Climate Change: The Tragedy of the Commons?

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1. Background

What do land use and climate change have in common? Garrett Hardin (1968) provides the connection in his *Science* article, "The tragedy of the commons." In the old English "commons" system, a plot of land (a "common") was allotted to the commoners for grazing, farming, and collecting wood. Each person's cattle consumed a relatively small portion of the available grass and each ax chopped down few trees. However, when they all did this, the land was quickly overgrazed, the soil lost its nutrients, and the forest disappeared. The "commons" then became useless. Had the land been managed and each person's use somehow limited, the setup would have been sustainable, and the commons would have lasted a very long time.

Most atmospheric scientists believe that humans can and do affect our atmosphere by adding pollution to the system. Each factory and power plant adds a small amount of pollution. Nevertheless, the collective effect is potentially destructive. The ozone hole and global warming are two major environmental concerns of our time. The international community has reacted and is in various ways. If successful, these efforts could prevent a tragedy from happening to earth's precious atmosphere.

2. The Ozone Hole and the Montreal Protocol

Stratospheric Ozone (O_3) filters out most of the sun's ultraviolet radiation. This high energy radiation is harmful to life on earth. Lowering ozone concentrations leads to increased skin cancer in humans, for example.

Ozone concentrations are normally 250 DU (Dobson Units; the thickness in millimeters when ozone is brought down to 1000 mb adiabatically) in the tropics and over 400 DU in high latitudes. However, since the late-70's, "ozone holes" have formed annually over Antarctica during the Austral spring (Fig. 1). During the cold, isolated polar night, polar stratospheric clouds form. In the spring, chlorofluorocarbons (CFCs), along with other chemicals, act as a catalyst to destroy ozone in the vicinity of these clouds. Ozone concentrations can fall below 200 DU during these events.

Stratospheric ozone depletion from CFCs had been predicted in a paper by Molina and Rowland (1974). This research was not appreciated by the CFC industry, which ran numerous defensive press releases and articles in such publications as the *New York Times*, the *Wall Street Journal*, *Business Week*, and the London *Observer* (Blyskal and

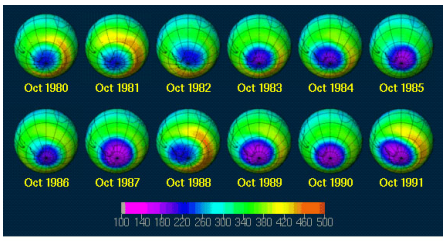

Figure 1: Antarctic ozone holes from 1980-1991. From www.atm.ch.cam.ac.uk

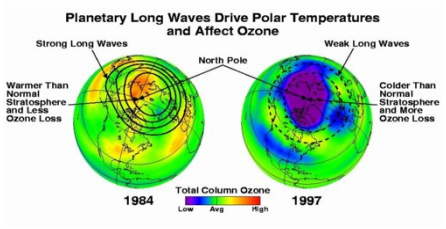

Figure 2: Example of a year without an Arctic ozone hole and one with an Arctic ozone hole. From http://science.nasa.gov

Blyskal 1985). They also paid at least one respected scientist (Richard Scorer) to argue against Molina and Roland (Roan 1989). Nevertheless, the ozone holes had only grown since their discovery, and Molina and Roland won the Nobel Prize in Chemistry for discovering that CFCs can deplete the ozone layer. More importantly, the international community recognized the threat and was ready to act.

The 1987 Montreal Protocol was the first international attempt at resolving a global environmental issue through cooperative action (Makhinjani and Gurney 1995). It called for the developed countries to freeze CFC consumption in 1989 and phase it out in 1996. The US had already banned CFC use in 1978. Developing countries were to freeze consumption in 1999 and phase out the chemicals' use in 2010. Since the original Protocol, amendments have been made to include other gasses and more countries. Originally, only 27 countries had agreed to the Protocol, but currently there are over 180 participants.

In the mid 90's ozone holes started appearing over the Arctic (Fig. 2), though less dramatic and less well-defined than those over the Antarctic (Muller et al. 1997). The Arctic ozone hole is attributed to relatively cooler winters in the stratosphere, which is more favorable for the creation of the polar stratospheric clouds that aid ozone depletion (Muller et al. 1997). The appearance of ozone holes over the Arctic is a surprise given the efforts of the Montreal Protocol, even if they do not appear every year.

The 2004 Antarctic ozone hole was 20 per-cent smaller than in 2003, but the 2003 hole was the second largest observed, and the largest observed in August (Fig. 3). It is still too early to tell whether the recent CFC reduction, which has been a measurable success of the Protocol (Fig. 4), is really leading to the elimination of the ozone holes.

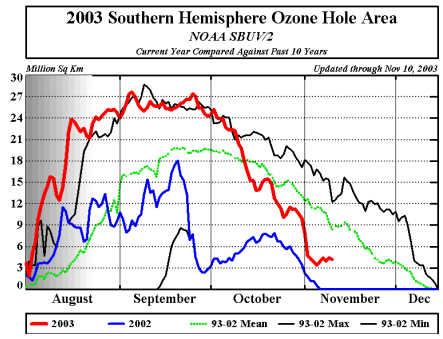

Figure 3: Comparison of the sizes of the 2003 Antarctic ozone hole with other years. From www.cpc.ncep.noaa.gov

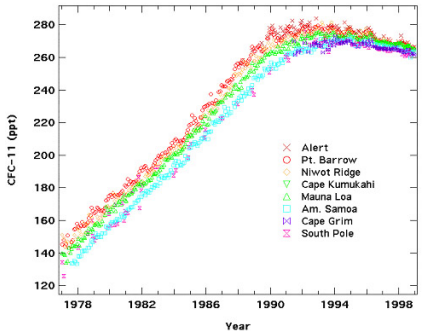

Figure 4: Measurements of atmospheric CFC concentrations in the lower atmosphere versus time. After Elkins et al. (1993)

If global warming is causing cooler *stratospheric* temperatures, stratospheric water vapor would condense more readily and polar stratospheric clouds may be more prevalent. Then the ozone holes may persist for decades despite the efforts of the Montreal Protocol (Stolarski 1997; Muller et al. 1997).

3. Global warming and the Kyoto Protocol

a. Early History of Global Warming

Surface temperature observations and indirect temperature measurements lead the majority of climatologists to believe that the planet has warmed 0.6^{o}C over the last century, that it is mostly our fault, and that in the future warming will accelerate further if steps are not taken by the international community (Kellogg 1991). The greenhouse effect is one of the most accepted aspects of climate theory: Gasses that are absorptive in the long wave terrestrial radiation trap this radiation in the troposphere and lead to warming above the planet's radiative equilibrium temperature. The idea behind

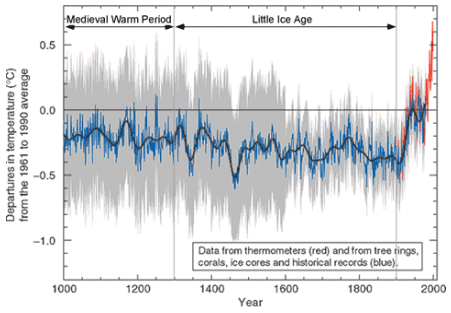

Figure 5: The "hockey stick profile." Measured and proxy global mean temperatures over the last 1000 years. From www.unc.edu

global warming is that humans have been emitting these "greenhouse gasses" into the atmosphere since the industrial revolution, and that increasing these gasses will lead to further warming and a noticeable change in climate.

The first description of a possible global human-induced warming was by the Swedish scientist Arrhenius (1896). However, for the first half of the twentieth century, climate change research focused mainly on possible extraterrestrial influences on the climate. After all, surface temperature observations were not yet as extensive as they currently are, and there was yet no need to seek out proxies for temperature like ice cores and tree rings. In the first few decades of the 1900s there was interest in correlating sunspot activity to surface weather, but the correlations turned out to be insignificant (Bigelow 1903; Norton 1957; Hartmann 1994). Efforts to relate the occurrences of ice ages to variations in the earth's orbit, so-called Milankovitch or orbital parameter theory, has seen a longer and more successful history (Croll 1890; Milankovitch 1941; Hartmann 1994). But this theory acts on timescales much longer ($\approx$40000 years) than the observed global warming trend during the last century (Fig. 5).

Gilbert Plass, one of the *Manhattan Project* researchers, announced after a decade of spare-time research that human activities were raising global temperatures (Plass 1956). This was at a time when the increase in weather observations during the World Wars was leading scientists to accept the human-induced global warming hypothesis.

b. Impacts of Global Warming

In an extreme scenario (dramatized in *The Day After Tomorrow*) global warming sets off an ice age by showing or stopping the planetary ocean thermohaline circulation. Cold, dry, windy conditions over North America and Europe, and dry, intermittent monsoons in East Asia are the result (Schwartz and Randall 2003). Despite the remoteness of this possibility, military implications such as migrations and border skirmishes are noted in this report prepared for the Department of Defense (Schwartz and Randall 2003). Another catastrophic (but remote) possibility is a sudden (decade) 5-6 meter seal level rise from a collapsing West Antarctic Ice Sheet (Symposium 2004). This would be devastating to coastal areas and low-lying areas. Though extreme, these scenarios illustrate that the effects of global warming are not just on thermometer readings.

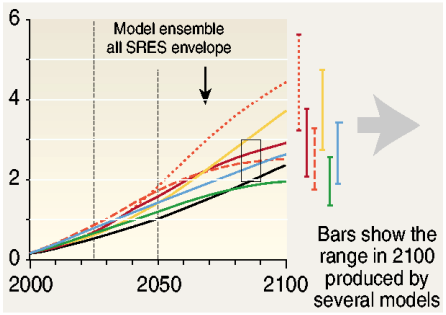

Figure 6: Global mean temperature projections with doubling of carbon dioxide above preindustrial concentrations, from several models (IPCC 2001).

In a system as complex as our climate system, changing one variable often has consequences for other variables. Changing the temperatures worldwide by a few degrees may not in itself sound alarming, but one must remember that other variables are affected as well. Most importantly, precipitation. Precipitation is a crucial determinant of where and when we can grow crops, and our current infrastructure is built around it. Under global warming, these infrastructures are forced to change in response to, say, global food demand. The resources (especial financial) to do this lie with the rich, who are also the biggest contributors of greenhouse gasses. It is hard to believe that these resources will be used in an equitable way throughout the whole earth, despite the fact that these greenhouse gasses affect the entire planet. Perhaps these effects should be emphasized more than ”the number,” the global mean temperature increase with a doubling of carbon dioxide.

Last October the European Climate Forum (EFC) met in Beijing to discuss the projected effects of global warming and the associated amounts of warming required for each effect. The approach was to determine how much warming is ”safe.” They divided the potential effects into determinative dangers, early warning dangers, and regional dangers. The determinative effects affect the whole planet and are the most troublesome. They include sea level rise and food scarcity. Early warning effects, like arctic sea ice retreat, boreal forest fires, and increased drought frequency, are already present and could get worse according to the EFC. Regional dangers are potential impacts on a regional scale like local water and food resources, infrastructures failing, and ruined ecosystems. Most of these effects occur with $\approx$ 2–5^{o}C warming, well within the range of model estimates (Fig. 6) (Symposium 2004; IPCC 2001).

c. International Response to Global Warming

In the 70's, increased occurrences (or awareness?) of extreme weather events lead to the First World Climate conference being held in 1979 in Geneva, and the Intergovernmental Panel on Climate Change (IPCC) was formed in 1988. As stated in the foreword of their most recent report (their third), their goal is to:

> (1) Assess available information on the science, the impacts, and the economics of – and the options for mitigating and/ or adapting to – climate change; and
> (2) Provide, on request, scientific/technical/socio-economic advice to the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) IPCC (2001).

The most recent meeting of the IPCC was 1-3 March 2005 in Honolulu, Hawaii. The purpose was mainly to begin preparations for the its fourth assessment report.

The first IPCC report had emphasized the influence of human activities on global warming (IPCC 1990), but the IPCC does not have authority to require specific action. Two years after the first report, the UN Framework Convention on Climate Change was signed at the Earth Summit in Rio de Janeiro; currently over 180 countries are parties to the agreement. The parties agree to act towards stabilizing greenhouse gas levels to "safe" levels and to report their actions in annual meetings; they emphasized the developed countries' responsibility to provide the resources for climate change research (UNFCCC 1992). The agreement did not call for any specific mandatory actions, but it recognized that the atmosphere is international "commons" and that some actions would be needed to keep it healthy. In 1997 the Kyoto Protocol was negotiated. It did call for specific actions. Developed countries are to cut emissions of most greenhouse gasses 5 percent by 2012. If a country exceeds its requirement, it can "sell" the right to emit some greenhouse gasses to another country. The Kyoto Protocol went into effect on 16 February 2005–ninety days after Russia ratified it, fulfilling the requirement for it to formally go into effect.

The U.S. never ratified the Kyoto Protocol and pulled out of it completely in 2001, claiming they would work to reduce emissions unilaterally. This kind of unilateralism is certainty a fundamental part of the Bush administration's foreign policy. But the U.S. is the biggest greenhouse gas producer, and there is no guarantee that the administration will in fact fulfill its promises. Also, the Protocol exempts developing countries like China and India, which are rapidly catching up to the developed world in greenhouse gas emissions (Fig. 7).

Carbon is a fundamental component of our largest energy source–the burning of fossil fuels. This makes the Kyoto Protocol harder to fulfill than the Montreal Protocol. Rather than simply using different chemicals in refrigerators, air conditioners, and spray paint, we are faced with fundamentally changing the way we procure something essential to our daily life–electricity. Alternative non-carbon releasing energy sources exist, such as nuclear fission, solar, wind, and hydroelectric power (nuclear fusion is still well in the future). Probably the most promising for general use is nuclear power, since not every part of the world is blessed with strong sunlight, steady strong winds, and rivers. However, nuclear energy has its own environmental and security issues.

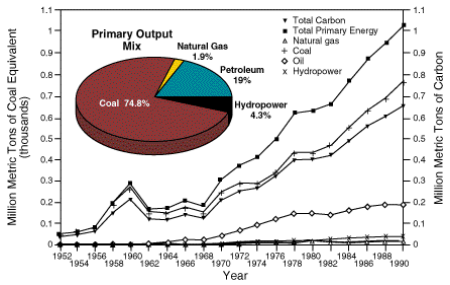

Figure 7: China carbon emissions, from www.esd.ornl.gov

Chernobyl and Three Mile Island come to mind when one is faced with the decision of whether to put a nuclear reactor in one's neighborhood, or even outside of one's city. Further, North Korea's admitted current nuclear weapon program and Iran's alleged program lead the international community–especially the U.S.–to be cautious about the use of nuclear fission. We must not forget that an operational fission bomb was developed before an operational fission reactor.

With no new energy sources in sight, the only way to reduce $C0_2$ emission is to burn less fuel and/or burn it cleaner. Hybrid cars are a good example of how this could be done (but in most cases the electricity used to charge the battery is produced by a coal power plant!), but industries are not eager to change while their current technologies are selling just fine, and while this generation of power plants still has decades of life. Thus it would seem that until energy consumption or industry practices fundamentally changes, it will be difficult to fulfill the Protocol, let alone reduce greenhouse gas concentrations to the pre-industrial values.

4. Summary

Hardin's popular article "The Tragedy of the Commons" may be applied humankind's use of the natural resources of the atmosphere. Here the dangers associated with ozone depletion and global warming are considered. In both cases, the industrial emissions of a gas are found to alter the atmosphere in a harmful way. The ozone holes are caused by several gasses, of which chlorofluorocarbons (CFCs) are the most dangerous. Global warming occurs when "greenhouse gasses" are added to the atmosphere. The strongest greenhouse gas is water vapor, but the second is carbon dioxide–an intrinsic result of burning fossil fuels for energy. Because the atmosphere cannot be "enclosed" like the fields of Britain, these issues are international in scope. In both cases, an international agreement has been drawn up which calls for reduced production of the harmful gas.

The Montreal Protocol (1987) was meant to address the issue of ozone depletion. Originally only 27 countries agreed to the Protocol. At first countries were reluctant probably because an international environmental agreement of this scope had not been attempted before. Further, there was considerable opposition from the chemical industry. But as the Antarctic ozone hole began to affect populated areas of South America, and as an ozone hole appeared over the arctic with decreased ozone concentrations

throughout the northern hemisphere, the Montreal Protocol participants increased to include most of the world. The U.S. action on this issue was immediate and decisive: CFCs had been banned almost a decade before the Montreal Protocol was even signed. Despite the efforts of the Montreal Protocol, ozone depletion may be aided by global warming, which is not likely to go away soon.

In the case of global warming, it was the Kyoto Protocol (1997) that was drawn up and carbon dioxide that was the major "bad" gas. This agreement involved most of the world at the start, but it's requirements are less stringent than the Montreal Protocol had been on CFCs, especially for developing countries. Whereas banning CFCs simply meant that different chemicals needed to be used for some modern conveniences, carbon is a fundamental component of our major energy source–the burning of fossil fuels–and there is no viable substitute in sight. The U.S., the biggest greenhouse gas producer, pulled out of Kyoto. Also, developing countries like China and India are rapidly catching up in energy consumption and greenhouse gas emissions, and the requirements of the Protocol are much more lax on these countries. Global warming will be an issue throughout most of the twenty-first century, and it may delay or reverse the rebound in stratospheric ozone expected from decreased CFC emissions. It would seem that our efforts have not yet solved this case of "the tragedy of the commons." Nevertheless an attempt is better than no action.

5. Acknowledgments

An online article "The Skeptics vs. the Ozone Hole" was helpful in summarizing the information in Section 2. It can be found at $www.wunderground.com/education/ozone_skeptics.asp$. Also, the information provided at the website $www.realclimate.org$ contained helpful commentary and background information for this paper. "RealClimate is a commentary site on climate science by working climate scientists for the interested public and journalists. We aim to provide a quick response to developing stories and provide the context sometimes missing in mainstream commentary." CNN.com's 15 February 2005 interactive global warming timeline ($http://www.cnn.com/interactive/tech/0502/timeline.global.warming/content.1.html$) was a useful summary of the history of global warming policy.

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