fischer et al., and the other scenarios studied by Parry et al. (2004 & 2005), Burkina Faso is projected to see mostly decreases under all climate models; Burundi may experience yield increases under some models; yields in Ethiopia are projected to increase in the west and decrease in the east; Malawi will likely see decreased yields; Mali shows mostly decreases with some models projecting an increase in the north; Niger may experience some yield increases in the south under some climate models; Rwanda will likely see mostly decreases with increases in the north under some models; yields in Uganda may decrease in the north and increase in the south; and Zambia will likely see decreases in the south and potential increases in the north (2005, p.2077). For those countries that may experience yield increases, adaptation strategies will still be important, but agriculture-led development will likely remain a viable strategy. As for those countries that are expected to experience general yield decreases across most models (Burkina Faso, Malawi, Zambia, and perhaps Mali and Rwanda) may be forced to search for alternative development strategies, for their agricultural sectors are likely to be severely damaged. Collier suggested that the best hope for some of these countries may be for neighbouring countries to grow so that they can gain from "spillovers" (Collier in ODI, 2005), yet this will be a long process with highly uncertain outcomes.

In general, Collier suggested that "agricultural development [is] not the key sector that [will] potentially achieve economic growth and poverty alleviation" in Sub-Saharan Africa (ibid). Similarly, Deborah Bryceson concluded that "diversification out of agriculture has become the norm among African rural population" (2000). With the projected effects of climate change on agriculture, this is likely to continue as an important livelihood adaptation strategy. However, Peter Hazell disagreed by suggesting that the 'natural-resource-led' and the 'manufacturing-for-export-led' strategies do not have the benefit of reaching a broad base of the country's poorest – dubbed the 'participation effect' by Christiaensen et al. (2006, p.1). Furthermore, "even if resource-rich countries spent their revenues very effectively" the benefits would be very slow to accrue for vast proportions of the population employed in the agricultural sector (Hazell in ODI, 2005). These alternate strategies suggested by Collier appear to lack the particular benefits of agriculture-led development, in terms of direct, indirect, and participation effects for the poor. In addition, "many households will be forced to remain in the farming sector for livelihood and security for some time to come as the population in Africa undergoes a three-fold increase this century" (Challinor et al., 2007, p.390).

6. DISCUSSION AND CONCLUSIONS

6.1. Agriculture-led Development Prospects

In the next few decades, several Sub-Saharan African countries will experience temperature increases of 0.5 to 1°C, enough to endanger the agricultural sector in dry regions. Depending on the success of adaptation strategies, changes in rainfall, and climate variability, the agricultural sector may be hard hit. Sub-Saharan African agriculture-based countries that are most likely to struggle with agriculture as climate change progresses are Benin, Burkina Faso, Chad, Guinea, Malawi, Mozambique, Nigeria, Sudan, Togo, Zambia, and perhaps Mali and Rwanda.

Chad, Nigeria, and Sudan have oil reserves and so may be better suited to pursuing natural-resource-led strategies. In order to overcome the obstacle of participation, revenues could be invested in projects that directly benefit the poor while also providing a return on that investment in order to sustain growth. Where possible, investment of oil revenues in irrigation projects can have "very reasonable" repayment periods (Kurukulasuriya et al., 2006, p.386) and irrigation may be sufficient to dampen some effects of climate change, at least in the near future under some scenarios. There is a question regarding whether this strategy is appropriate, given that fossil fuel combustion is a primary cause of climate change, which will be responsible for damaging the viability of agriculture in these countries. However, this may be their best opportunity for achieving middle-income status (Collier in ODI, 2005) so they are likely to use it under the defence that rich countries bear the onus for decreasing emissions.

Benin, Guinea, Mozambique, and Togo are natural resource poor, but coastal. Because these countries are likely to experience negative changes in agricultural productivity, pursuing a manufacturing-for-export strategy may be best. As above, this may not have the broad poverty alleviation effect and may disrupt the organization, cultural, and community benefits of rural life. However, where farmers are forced to abandon agriculture due to the effects of climate change, this could provide employment opportunities. The biggest challenge with this strategy, as mentioned by Collier, will be for these countries to compete with the Asian countries that already control a large segment of the market (2007, ch.10). Preferential trade policy in MDCs may be able to balance this; however, this may also take us down a questionable (and sometimes slippery) trade-protection path.

The countries that are in particularly dire straits are Burkina Faso, Malawi, Mali, Rwanda, and Zambia. These countries are projected to face significant challenges to agricultural production from climate change (although there is some hope for Mali, Rwanda, and Zambia under some climate models and emission scenarios). Furthermore, they are resource-poor and landlocked so are unable to follow the alternate strategies discussed above. Collier has suggested attempting to encourage 'spillover' effects from development in neighbouring countries. In addition, these countries may be the best targets for international development assistance. Where possible, investment in irrigation, market access infrastructure, and insurance or social assistance programs may enable farmers to adapt and continue agricultural production. However, this will be a significant challenge given the projected effects of climate change.

Countries where agriculture-led development strategies are likely to be more effective, given the temperature and precipitation implications of climate change, are Burundi, Cameroon, Côte d'Ivoire, Ethiopia, Ghana, Kenya, Madagascar, Niger, and Uganda. Cameroon has oil revenues and so can follow a natural-resource-led strategy. However, to ensure broad based benefits and poverty alleviation, these revenues should be channelled into agricultural development, for Cameroon may fare relatively well under climate change. Côte d'Ivoire, Ghana, Kenya, and Madagascar also have potential to gain from agriculture-led development strategies under some climate change scenarios. These countries are also coastal and so may wish to diversify into manufacturing as well, depending on trade policies as discussed above. Finally, agriculture-led development strategies are likely to be most effective in Burundi, Ethiopia, Uganda, and perhaps Niger. These countries are resource-poor and landlocked, but may be able to sustain agriculture-led development strategies under some climate change scenarios. Nevertheless, these strategies are likely to be their best option, at least in the short term. Development assistance targeted at adapting agriculture to climatic changes will likely play an important role.

6.2. Areas for Further Research

A priority for further research should be the efficacy of various adaptation strategies. In particular, climate and weather forecasting projects need to be improved in terms of spatial granularity and temporally tailored to the needs of local farmers (Archer et al., 2007). In addition, more information is required regarding the effects of temperature and precipitation on plant disease and pests, which may be detrimental to agriculture. Finally, the effects of increased climate variability and frequency and intensity of extreme events are often not considered when projecting climatic effects on agricultural yields. These consequences of climate change are likely to be important for agriculture and so efforts to include them in agricultural productivity projections will be valuable.

6.3. Final Thoughts

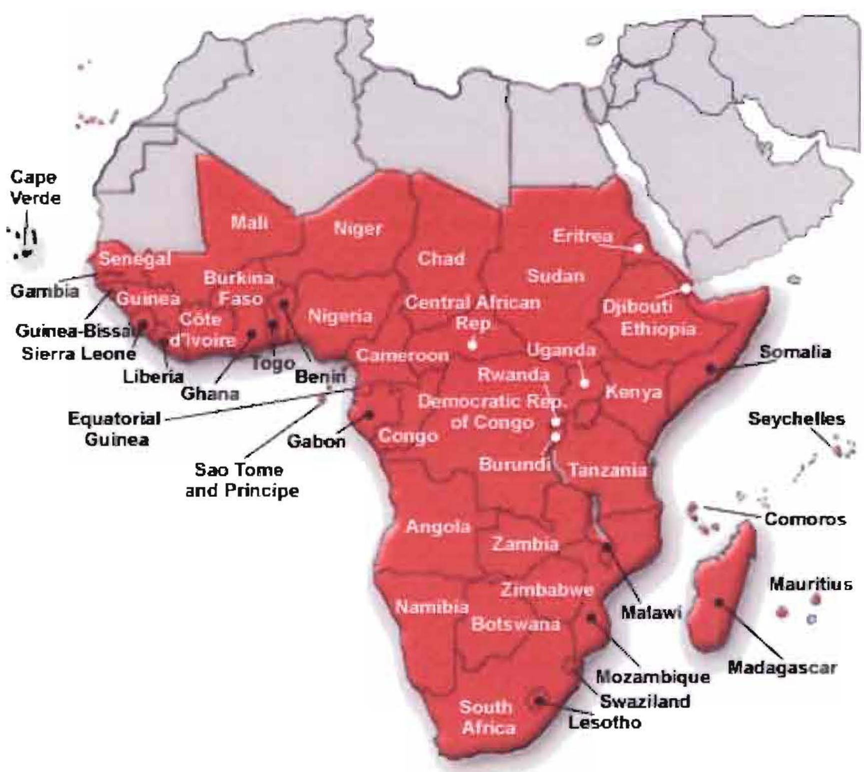
Although less developed countries have experienced some developmental success of late, recent spikes in oil and food prices may dampen these successes. Clearly, no one endeavour is the key to development; however, agriculture appears to show special promise for poverty reduction and growth effects on other sectors. Climate change is already presenting challenges to the organization of human activity and its projected manifestations in the form of increased temperatures, changed precipitation patterns, increased climatic variability, increased frequency and intensity of extreme weather events, and raised sea levels are likely to present significant developmental challenges, not least of which are to agriculture. As discussed above, adaptation strategies, including industrialization, may provide some scope for protecting agriculture from climate change. Where yield drops are small, these strategies, along with economic growth, may dampen or counteract the worst effects of climate change. However, adaptation strategies can be expensive and challenging to implement, especially in rural areas with declining freshwater availability. In most agriculture-based countries of Sub-Saharan Africa, diversification away from agriculture is likely to continue to be a common response to climatic challenges, especially in natural resource-rich and coastal locations. Agriculture-led development will likely remain viable for some countries that are projected not to experience the worst effects of climate change. In addition, these strategies will likely remain important (though perhaps less successful) in those countries that are projected to experience significantly negative effects of climate change but have few other options.

Global emissions are currently exceeding all IPCC SRES scenarios (Raupach et al., 2007, p.10289). Should this continue, the worst effects of climate change are very likely to occur across the globe and especially in Sub-Saharan Africa. While I have focused here on adaptation as an important strategy for less developed countries, mitigation among the more developed countries should be included in international development policies, for the effects of these emissions are likely to impact less developed countries first and most. Given the stated development goals agreed to by all nations and major international development agencies (UN, 2008), we must combat and respond to global climate change while effective mitigation remains possible.

APPENDICES

Appendix 1: Countries of Sub-Saharan Africa

Angola
Benin*
Botswana
Burkina Faso*
Burundi*
Cameroon*
Cape Verde
Central African Republic
Chad*
Comoros
Congo, Democratic Republic of the
Congo
Côte d'Ivoire*
Equatorial Guinea
Eritrea
Ethiopia*
Gabon
Gambia
Ghana*
Guinea*
Guinea-Bissau
Kenya*
Lesotho
Liberia
Madagascar*
Malawi*
Mali*
Mauritius
Mozambique*
Namibia
Niger*
Nigeria*
Rwanda*
São Tomé and Principe
Senegal
Seychelles
Sierra Leone
Somolia
South Africa
Sudan*
Swaziland
Tanzania
Togo*
Uganda*
Zambia*
Zimbabwe



Source: CIDA, 2007

*Agriculture-based countries (World Bank, 2007a, p.5)

Appendix 2: Definition of Agriculture

When discussing agriculture, I am referring to farming activities such as growing crops and raising livestock. These activities may be large-scale or subsistence, rain-fed or irrigated. Throughout, I will focus on common agricultural goods produced in Sub-Saharan Africa such as maize, sorghum, millet, and rice (FAO, 2008) as any effects of climate change on these will have significant implications for farmers, state economies, and food security. There is limited literature on the importance of livestock for development; however, livestock can behave as an asset base for farmers. Should they be forced to consume this asset (literally or by sale) because of a loss in income from agricultural crops, the asset barrier between stochastic and structural poverty may be broken (Little et al., 2006). In general, "agriculture plays a dominant role in supporting rural livelihoods and economic growth over most of Africa" (Challinor et al., 2007).

Appendix 3: Definition of Development

Drawing on the writing of Amartya Sen, I consider development to be a process of advancement towards a situation in which people have the freedom to achieve their full human capabilities (Sen, 1999). This process can be encouraged by increasing individual or national income levels, but "social and economic arrangements (for example, facilities for education and health care) as well as political and civil rights (for example, the liberty to participate in the public discussion and scrutiny)" are also of vital importance (ibid, p.3). "Similarly, industrialization or technological progress or social modernization can substantially contribute to expanding human freedom, but freedom depends on other influences as well" (ibid, p.3). Two vital components of development that will receive special attention in this investigation are extreme poverty alleviation and food security.

Bearing this definition in mind, international development is a process by which foreign state and/or non-state actors contribute capital, skills, labour, or technology towards enabling others (individuals, businesses, or countries) to increase their freedoms and capabilities. Agriculture-led development refers to strategies that seek to achieve these development goals through improving agricultural productivity.

Appendix 4: Global Climate Change

The Science

The sun emits ultraviolet and visible light that passes through the atmosphere and hits the Earth's surface. Some is absorbed and the remainder is reflected in both the visible light spectrum (that is how we see) and as lower energy infrared radiation. For most of human history before the industrial revolution, much of this infrared radiation would escape through the atmosphere and back into space while some would be absorbed and reemitted in all directions by specific atmospheric gases, commonly known as greenhouse gases (GHGs). It is vital that some infrared radiation be absorbed and reemitted towards Earth by natural levels of these gases in order to maintain the temperature range that allows for the existence of liquid water on the Earth's surface and, hence, life as we know it. However, since the industrial revolution, human activity has increased atmospheric concentrations of GHGs, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (IPCC, 2007, p.37). With increasing levels of these gases in the atmosphere, more infrared radiation is absorbed and reemitted, warming the air and returning some to Earth. The ultraviolet light continues to pass through the atmosphere unimpeded, but the infrared radiation does not escape as easily. As a result, the Earth's average surface temperature rises. (IPCC, 2007; McKibbin & Wilcoxen, 2002, p.108; Pallant, 2007)

Over the history of the Earth (roughly 4.5 billion years), there have been very significant climatic changes. Approximately 50 million years ago, it is likely that the planet was quite warm with no ice cover, whereas, roughly 500 million years ago the planet may have been completely covered with ice (Emanuel, 2007, p.7). The Earth's environment is fragile and unstable, varying significantly with, for example, small changes in its orbit, which "change the distribution of sunlight with latitude" (ibid, p.8).

It is likely that life has always had various effects on the planet's climate, particularly with the advent of photosynthesizing plants that produced oxygen from carbon dioxide. Nevertheless, as a result of human activity, "the atmospheric concentrations of CO_2 and CH_4 in 2005 exceed[ed] by far the natural range over the last 650,000 years" (IPCC, 2007, p.37). In addition, "there is *very high confidence*[28] that the global average net effect of human activities since 1750 has been one of warming, with a radiative forcing of +1.6 [+0.6 to +2.4] W/m^2" (ibid). It is likely that this rate of change is the fastest experienced on Earth in the past 10,000 years (Houghton, 2004, p.139-40). This is particularly significant, because ice core data show that, in the past, the climate has reacted unpredictably to slow, steady changes in radiative forcing (Emanuel, 2007, p.53). "Far from changing smoothly, it remains close to one state for a long time and then suddenly jumps to another state. We do not understand this, and are worried that a sudden climate jump may be part of our future" (ibid).

It has been suggested that because of these natural cycles in the Earth's climate, we are overdue for another ice age. If this were true, one could make a case for allowing increased GHG emissions in order to avert or delay the next ice age. However, these arguments are baseless, for "over at least the next 50,000 years the solar radiation incident in summer on the polar regions will be unusually constant so that the present

[28] The IPCC has various methods to speak of uncertainty. Here, "*very high confidence*" refers to confidence levels of "expert judgment of the correctness of underlying data, models or analyses" of "at least 9 out of 10" (IPCC, 2007, p.27).

interglacial is expected to last for an exceptionally long period" (Houghton, 2004, p.137-9). In addition, even small climatic changes since the last ice age were debilitating to early civilizations in Mesopotamia and the Americas (Emanuel, 2007, p.52). It is an understatement to say that things are different in modern civilizations, most notably astonishing technological advances. However, we are still reliant on oxygen, agricultural products, and freshwater for sustenance. It is, therefore, necessary to understand the projected impact of these climatic changes we are causing.

Projected Effects of Climate Change

The effects of climate change are expected to be significant for the biosphere, including the organization of human civilization. With the observed and projected increases in global average temperatures and changes in precipitation patterns will come a continued rise in sea levels, declining freshwater availability, loss of biodiversity, and increased disease burden. These, in turn, may cause migration, changes in agricultural yields, increased sensitivity to future changes, and, in some cases, increased risk of conflict.

The Intergovernmental Panel on Climate Change has identified four primary storylines to project the magnitude and effects of climate change under various possible future states. The four families of scenarios (called SRES scenarios for the IPCC Special Report on Emissions Scenarios (IPCC, 2000)) are A1, A2, B1, and B2[29] (IPCC WGII, 2007, p.32). These scenarios are simplified categories of possible future paths of social, economic, and technological development. However, they do provide a means of examining a range

[29] The letter (A or B) denotes the relative future emphasis on global integration or regionalization with A implying greater integration and B implying greater regionalization. The number (1 or 2) denotes the relative future emphasis on economic or environmental priorities with 1 implying an environmental emphasis and 2 implying an economic emphasis. (IPCC WGII, 2007, p.32)

of plausible future states and the relative impact of variables such as population growth, the speed and direction of technological innovation, the level of economic integration, etc. (ibid). Some scenarios have variations. For example, the A1 family contains three possibilities for the direction of technological change with respect to the source of energy: A1FI assumes a continuation of a "fossil fuel intensive" energy path; A1T assumes broad use of "non-fossil fuel energy sources"; and A1B assumes the source of energy is "balanced across all sources" (ibid).

Temperature and the Hydrological Cycle

Since the 1960s, observed and modelled temperatures have diverged from the temperature range projected with only natural forcing models, which means that the observed warming is "*very likely*[30]" a result of human activity (ibid, p.39-40; appendix 5). This warming trend would continue, albeit at a slower pace, even if atmospheric GHG concentrations were immediately stabilized at year 2000 levels, as the effect of existing emissions takes decades to fully materialize (ibid, p.46).

Under SRES projections, the range of temperature change by 2100 is 1°C to >6°C relative to the 1980-1999 average (ibid). Best estimates range from 1.8°C for the B1 scenario, 2.4°C for the A1T and B2 scenarios, 2.8°C for the A1B scenario, 3.4°C for the A2 scenario, and 4.0°C for the A1FI scenario (ibid; appendix 6). The effect of increasing temperatures is, and will be, important, especially in the polar regions and semi-arid climates on the threshold of desertification such as Africa's Sahel region.

[30] "*Very likely*" here refers to a likelihood of greater than 90% (IPCC, 2007, p.27).

Effects on ecosystems will be amplified by related changes in global hydrological patterns and cycles. "The twin perils of flood and drought actually both increase substantially in a warmer world" (Emanuel, 2007, p.52). Precipitation patterns are expected to change significantly with some regions experiencing decreases and others experiencing increases (IPCC, 2007, p.47; see appendix 7). In addition to projected changes, there is likely to be an increase in variability and an increase in the frequency of heavy precipitation events, which can be detrimental to crops, cause flooding, contaminate groundwater, increase the risk of respiratory and skin diseases, and obstruct transportation infrastructure (ibid, p.53).

With rising temperatures, other extreme events are also expected to occur related to the hydrological cycle. Tropical cyclones are expected to increase in frequency and intensity, as are heat waves, heavy precipitation events, and extended droughts (ibid). These events are expected to have primarily negative effects on agriculture, water resources, human health, and society in general (ibid).

Rising Sea Levels

As the global average temperature increases, the sea level rises due to melting glaciers and ice caps and thermal expansion[31] (ibid, p.30). Since the early 1960s, the global average sea level has risen by approximately 76 millimetres or an average of 1.8 mm per year (ibid). Between 1993 and 2003, the rate was approximately 3.1 millimetres per year (ibid). Due to the time lags associated with thermal expansion, even under immediate stabilization of atmospheric GHG concentrations at year 2000 levels, thermal expansion

[31] As water warms, it expands. Thermal expansion accounted for approximately 57% of sea level rise since between 1993 and 2003 (IPCC, 2007, p.30).

would add 0.3 to 0.8 meters to the sea level by 2300 (ibid, p.46). With future warming of 2 to 3°C (expected by the 2090s under all scenarios, except B1, and earlier for A1B, A2, and A1FI) the planet will likely be committed to "several meters of sea-level rise due to ice sheet loss" (IPCC WGII, 2007, p.66; appendix 8).

The effects of sea level rise will be particularly significant for small island states and coastal deltas with millions of people projected to be at risk of displacement by 2050[32] (ibid, p.41). Small island states will experience "increasing coastal inundation and damage to infrastructure due to sea-level rise" as temperatures continue to increase (ibid, p.67). In addition to inundation, rising sea levels are also expected to increase the rate of soil salinization and drinking water contamination. These will have detrimental effects on coastal and delta agricultural activities as well as freshwater availability. Sub-Saharan African countries at risk of delta flooding are Nigeria, Benin, Togo, and Senegal. Also at risk are the small island states of Cape Verde, São Tomé and Principe, the Seychelles, Comoros, and Mauritius.

Freshwater Availability

Significant observed losses in snow pack volume and glaciers are expected to continue and accelerate under warming scenarios (IPCC, 2007, p.49). This, combined with changes in precipitation and evapotranspiration, will change runoff patterns. Higher latitudes and "some wet tropical areas" are likely to experience an increase in runoff of

[32] By 2050, current sea level trends will place over 1 million people at risk of displacement in each of the Nile, Ganges-Brahmaputra, and Mekong river deltas (IPCC WGII, 2007, p.41). Furthermore, between 50,000 and 1 million people will be at risk of displacement in each of the Mississippi, Godavari, and Changjiang river deltas (ibid). In addition 5,000 to 50,000 people will be at risk of displacement in 18 other river deltas across the world (ibid).

about 10 to 40% (ibid). Dryer regions and mid-latitudes are likely to experience a decrease in runoff of about 10 to 30% (ibid). "The negative impacts of climate change on freshwater systems outweigh its benefits (*high confidence*[33])" (ibid) and the effects of these changes will be significant as "more than one-sixth of the world's population live in glacier- or snowmelt-fed river basins" (IPCC WGII, 2007, p.35).

As a result, the developing regions of Africa, Asia, and Latin America are expected to experience an increase in the number of people affected by water stress by 185 million to 1.53 billion under warming projections of less than 1.5°C (ibid, p.67). These projections increase to 630 million to 1.78 billion under warming projections greater than 1.5°C (ibid). Water stress can negatively affect livelihoods by decreasing agricultural yields and general productivity, especially among the poor.

Ecosystems and Biodiversity

Although ecosystems have significant and important capacity to adapt to environmental changes, it is "very likely" that in the next 100 years or so they will be "exposed to atmospheric CO_2 levels much higher than in the past 650,000 years, and global mean temperatures at least as high as those in the past 740,000 years" (ibid, p.37). Resilience of ecosystems often depends on vibrant biodiversity and so as species become more stressed due to geologically fast climatic changes, the capacity of ecosystems to adapt may be hampered. With warming of 2 to 3°C (expected by the end of this century under all scenarios except B1), 20 to 30% of species assessed "are likely to be at increasingly high risk of extinction" (ibid, p.38). For example, ocean acidification associated with climate

[33] *High confidence* implies "the assessed chance of a finding being correct" is "about 8 out of 10" (IPCC, 2007, p.27).

change is negatively affecting corals, which are home to thousands (potentially millions) of species at various points along the marine food chain (NOAA, 2008). Climate change will also affect ecosystems under human cultivation. Under low to moderate warming, higher latitudes may experience an increase in yields and arable land (Parry et al., 2004 & 2005). However, at lower latitudes (where most LDCs are located) yields are projected to decrease, especially where crops are rain-fed (ibid). Under higher warming projections, global yields are expected to fall, with negative implications for poverty and global food security (ibid).

Disease

According to the IPCC, most of the effects of climate change on human health are, and will continue to be, negative (IPCC WGII, 2007, p.43). The number and location of people affected by malaria will increase and shift to areas previously too cold or dry for mosquitoes (ibid). In addition, the number of people suffering from malnutrition, death and disease from extreme weather events, "cardio-respiratory diseases from changes in air quality," and infectious diseases are all projected to increase by varying magnitudes (ibid). The most severe will be the increases in malnutrition as well as death and disease from extreme weather events (ibid). There is expected to be a positive impact from fewer "cold-related deaths," and the increase in disease vectors in some areas will be partially offset by a decrease in other areas (ibid).

In addition to these observed and projected effects on human health, there will likely be effects on plant disease and pest prevalence and range. For example, the pine forests of British Columbia's temperate interior are suffering from a mountain pine beetle infestation that has killed millions of hectares of forest in recent years (NRC, 2003). The pine beetle population and range have historically been limited by cold winter temperatures. Scientists expect that the primary cause of the epidemic is warmer weather due to human-induced climate change (ibid). This has particularly important effects because the dead and dying trees will release CO_2 and will no longer sequester CO_2 from the atmosphere, producing a climate change feedback loop. "The spatial and temporal distribution and proliferation of insects, weeds, and pathogens is determined, to a large extent, by climate, because temperature, light, and water are major factors controlling their growth and development" (Rosenzweig et al., 2001, p.96).

The implications of climate change for agricultural pests are complex and difficult to generalize. However, where temperatures increase there will be an associated increase in the rate of development of insects, but also a decrease in their longevity (ibid, p.97). In addition, climatic changes related to rainfall patterns and humidity are associated with pest infestations and plant pathogen growth, all of which can be detrimental to yields (ibid). There are likely to be positive and negative changes in plant pest and disease vectors, which will require new adaptation techniques in some place and may relieve crops in others.

Risk of Conflict

Where state institutions and capacity are weak, nascent, or over-extended the society's adaptive capacity will be limited. In such contexts, the effects on livelihoods of increased water stress, increased food and resource scarcity, and damage to property are more likely to increase the risk of violent conflict than where state institutions are well developed and state capacity is strong. Areas with increased runoff and/or precipitation will not necessarily be better off due to increased variability of precipitation (considered by Buhaug et al. (2008, p.7) to be of greater risk to livelihood than steady decreases) and susceptibility to flooding which can threaten society, water quality, and physical infrastructure (IPCC, 2007, p.49). Where changes in access to fresh water negatively affect livelihoods in contexts of weak institutional capacity, the opportunity cost of conflict may decrease such as to increase the risk of violent civil conflict (Collier & Hoeffler, 2004). Similarly, where changes in agricultural yields exacerbate inequality by damaging the livelihoods of the poor (more often reliant on rain-fed agriculture), grievances may increase which some suggest is also associated with violent conflict (Cramer, 2003).

Appendix 5: Global and Continental Temperature Change

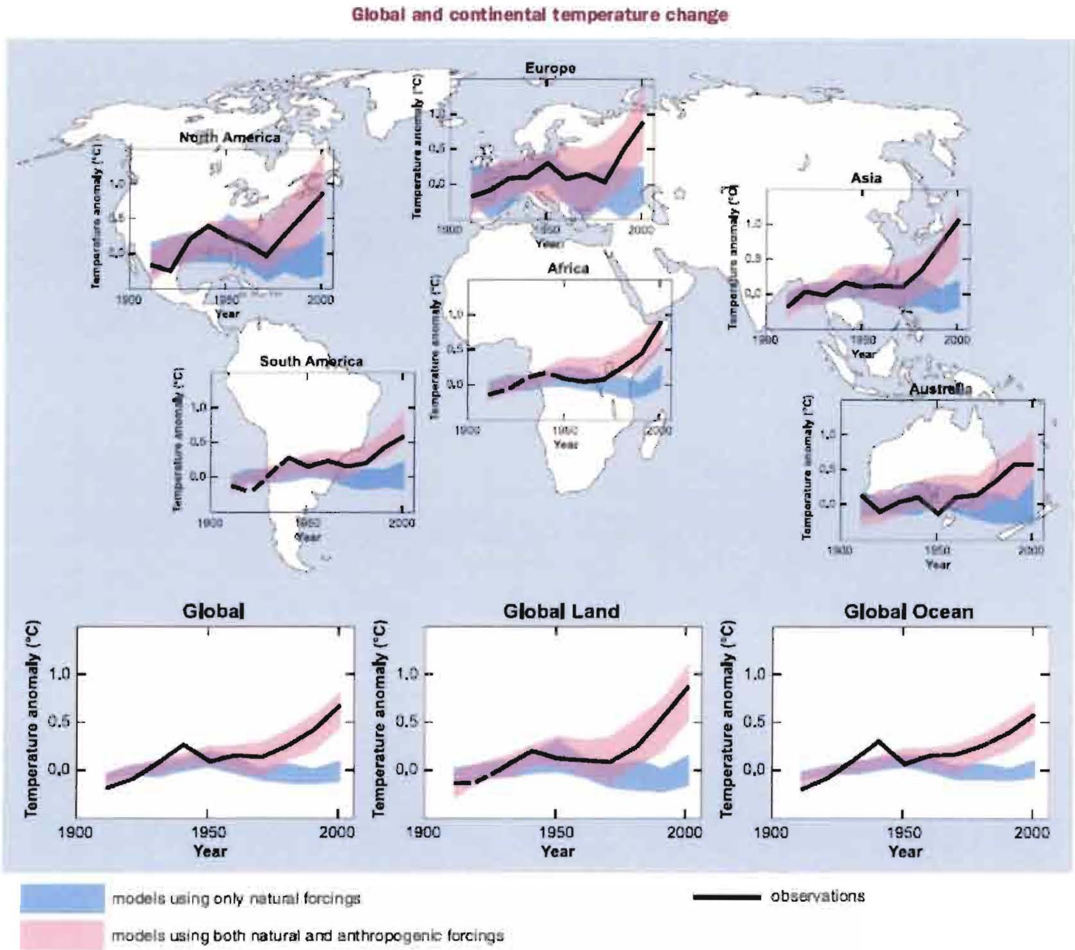


Figure 2.5. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906-2005 (black line) plotted against the centre of the decade and relative to the corresponding average for the 1901-1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5 to 95% range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5 to 95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings. {WGI Figure SPM.4}

Source: Figure 2.5 in IPCC, 2007, p.40

Appendix 6: Projected Surface Warming

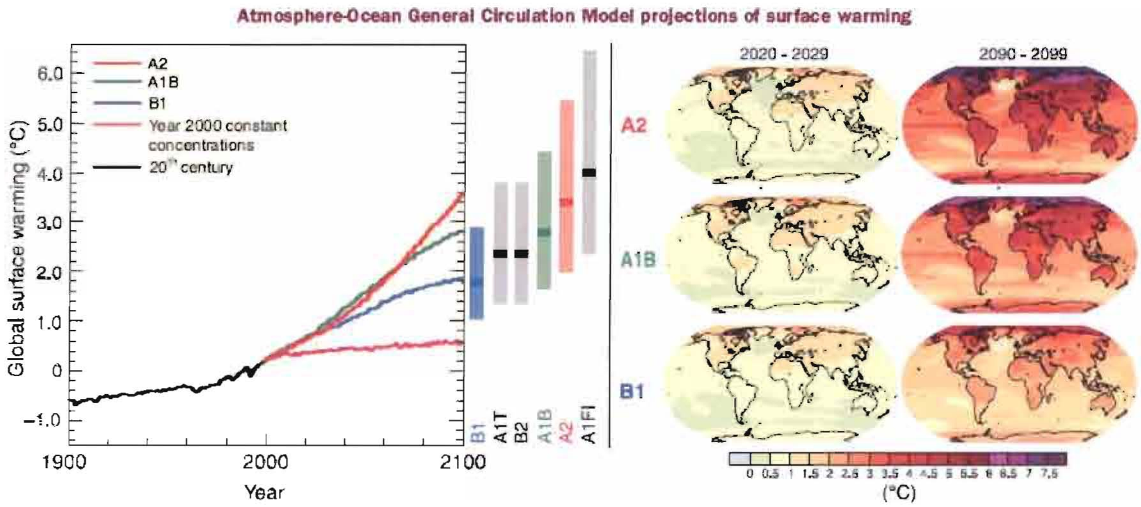


Figure 3.2 **Left panel:** *Solid lines are multi-model global averages of surface warming (relative to 1980-1999) for the SRES scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. The orange line is for the experiment where concentrations were held constant at year 2000 values. The bars in the middle of the figure indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios at 2090-2099 relative to 1980-1999. The assessment of the best estimate and likely ranges in the bars includes the Atmosphere-Ocean General Circulation Models (AOGCMs) in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints.* **Right panels:** *Projected surface temperature changes for the early and late 21st century relative to the period 1980-1999. The panels show the multi-AOGCM average projections for the A2 (top), A1B (middle) and B1 (bottom) SRES scenarios averaged over decades 2020-2029 (left) and 2090-2099 (right). {WGI 10.4, 10.8, Figures 10.28, 10.29, SPM}*

Source: Figure 3.2 in IPCC, 2007, p.46

Appendix 7: Projected Precipitation Changes

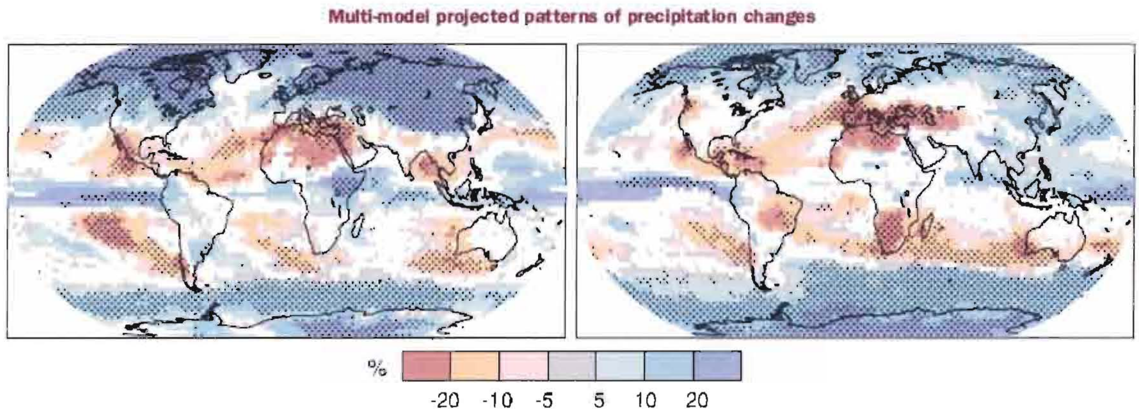


Figure 3.3. Relative changes in precipitation (in percent) for the period 2090-2099, relative to 1980-1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. {WGI Figure 10.9, SPM}

Source: Figure 3.3 in IPCC, 2007, p.47

Appendix 8: Scenario Warming and Projected Effects

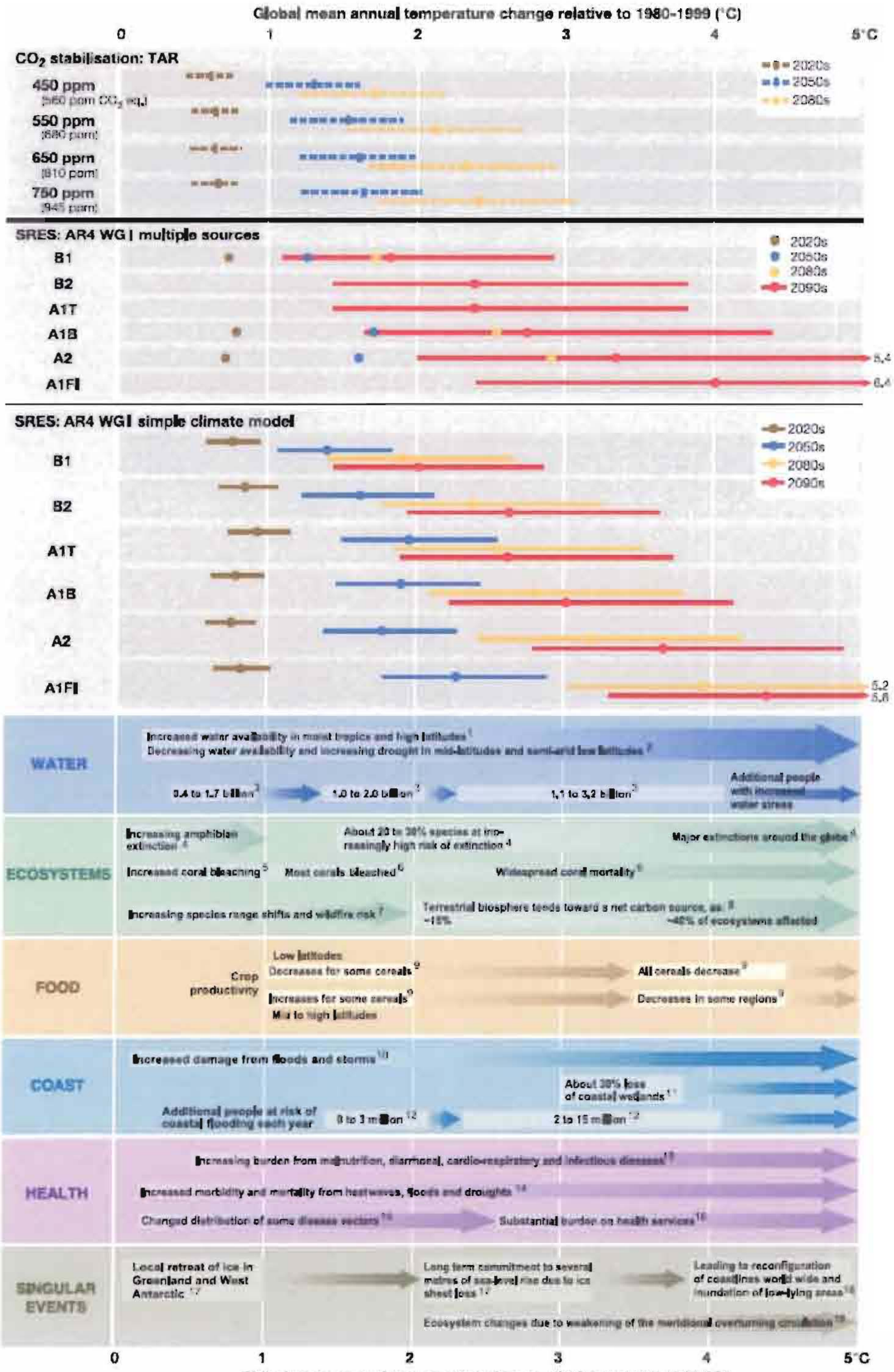


Table TS.3. *Examples of global impacts projected for changes in climate (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature in the 21st century [T20.8]. This is a selection of some estimates currently available. All entries are from published studies in the chapters of the Assessment. (Continues below Table TS.4.)*

Source: Figure TS.3 from IPCC WGII, 2007, p.66

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