

## Climate Change and Global Productivity of Plant Goods and Services

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The world today is faced with great challenges to produce adequate food, fiber, feed, industrial products and ecosystem services for the globe's 6.4 billion people. With nearly 80 million added every year, we must develop ecosystem goods and services to meet 8 billion by the year 2025 and over 12 billion by 2050. About 84% of this growth is expected to occur in the developing countries. Since there is essentially no new arable land that can be cultivated, the increased food supply must come primarily from more intensive cultivation of existing arable land. Furthermore, with intensive agriculture, soil degradation will become a major concern. The world's water resource is also finite, and increasing population demands will result in less available water for agriculture. Metropolitan and urban communities nearly always have higher priorities than agricultural production for scarce resources such as land and water. In many highly populated countries, food and fiber needs are being met by irrigating up to 75% of the arable land, and by introducing high yielding dwarf cultivars of most grain crops that accommodate higher input use to maximize production. In addition, the benefits humans derive from natural ecosystems such as marketable products and goods (timber, fish, pharmaceuticals etc.), recreational opportunities (camping, boating, hunting, hiking, sports fishing etc.), maintaining biodiversity, aesthetic and spiritual experiences, and finally services (erosion control, water purification, carbon sequestration, oxygen production etc.) are being threatened by growing human population through habitat destruction and air and water pollution. Added to these stresses comes a threat – global climate change resulting from increased greenhouse gas concentrations in the atmosphere due to anthropogenic activities.

Climate change is not a new phenomenon. Planet's climate has changed tremendously over geologic time, and still occurring. But what does appear to be different is the possibility of a new driving force and cause of the climate change. Changes we normally observe over a geologic time period are happening in a shorter span, particularly since the start of Industrial Revolution. Apparently, human activities are causing climate change. The concentrations of key anthropogenic greenhouse gases such as carbon dioxide (CO<sub>2</sub>), methane, nitrous oxide and tropospheric ozone have reached their highest levels ever, primarily due to the combustion of fossil fuels, agriculture, and land-use changes. Pre-industrial concentrations of CO<sub>2</sub>, methane and nitrous oxide were about 280 ppm, 700 ppb and 270 ppb, respectively. The ozone depleting chemicals such as

chlorofluorocarbons (CFC-11) and hydrofluorocarbons (HFC-23) did not exist during that period, and perfluoromethane was about 40 ppt. The current CO<sub>2</sub> concentration is about 365 ppm (increasing at the rate of 1.5 ppm/year), methane is about 1745 ppb (7.0 ppb/year) and nitrous oxide is about 314 ppb (0.8 ppb/year). Even if we curtail the emissions; these gases will stay in the atmosphere for a long time as the atmospheric life time for these chemicals vary (5-200 years for CO<sub>2</sub>, 12 years for methane and 114 years for N<sub>2</sub>O). These changes in the atmospheric chemistry are causing the so called "greenhouse" effect (Fig. 1).

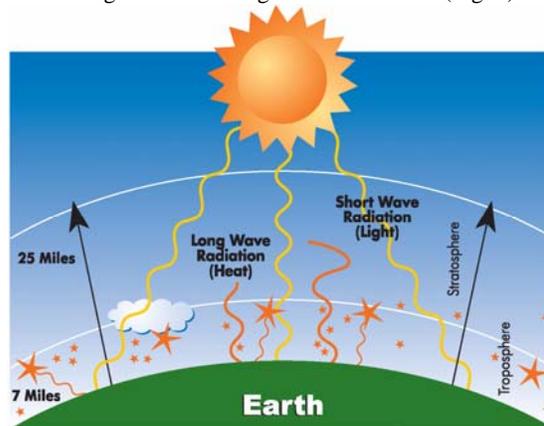


Fig. 1. The earth is covered by a blanket of gases which allow light energy from the sun to reach the earth's surface, where it is converted to heat energy. Most of the heat escapes our atmosphere, but some is trapped. This natural effect keeps the earth warm enough to sustain life. However, human activity such as burning fossil fuels (coal, oil and natural gas) and land use changes is pumping more greenhouse gases into the atmosphere that traps more heat, so the earth becomes warmer.

As the Sun's energy passes through the atmosphere and warms the Earth surface, some is reflected back into the atmosphere and dissipates into the space. The greenhouse effect refers to accumulation of specific gases that absorb the reflected radiation, effectively trapping heat in the lower atmosphere similar to what occurs in a glasshouse. The most important heat trapping gases are carbon dioxide, water vapor, methane, nitrous oxide, chlorofluorocarbons, and ozone. If current greenhouse gas emission rates continue into the future, both agricultural and natural ecosystems will face enormous pressure from the stressors caused by these heat trapping gases. Past changes have presumably resulted in about 0.6 °C increases in global temperature over the last century. The climate models project that there will be even greater warming during the 21<sup>st</sup> century. The CO<sub>2</sub> concentration is projected to reach 405 to 460 ppm by 2025, 445 to 640 ppm by 2050 and 540 to 970 ppm by 2100. The projected global mean temperatures for those CO<sub>2</sub> stabilization scenarios are 0.4-1.1 °C by 2025, 0.8-2.6 °C by 2050 and 1.4-5.8 °C by 2100 above values in 1990. Similarly, the projected mean sea level rise for

those periods are 3 to 14, 5 to 32 and 9 to 88 cm, respectively. These changes in climate are unprecedented during the last 10,000 years. It is also projected that all land areas will warm more rapidly than the global average, particularly at high northern latitudes in the cold season. Also, the projections indicate that there will be more hot days; fewer cold days, cold waves, and frost days; and reduced diurnal temperature range with higher nighttime temperatures. As the world becomes warmer, the hydrological cycle will also become more intense resulting in more uneven and intense precipitation. This will result in increased summer drying and associated risk of both droughts and floods. The projected climate change will have beneficial and adverse effects on both environmental and socio-economic systems, but the larger and more abrupt changes in climate will cause the more adverse effects to predominate.

In addition to the greenhouse effect, there is another phenomenon known as "ozone hole". A form of oxygen, ozone plays two roles in the atmosphere. Near the ground, ozone is an air pollutant and a minor greenhouse gas that damages human health and the environment. In the upper atmosphere known as stratosphere (10-30 miles above the earth's surface), it forms a layer that helps protect life on the earth from the sun's harmful rays, the ultraviolet radiation. The "ozone hole" refers to thinning of this layer because of chemical reactions in the stratosphere, especially at higher latitudes due to release of ozone depleting chemicals known as halocarbons. The rate of change in CFC-11 has declined due to binding of member countries of the guidelines proposed by Montreal Protocol, but the concentrations are still high (268 ppb) and other chemicals such as HFC-23 and perfluoro methane are at about 14 and 80 ppt, respectively. The atmospheric concentrations of many of these gases are either decreasing or increasing more slowly in response to reduced emissions under the regulations of the Montreal Protocol and its Amendments. The resident atmospheric times for these chemicals, however, vary greatly; 45 years for CFC-11, 260 years for HFC-23 and over 50,000 years for perchloromethane and will have long-term effects on climate system. As a result, the ozone layer in the stratosphere has thinned substantially resulting in about 35% increase in ground-level ultraviolet radiation from the preindustrial period. Higher ground-level ultraviolet radiation has many effects on human, animal and plants systems.

#### **What is potentially at stake?**

Climate change will have potential impacts on every sector of our society. However, vulnerabilities vary across regions, and also adaptations vary greatly among regions and countries.

**Agriculture and food security:** Based on both experimental and modeling evidences, crop yield responses to climate change are projected to vary widely, depending upon species, cultivar, soil properties, pests and pathogens. Even though rising

carbon dioxide levels can stimulate crop growth and yield, CO<sub>2</sub>-fertilization and water-saving effect may not always overcome the climate induced adverse stressors such as rising temperatures and increasing droughts. Crop yields to climate change are generally projected to be positive at mid-latitudes for small temperature increases but large yield decreases if temperature changes are more. The reproductive potential and capacity of many plant species are extremely sensitive to higher temperature and experimental evidence shows that rising CO<sub>2</sub> may not ameliorate the negative effects of high temperature on these life critical processes. For tropical and subtropical regions, the modeling assessments show that crop yields decrease generally with even minimal increases in temperature, because many crops are near their maximum temperature tolerance, particularly in dry/rainfed agricultural areas.

**Hydrology and water resources:** The influence of climate change on hydrology and water resources varies greatly among regions. Climate model projections indicate increased stream-flow in high latitudes and Southeast Asia, and decreased in central Asia, the area around the Mediterranean, southern Africa, and Australia. Arid and semiarid regions of Asia are expected to experience severe water shortage and stress with projected changes in climate. This will lead to more potential droughts in the summer, and will be more pronounced in the event of extremes in precipitation events as projected in the future climate. Fresh water availability and quality of the available water will be highly vulnerable to projected changes in climate, particularly in developing countries. In addition, growing populations and concentration of population in urban areas as we are witnessing now, and land use changes will exert increasing pressures on water quantity and quality. In addition, many coastal areas will experience increased flooding, accelerated erosion, loss of wetlands and mangroves, and inundation of seawater into fresh water sources due to projected changes in climate.

**Natural ecosystems:** Past climate change effects and vegetation modeling studies indicate that climate change has the potential for significant disruption of natural ecosystems. Migration of ecosystems or biomes as discrete units is unlikely to occur; instead at a given site, species composition and dominance will be drastically affected. Climate change is projected to lead poleward movement and a shift toward higher altitudes of many animals and plants. Many species and populations currently under high risk are projected to be under greater risk because of pressure from human induced climatic change factors and land-use changes. These stressors not only place immense pressure on natural ecosystem services and goods, but also cause some species classified as critically endangered to become extinct and endangered or vulnerable species to become rarer and thereby closer to extinction in the coming decades. In addition, watershed hydrology and water resources are

projected to change in the future climates, which in turn, will have much greater impact on natural ecosystems. Also, terrestrial ecosystems are an important component of the global carbon cycle, currently sequestering and storing approximately one fourth of the human carbon emissions, and thus providing an important service in decreasing the rate of CO<sub>2</sub> accumulation in the atmosphere. However, when considering managed or natural forests, we should focus on the multitude of benefits that natural ecosystems provide such as wildlife and aesthetic values rather than a single element based management strategy such as carbon sequestration.

In addition to natural and agricultural ecosystems, human health, settlements, energy and industry will be greatly influenced by changes projected in climate. However, the vulnerability of human populations and natural systems to climate change will differ greatly across regions and across populations within a given region. Resource rich economies will be in a position to adapt and cope with climatic changes compared to resource poor economies. Some regions and states such as island states, and low-lying areas are particularly vulnerable to sea level rise and storms projected in the future climate.

#### **Management or mitigation strategies**

There are several options to reduce the emissions of and to mitigate climate change impacts on human, animal, agricultural and natural ecosystems (Fig.2). Technological and other methods of limiting greenhouse gas emissions and developing alternative energy sources should be given higher priorities in all countries.

We may have to look back into the last century water management and use policies and see if the past approaches which relied on the construction of massive storage for water such as dams, aqueducts, pipelines and treatment plants that benefited millions of people can meet the future water needs. We should bring ecological needs in devising future water management and use. A long-term water management and use planning should involve all stakeholders to meet the basic human and ecological need for water, improving water quality, and eliminating overdraft of ground water. Also, we should reduce the risks of conflicts between states within the countries and between nations over shared water flow and use.

Preserving natural ecosystems and developing sustainable agroforestry should also be utmost important. Impacts of climate change on biodiversity have received little attention, and linking biology of biodiversity to climate change is much more difficult to assess. We now have some general understanding on how certain groups of plants will respond to climate change, but in experimental settings, no two plant species responded the same way to changes projected in climate. Mixes of plant species responded even more differently than individual species. Therefore, loss of a few species on processes such as photosynthesis may not be that great. However, climate change may eliminate some species

from the landscapes and may also cause the mix of species in a given biome, and substantial species loss will diminish the gene pool available for developing new foods, medicines and industrial products.

As for as agriculture is concerned, we should focus on crop management strategies to minimize agriculture contribution to greenhouse gas emissions. In addition, develop cultivars tolerant to stresses either through traditional breeding or biotechnology methods, develop strategies minimize impacts of water stress by devising water-saving irrigation technologies. Preserving crop genetic resources should also be given utmost importance as they may provide the genetic material for developing stress resistant crop cultivars. This is very important for countries closer to equator where high temperatures are currently limiting crop yields, and in a changing climate, these regions will have fewer options to change planting dates to optimize production. The crops in these regions are already experiencing yield losses because of prevailing higher than optimum temperatures during the cropping seasons.

#### **Concluding remarks:**

Climate change cannot be viewed in isolation, but rather must be considered in a broad context of other human and naturally occurring stresses on ecosystems such as air and water pollution, habitat destruction and fragmentation and land-use changes and biodiversity and invasive or species dominance. We must develop strategies, irrespective of developed or developing nations, in reducing the impacts of climate change on human, natural and agricultural ecosystems. We have already introduced enough greenhouse gases to warm the planet for many decades to come. We are living and seeing the signs of that environmental change did to the planet's natural resources. If we don't take action to prevent or slow the direction of climate change, we will create an environment that may not be as productive of goods and services as we have today for future generations. Climate change has no boundaries and the impacts of climate change on our planet's resources have implications for human wellbeing in the near future, and for many generations to come. We should place utmost importance in research that documents the signs of climate change on natural, agricultural, and human systems, and also develop models that provide adequate warning and guidance for policy makers to act proactively rather reactively to climate change. There are opportunities for everybody to transfer technologies and practices that have the potential to adapt to climate change and/or reduce emissions of greenhouse gases that influence climate. At present, we may not have all the answers, but we should take actions now to prevent damage done to climate, and its impacts on ecosystems. The future generations will surely blame us if they find that we understood the reality and dire magnitude of anthropogenic climate change, but failed to act to at least to mitigate the processes that cause climate change.

**Further Reading:**

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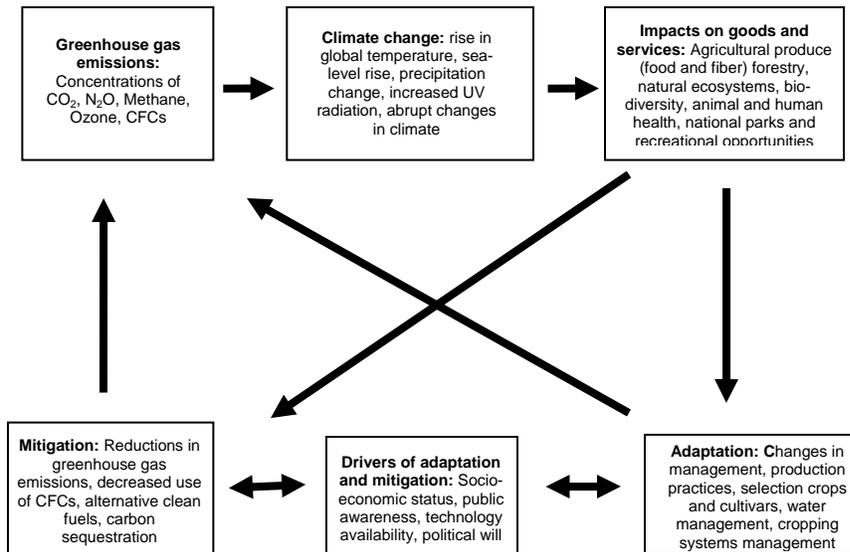


Fig. 2. Linkages between various facets of greenhouse gas emissions, climate change, ecosystem goods and services, and drivers of adaptations and mitigation and options.