Global Climate Change and Food Security: A Brief Review:

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Introduction

The reliance on fossil fuels for energy is likely to continue for the immediate future. Indeed, in spite of the scientific consensus that shaped the latest Intergovernmental Panel on Climate Change (IPCC, 2007) projections, actual CO2 values continue to exceed even the most dire, "business as usual" IPCC scenarios (Figure 1).

The observed increase in he concentration of atmospheric carbon dioxide and other anthropogenic gases has two general consequences for plant biology, and hence, food security. The first of these is related to climate stability. The observed change in atmospheric CO_2 has been accompanied by documented increases in other radiation trapping gases such as methane (CH_4) (0.9% increase per year), nitrous oxide (N_2O) (0.25% per year), and chlorofluorocarbons (CFCs) (4% per year). The rise of CO_2 and associated "greenhouse" gases could lead to a 3-12^{o}C increase in global surface temperatures, with subsequent consequences on precipitation frequency and amounts (IPCC 2007). However, the extent to which the increase in CO_2 and other anthropogenic greenhouse gases alter surface temperature and water availability is likely to vary temporally and geographically (Cushman 1999), with subsequent effects on climatic extremes. The other consequence is related to the role carbon dioxide plays in photosynthesis and growth. Plants evolved at a time of high atmospheric carbon dioxide (4-5 times present values), but concentrations appear to have declined to relatively low values during the last 25-30 million years (Bowes 1996). The values have been low enough, long enough, so that evolution has selected for a small percentage of plants, principally tropical grasses that have maximum photosynthetic rates even at the current low CO_2 concentrations. However, these grasses (termed "C_4" plants) only comprise about 3-4% of all known plant species, the bulk (95%) of the 250,000+ plant species (termed "C_3" plants) lack optimal levels of carbon dioxide. For these plants, the recent rise and projected increase in atmospheric carbon dioxide represents an upsurge of an essential resource. To that end there are, literally, hundreds of studies showing that both recent and projected increases in atmospheric carbon dioxide can significantly stimulate growth, development and reproduction in a wide variety of C_3 plants (see Kimball 1983, Kimball et al. 1993, Poorter and Navas 2003 for reviews examining the response to future CO_2 concentrations, Sage 1995 for a review of the response to recent CO_2 increases).

The "Green Revolution.

To understand the probable impacts of both increasing CO_2 and climate change on food security, it is necessary to appreciate the impact of the "green" revolution during the 20th century. The green revolution reflects the development of dwarf cereal varieties that did not lodge when given additional water and fertilizer. Rather, these varieties allocated more energy to grain production and less to vegetative matter. As a result, yields of rice, wheat and other cereals exploded around the world (FAO 2009). This sudden upsurge in food supply at a time when famine was either endemic or threatening, was deemed the green "revolution" by William Gaud, then administrator of the Agency for International Development (AID) in 1968 (Harrar 1970). It was an acknowledgement of the work by Norman Borlaug, George Harrar and other plant breeders in the development and release of these dwarf cereals.

Climate and Food Security: Direct Effects.

At present, the global population of 6.8 billion is only possible because of gains made in cereal production by the green revolution. Yet those gains are, in turn, dependent on large external inputs of water and fertilizer. How is climate change likely to directly affect these external inputs?

Water. Water, particularly in the form of irrigation, is necessary to maximize yields. Crops that are not irrigated do not achieve maximum potential yields. To illustrate this, consider rice, a subsistence crop that supplies the majority of calories for 1.5 billion people. Although acreage planted in rice is roughly equivalent between irrigated and non-irrigated fields, it is the irrigated rice that accounts for 75% of the total rice production (e.g., Smith et al. 2007).

Where does the water for irrigation come from? Although ground-water is used, water runoff from mountain ranges is a principle source for irrigation. For example, the Himalayas, the largest collection of snow/ice between the poles, supplies water for seven major river systems in Asia. It is these rivers that supply the irrigation water that is needed to feed approximately 3 billion individuals.

But the ice and snow in the mountains is melting, due in no small measure to global warming. Increased melting is likely to initially result in flooding, or a water surplus; eventually followed by drought. Without snow or ice cover, sustainable, reliable supplies of irrigation water will not be available. Yet, irrigated agriculture is the primary user (~75%) of fresh water, and without it, maximum crop yields are not achievable.

Fertilizer. Many people when they think of a farm, picture a sharing of resources between animals and plants (e.g. fertilizer for corn, corn for cows). However, modern agriculture, which can involve thousands of acres, must rely on synthetic fertilizers in order to maintain maximum yield of cereals. Fertilizers, another significant input needed to sustain the green revolution, are heavily dependent on energy. For example, the Haber-Bosch process which converts N_2 gas to ammonia for fertilizer is conducted at high pressure and temperature, and is energy intensive, requiring a large input of natural gas (methane). Hence, as energy prices increase, there is a direct correlation with fertilizer prices, fertilizer input and increasing food costs.

Climate Variability. The green revolution varieties came into use during a time of maximum climate stability during the 20th century (Figure 2). Recent evaluations of temperature thresholds for example demonstrated that pollen sterility, and seed set are much more temperature sensitive than vegetative growth for many key crop species (Table 1). Recent evaluations for temperature sensitivity for key crops in North America, including soybean and corn, indicate a non-linear response of yields to temperature, with significant decline in yields even with small temperature increases above a physiological threshold (Schlenker and Roberts 2009).

Climate and Food Security: Indirect Effects.

We have examined, in part, those physical or abiotic changes likely to occur with climate change. However, it is also clear that, at the biological level, a number of other changes are also likely to occur.

Agro-ecosystems. It is easy to forget when looking at a farmer’s field that more than one organism is being grown there. Fields are home to weeds, insects, diseases, etc. It is this amalgam of different organisms that has been referred to as an “agro-ecosystem”.

As with any environmental change, different species are likely to be impacted differentially. For example, weeds, which impose a major limitation on crop yields, are also likely to respond to climate. In the United States, kudzu (*Pueraria lobata*), is sometimes referred to as a “vegetative form of cancer”. A leguminous vine, it can grow above all other plant forms, and come to dominate the plant community.

Kudzu until recently had been limited primarily to the southeastern United States (Sasek and Strain 1991); however recent observations have indicated it is now present in southern Canada. To illustrate how complex agro-ecosystems can be, kudzu is also related to soybean, and can host Asian soybean rust, a pathogen which can threaten the entire U.S. soybean crop. Overall, as climate changes, crop production is likely to face new threats at the agro-ecosystem level, from weeds like kudzu, but also from new diseases, and new insects.

Food Quality. In response to both climate and carbon dioxide, qualitative changes in seed production also occur, in part, due to internal allocation of nitrogen and carbon. For cereals, a number of studies have shown an overall reduction in protein content (e.g. Rogers et al. 1998), as well as a potential reduction in some micro-nutrients (Loladze 2002). Conversely, there are some studies that indicate an improvement in nutritional quality, such as an increase in anti-oxidants in strawberries with rising CO2 (Wang et al. 2003). Overall, however, changes in food quality and nutritional value have not been well elucidated in the context of CO_2 and/or climate.

Food Safety. Disease outbreaks and sickness due to tainted food remains a consumer priority. Climate change will bring warmer temperatures and additional climatic extremes, particularly more extreme precipitation. Conditions that are likely to improve the spread of food borne pathogens such as E. Coli and Salmonella. However, at present, the epidemiology of such pathogenic outbreaks on food safety is unclear. A scientific assessment of the likely impacts and preventive measures is needed.

Climate and Food Security: Adaptation.

There are a number of means by which climate change is likely to adversely affect food security. In the context of these vulnerabilities, what are potential solutions that can safeguard crop production?

Exploitation of Genetic Resources. Remember that CO_2, in addition to being a greenhouse gas, is also a resource for plant growth as it provides carbon for photosynthesis. Other resources include nutrients, water and sunlight. But just as we would not expect all plants to respond the same way to an increase in sunlight, water or nutrients, we would not expect all plants to respond the same way to CO_2. What then are the best, most responsive crop varieties? Can these varieties be exploited not only to convert additional CO_2 into seed yield, but to also identify more temperature or drought tolerant lines? Initial data indicate that there is significant intraspecific variation among both cultivated and wild lines of cereal species which could be used to begin to maintain or even increase crop yields with CO_2 and/or climate (Newton and Edwards 2007, Ziska and McClung 2008).

Infrastructure/technology. While technological innovations are always an adaptive strategy, we should avoid putting all resources into a magic, one size fits all solution. Rather, there are a number of opportunities to increase the efficacy of available tools. For example, by increasing infrastructure needed for water availability (small dams), more efficient delivery of water (drip irrigation), precise application of fertilizer (SPAD meter), efficient delivery of inputs needed to achieve maximum yields can be achieved.

Polyculture. One underappreciated aspect of food security and climate is sustainability of production. To achieve such sustainability, a poly or multiple culture approach should be utilized. For example, crop and animal diversity should be considered with fertilizer and soil health improved by the judicious use of animal husbandry while animals in turn, are fed by crops grown on the farm. By maintaining biological diversity, this helps to ensure that any one crop or animal line is not eliminated due to climatic extremes. Traditionally, this approach has been very successful. However, as farms become larger, and costs escalate, there has been a recent trend to streamline crop and animal production. Such streamlining includes the use of concentrated animal feeding operations, or CAFOs. Unfortunately, in this instance the waste generated by such large feedlots is water soluble, and has resulted in the recent appearance of large "dead zones" in the Gulf of Mexico.

Biofuels. Although future methodologies are anticipated with respect to cellulosic fermentation and ethanol production, at present, most of the ethanol needs of the United States are being met by the conversion of carbohydrate in corn (i.e., starch) to ethanol (Farrell et al. 2006). In 2006, approximately 20% of US corn production was diverted to ethanol, with a projected increase to 27% for 2007, (~34.5 billion liters) (RFA. 2007). At the present rate of growth, ethanol production is projected to increase to 44 billion liters per year before the end of the decade (RFA 2007). Since corn is one of the three principle cereals (i.e., corn, wheat and rice) that supply 50% of the world's calories, there is increasing concern that greater diversion of corn feedstocks to meet ethanol demand may contribute to rising food prices and global hunger (Msangi et al. 2007).

Overall, biofuels should be seen as a complement, and not a competitor, of food production, particularly for cereals such as corn. In this regard, alternative sources of biofuel, particularly those that utilize marginal lands, and require little external input (e.g. pesticides, irrigation), would be desired (e.g., cassava, sweet potato, Ziska et al. 2009).

Research and Education. We do not know all of the adaptive measures yet; in large part because we do not yet appreciate the impact and time course of climate change itself. To appreciate the dynamic and uncertain nature of global climate change requires, above all us, a long-term commitment in research and education. Yet, investment in agricultural research, as a whole has been declining during the last two decades, particularly for the developed countries (USDA-ARS, 2009).

Conclusions.

In this brief review I have attempted to outline the most significant impacts, and likely solutions regarding global climate change and food security. It should be emphasized however, that food security requires an appreciation of other global challenges, including greater diversion of food to fuel, increasing demands for a higher protein (more meat) diet for an emerging global middle class, diminishing global farmland for arable crops, etc. To solve these issues requires not an application of resources to one issue, but an appreciation that nutrition, food security, bioenergy and climate change are, and will always be, interlinked. To that end, only an integrative, sustainable, solution, one involving stakeholders at multiple levels will provide a long-term answer to the issue of food security.

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Figure 1. Projected scenarios of carbon dioxide emissions (IPCC 2007), with the red dots indicating actual CO_2 emissions as determined from Canadell et al. 2007. Recent emissions are greater than those projected for the A1FA, "business as usual" scenario.

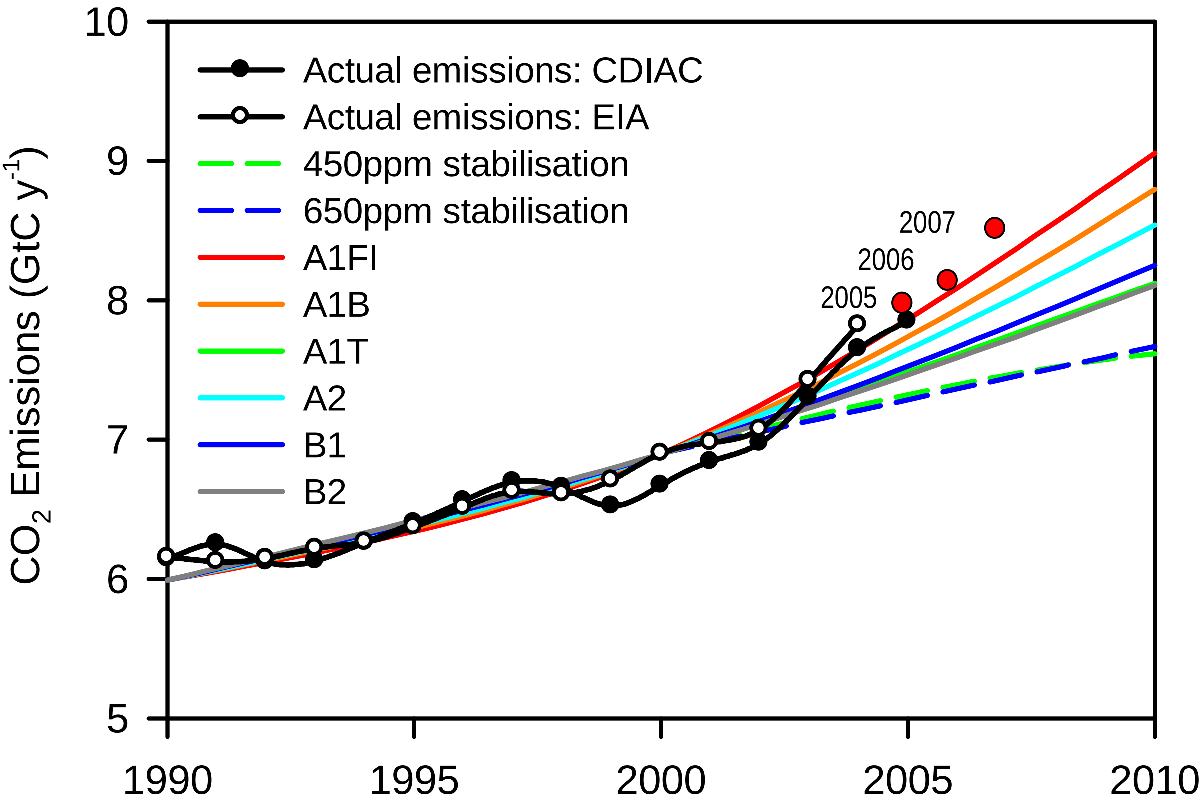
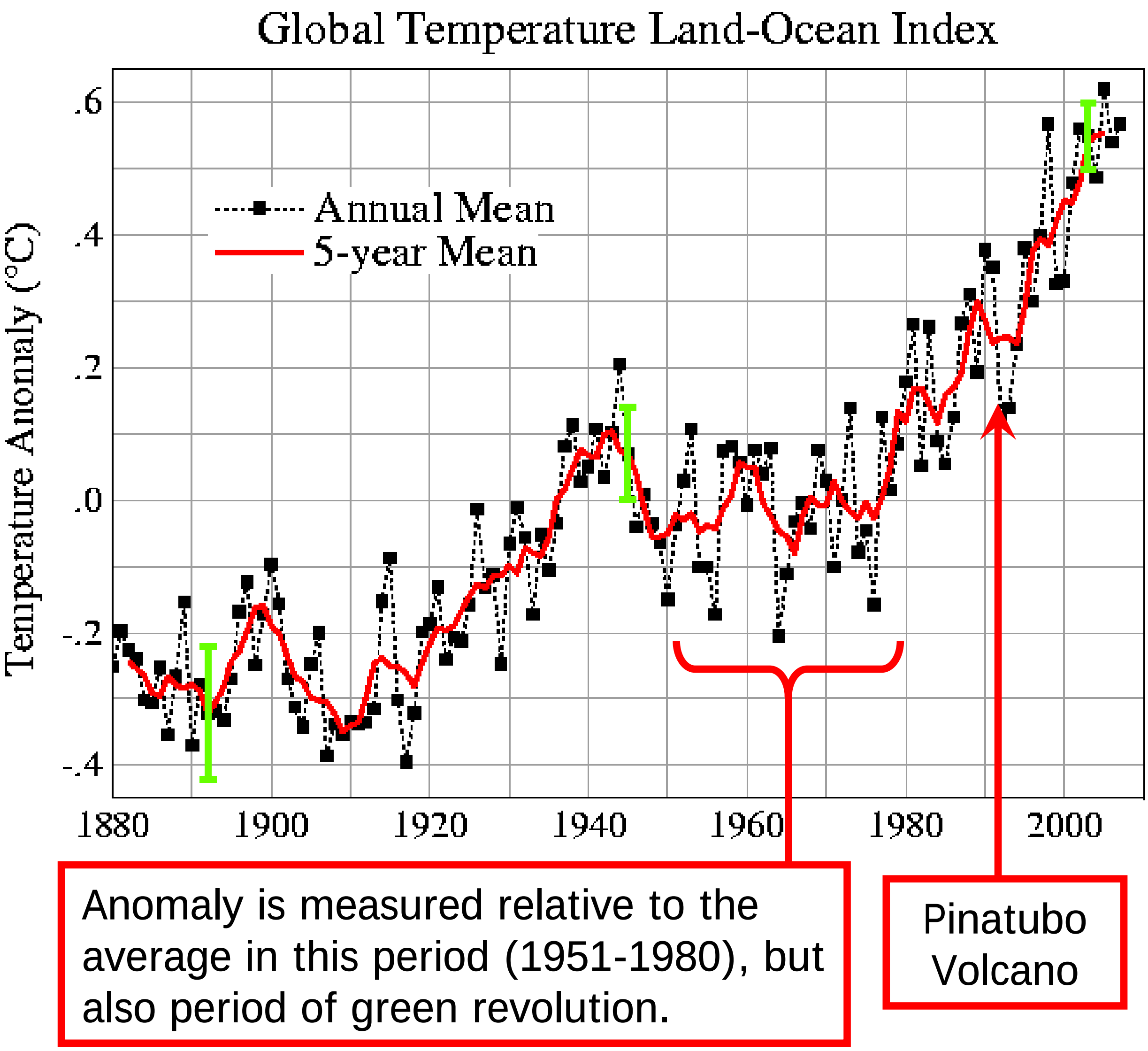


Figure 2. Changes in land-ocean index as determined by the National Oceanic and Atmospheric Administration (NOAA). Note that many of the “green revolution” varieties of cereals were developed during a time of climate stability.



Anomaly is measured relative to the average in this period (1951-1980), but also period of green revolution.

Pinatubo Volcano

Table 1. Different temperature optimums for vegetative and reproductive (flowering) function for different crop species. Note that flowering temperatures, are more sensitive than those of vegetative processes and that failure (no seed set) can occur at temperatures between 35-40^{o}C. Data are from Hatfield et al. (2008).

Crop	Opt.Temp. Vegetative	Opt.Temp. Flowering	**Failure Temp Flowering**
Maize	28-35^{o}C	18-22^{o}C	**35^{o}C**
Soybean	25-37^{o}C	22-24^{o}C	**39^{o}C**
Wheat	20-30^{o}C	15^{o}C	**34^{o}C**
Rice	28-35^{o}C	23-26^{o}C	**36^{o}C**
Sorghum	26-34^{o}C	25^{o}C	**35^{o}C**
Cotton	34^{o}C	25-26^{o}C	**35^{o}C**
Peanut	31-35^{o}C	20-26^{o}C	**39^{o}C**