

GLOBAL CLIMATE CHANGE AND ITS EFFECTS

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My task is to try to set the stage with respect to the size of the climate issue – what we know, what we don't know, what we sort of understand. Definite uncertainties exist. We don't know as much as we wish we did, and right now the question is how should we address the issue.

Emissions from Human Activities are Changing Atmospheric Composition

Presently, we are causing the CO₂ concentration to rise and it is clearly a result of human activities. The concentration of CO₂ was about 280 parts per million (ppm), or 0.028%, before the start of the Industrial Revolution; it is now over 360 ppm. The rising CO₂ concentration is caused by emissions are of two types. Since the start of the Industrial Revolution, there have been substantial emissions due to cutting down forests for the purpose of expanding agriculture (Figure 1). The biospheric emissions from deforestation are currently roughly



Figure 1: Deforestation worldwide adds 1 to 2 billion metric tons of carbon to the atmosphere each year. CLIMATE CHANGE, State of Knowledge, October, 1997; photo by ©P. Grabhorn.

one billion metric tons of carbon per year. In comparison fossil fuel emissions total about 6 billion metric tons of carbon per year. To put that into perspective, there are six billion people on the planet, so emissions total one metric ton of carbon per person per year, all being added to the atmosphere.

The atmosphere has an annual cycle where the CO₂ concentration tends to be high in the winter and low in the summer. Each year, the greening of the planet to create leaves, grass, etc., pulls CO₂ out of the atmosphere during the summer and returns CO₂ to the atmosphere in the fall and winter. If you multiply the seasonal change in CO₂ concentration of 7 to 8 (ppm) change each year by the volume of the Northern Hemisphere, you find out how much carbon is going into the hemispheric greening each year and how much is coming back out. It turns out to be about 7 or 8 billion metric tons of carbon per year which is roughly the same amount that is being put into the atmosphere each year as a result of human activities. In other words, human activities put as much CO₂ into the atmosphere each year as it takes to green the Northern Hemisphere each year. That is a lot of carbon.

As I said, the emissions of CO₂ per person are about one ton of carbon per year on a global average, but there is a dramatic variation across the globe. The United States is responsible for about 5 tons per person. Europe and much of the rest of the developed world adds about 3 tons per person each year, while citizens in most of the developing world add only a few tenths of a ton of carbon per person each year. These are dramatic differences.

It is important to realize in this debate that carbon emissions per person is a way of looking at this issue in terms of capita the relative equity around the world. Another way to look is at total emissions per country; using this measure the United States puts out the most and China's amount is growing at the fastest rate. We need to recognize that, while there are many different ways of portraying carbon emissions in the political arena, there is strong agreement that it is a human-induced effect.

We are also adding other components to the atmosphere. The second most important greenhouse gas that is being added by human activities is methane. Its concentration has been going up significantly. During preindustrial times its concentration was 700 parts per billion (ppb) or so, and it is now over 1700 ppb. In addition, we have been adding chlorofluorocarbons and nitrous oxides. To complicate things even further, we are also adding sulfur dioxide to the atmosphere, which creates aerosols, producing that whitish haze that we have in industrial areas. Quite clearly, human activities are changing the composition of the atmosphere. We are driving the climate system. The changes in these concentrations are affecting the climate, enhancing the natural greenhouse effect.

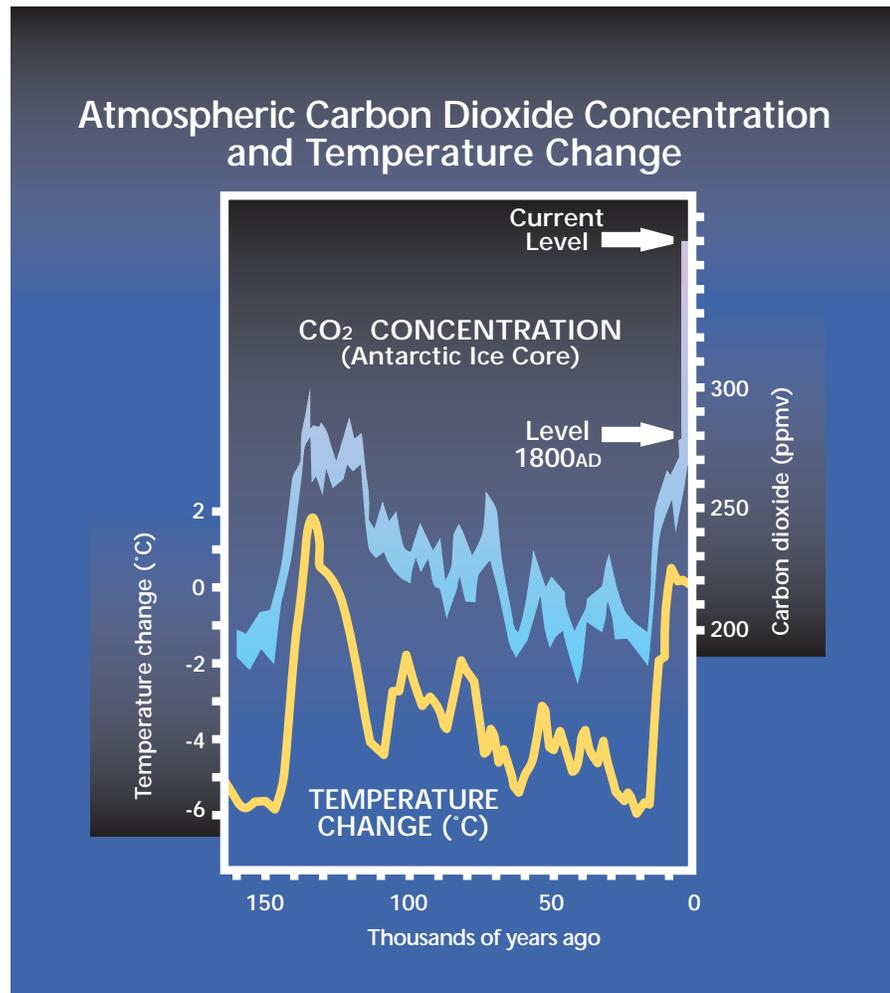


Figure 2: Atmospheric carbon dioxide concentration and temperature change. Source: Vostok ice core data from Barnola et al., 1987; current data from the Carbon Dioxide Information Analysis Center, 1997, Oak Ridge, TN.

Changing Atmospheric Composition will Enhance the Natural Greenhouse Effect

We know that the composition of the atmosphere determines how much heat (or infrared) energy is absorbed by the atmosphere and reradiated back to the surface. It is nice to think, especially on this sunny day, that solar radiation keeps us warm and provides the energy for the planet. While this is true, the surface actually receives twice as much heat energy radiated from the atmosphere as from solar radiation. Thus, solar energy absorbed at the surface is radiated away as heat energy, but then recycled by the atmosphere back to warm the surface.

We know that this is a real effect. One way we know this is by looking at what the climate might be if we were to have no atmosphere at all – like the moon. There is a very different climate on the moon. We also know this if we look at the climates of the planets. Observations indicate that Venus is very hot. The surface temperature is 700-800 °F. You might think that it is hot because it's closer to the Sun. This is

only partly true. It turns out that because Venus is very cloudy, it absorbs less solar energy per square meter than the Earth. It is very hot, it turns out, mainly, because of the very strong greenhouse effect, not just because it is closer to the Sun.

We also know that CO₂ and the climate are related because we can look back into the Earth's history. This graph (Figure 2) reconstructs conditions about 160,000 years into the past based on records of ice cores from the Antarctic. The blue curve is the concentration of CO₂ that is measured in tiny air bubbles that are trapped in the ice. Starting at zero (the present), there is a preindustrial concentration 280 part per million. Going back about 20,000 years, the CO₂ concentration during the peak of the last glacial (or "ice age") was about 200 parts per million, and this low level extends back for about 100,000 years. Going back 120,000 years or so, to the previous interglacial, the CO₂ concentration was about 300 parts per million. Scientists have since continued the record back about 400,000 years. Now the association is not perfect, but it is reasonably clear from the geologic evidence that the timing of glacial cycles is probably driven by changes in the Earth's orbit. Yet, if you consider just changes in the Earth's orbit as the driving force in a climate model, it will not produce an ice age. In order to get the conditions for an ice age, a major feedback mechanism like changes in CO₂ is needed. The evidence shows that carbon dioxide and methane are causing an important amplifying effect, with their greenhouse enhancement contributing to glacial cycling.

Enhancing the National Greenhouse Effect is Causing Changes in the Climate

Given the activities that have been changing the CO₂ concentration for a couple hundred years, are these changes affecting the temperature of the Earth? This is a record of the surface temperature (Figure 3) of the Earth's surface taken from numerous stations and ships representing land and ocean regions. The evidence shows that the aver-

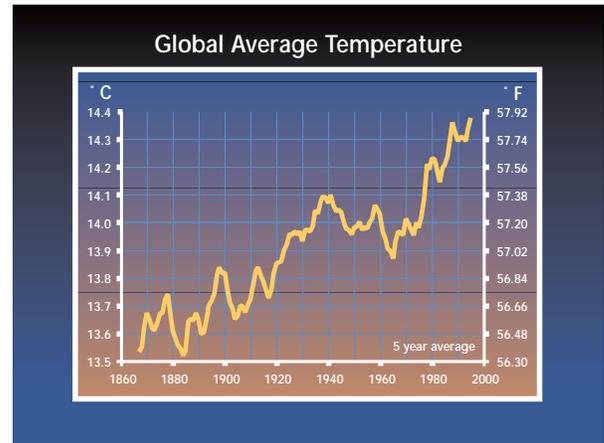


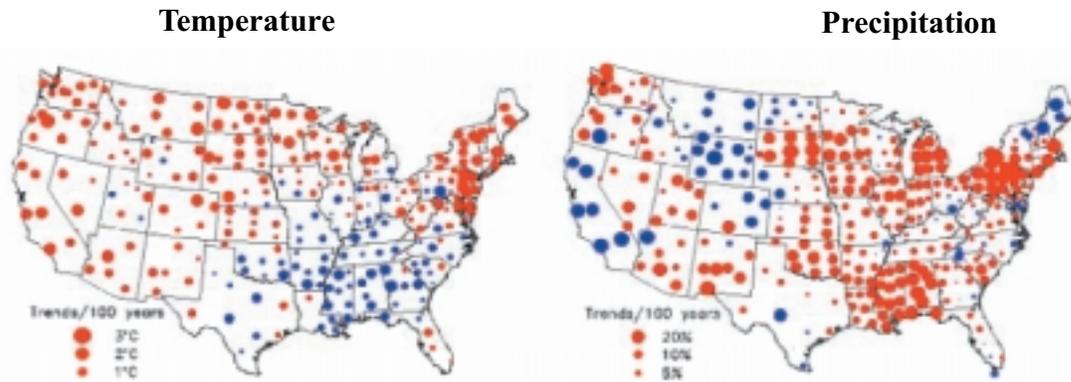
Figure 3: The global average temperature has risen by about 1° F over the last century. Source: Data from Hansen et al., 1995, Goddard Institute for Space Studies.

age temperature of the earth is climbing gradually. It has risen about 0.6 of a degree Celsius or so over the last hundred years. The increase is not completely smooth and scientists are working to understand why. But the temperature of the Earth is clearly going up.

Other kinds of changes are also occurring. Figure 4 provides a record of where the temperature is going up in the U.S. over the last 100 years. It is warming almost everywhere. The size of the dot is an indication of the size of the trend. In some places it is warming more than others. To understand why there are changes in different regions, we must understand the regional details of climate change and that can be difficult. For example, in the North Atlantic, temperatures can be affected dramatically by what is happening to the ocean currents. Over the industrialized regions of the U.S. and to some extent over parts of Europe, the presence of sulfur aerosols may be diminishing the warming influence by somewhat masking the effect of the greenhouse gases.

There are also changes in precipitation occurring over the U.S.— it is gradually getting wetter. That is expected from the warming of the world, which will intensify the hydrologic cycle. Again the pattern over the U.S. is not completely uniform. As was commented by the speaker last night,

Temperature and Precipitation Trends, 1900 to Present



Red circles reflect warming
Blue circles reflect cooling

Red circles reflect increasing precipitation
Blue circles reflect decreasing precipitation

Figure 4: U.S. temperature and precipitation on trends over the last 100 years. Source: Karl et al. (1996).

we do need to look critically at the data, particularly when we see systematic differences across state boundaries. Some state boundaries correspond with natural features like the Sierra Mountains, for example, along the California border. But that is not always the case and we do have to be careful. Overall, however, we are seeing a general increase in the amount of precipitation, and there is additional evidence that this increase in precipitation comes primarily in the form of heavy storms (as opposed to more frequent, light rains).

So, in answer to the question “Is the world really changing?” I think it is. The near-surface temperatures are rising and the ocean surface temperatures are rising; temperatures measured in boreholes in the Arctic are showing warming; mountain glaciers are melting; and sea levels are rising from thermal expansion and from additional water from melting glaciers. There are a host of things that are happening, including the movement of some species to new locations. There are numerous indications that changes are occurring. The difficult question is to understand why that is the case.

One of the things that the Intergovernmental Panel on Climate Change (IPCC) reported on was research to what extent these changes are due to human activities. First of all, the rate of warming that has occurred recently is dramatically different than for most periods in the past. There have been a few periods in geological history where similar dramatic changes have been recorded, but there were also other simultaneous events in the natural world, that most likely contributed to the dramatic warming. Now, in the absence of these natural factors changing in these unusual ways, we are nonetheless seeing a rapid rise in temperature. Basically, the temperature is unusually warm compared to the other period in the past. We are seeing that the lower atmosphere has warmed over the past several decades, while the upper atmosphere has cooled. This type of change is an indication that greenhouse gases are causing the change rather than other factors. If the change were due to an increase in solar radiation, both the upper and lower atmosphere would be warming. That is not happening. Because greenhouse gases remain in the atmosphere for decades to centuries, whereas aerosols remain for only a couple of weeks, the greenhouse warming influence will

dominate over the long term. And so there is a range of factors that led the IPCC to conclude that, while we can't prove it definitively (i.e., we can't prove it beyond all doubt with very high statistical certainty), the balance of evidence suggests that there is a discernible human influence on the global climate.

The IPCC tried to estimate the magnitude of these changes. They used simplified climate models that include the effects of rising concentrations of greenhouse gases, the cooling influence of sulfate aerosols, and the natural variations that we think have occurred in the solar radiation, which probably caused a fair amount of the variability in earlier times. Comparing the model results with observations, the IPCC concluded that humans are indeed influencing the global climate.

The agreement however, is not perfect. One of the factors not yet included in these models are major volcanic eruptions. There was a series during the first decade of this century that likely tended to make that period a little bit cooler. There were also some major volcanic eruptions during the 20th that were not taken into account, such as Pinatubo eruption in 1991 (Figure 5). One interesting point is that, if these lower dips that occurred in the 19th century (e.g., 1883) were due to the



Figure 5: Aerial view of Mount Pinatuba after the cataclysmic June 15, 1991 eruption. Source: USGS/Cascades Volcano Observatory, photo by E.W. Wolf.

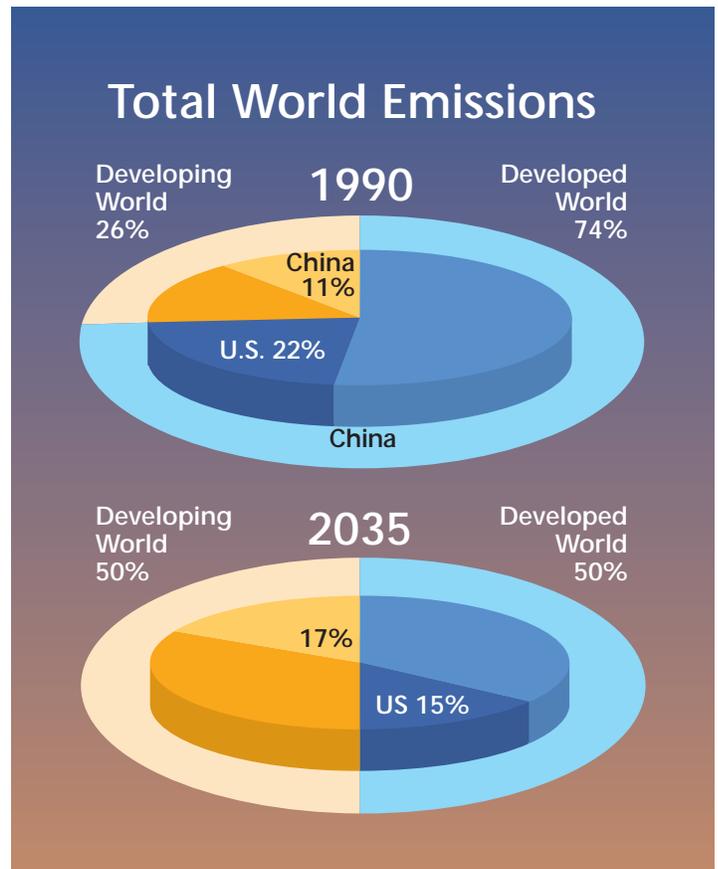


Figure 6: Total World Emissions, 1995 and 2035. Sources: Carbon Dioxide Information Analysis Center, 1997, Oak Ridge, TN; Edmonds, 1997, Battelle Laboratories, using IPCC IS92A emission scenario.

effects of major volcanic eruptions, and we think they were, the cooling after the Pinatubo eruption (which was comparable in size to the 19th century eruptions) did not take temperatures down anywhere near to what they were after the 19th century eruptions. This is one more indication that there is a warming trend that seems to be strongly influenced by human activities.

Future Emissions will Accelerate Global Warming

If we have a reasonable understanding that there has been a human effect on the recent climate, what is going to happen in the future? Human activities are currently causing the emission of 6 billion tons of carbon from fossil fuel combustion, with most of that coming from the developed nations of the world (Figure 6). In the future, there is likely to be some growth in the developed country emissions and very large growth in developing

country emissions. The IPCC estimated 20 billion tons of carbon per year in the year 2100. By that time there may be 10 billion people in the world, yielding a global average total of two tons of carbon per person per year. Compared to what we have right now, which is one ton per person per year, that will represent significant growth in per capita use, but use will still be much less than in the U.S. today. There are some people who have looked at the IPCC estimate for the central trend and think they are actually underestimating what could occur because the people of the world will want to use much more energy, and carbon emissions would be even higher in the future. Alternatively, if new energy technologies are widely introduced, emissions could be less.

So what will rising emissions mean for the future? Over the past 200 years we have gone from a natural CO₂ concentration of 200-300 ppm to a level of 360-370 ppm (Figure 7). By the year 2100, if we have these kinds of emissions, which is not at all implausible, the CO₂ concentration will rise to 700 parts per million, which was last experienced on the Earth, about 40 or 50 million years ago. This would be a very dramatic change.

Because projecting changes in emissions and concentrations are uncertain, the IPCC projects relatively broad range of possible future concentrations. The lower case scenario shown in Figure 7 goes up to about 500 ppm in 2100, and this is based on the assumption that there will only be 6 or 7 billion people in the world in the year 2100. Most people think the population is going to be a lot higher than that, and IPCC also has scenarios going to higher levels.

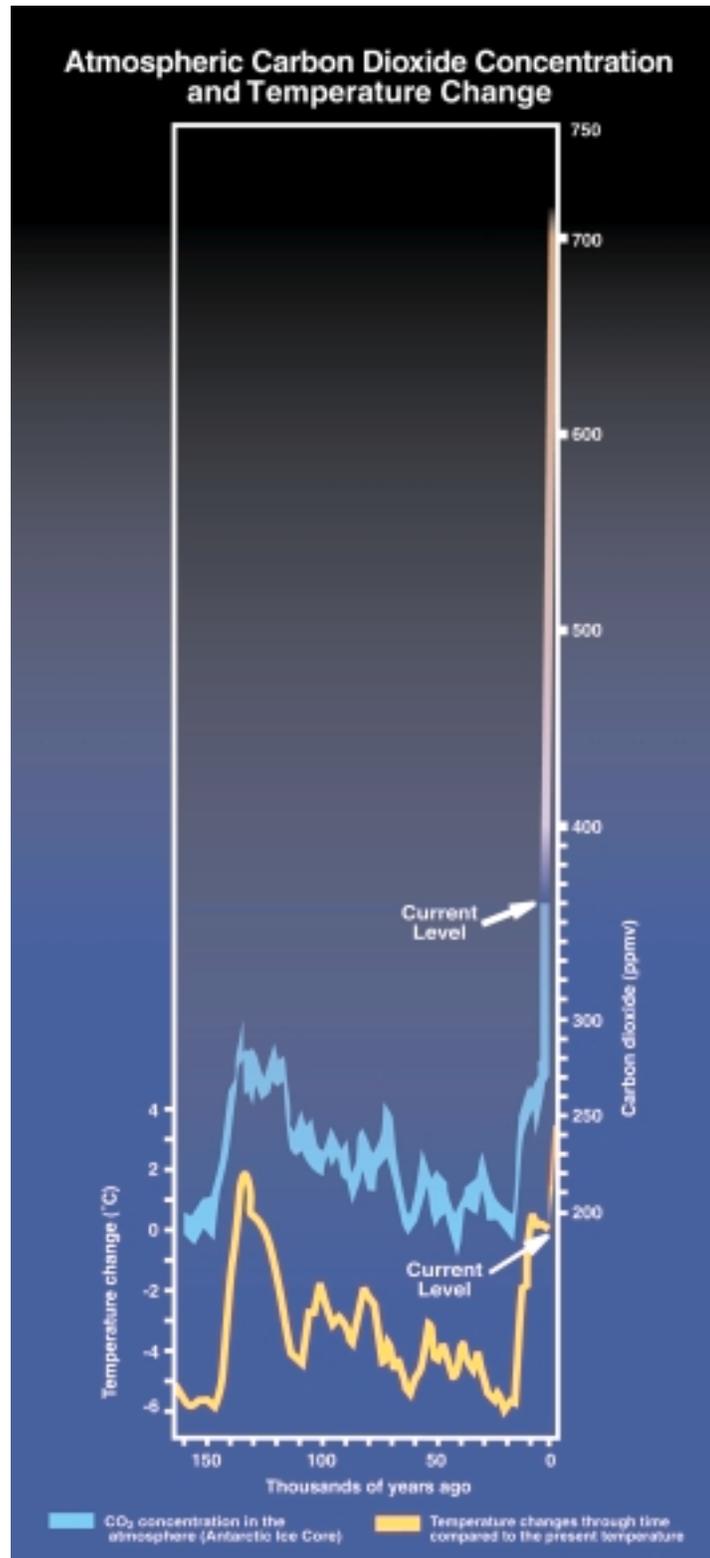


Figure 7: Atmospheric carbon dioxide concentration and temperature changes as projected to year 2100. Sources: Vostok ice core data from Barnola et al., 1987; current data from Carbon Dioxide Information Analysis Center, 1997, Oak Ridge, TN; Edmonds, 1995, IPCC emission scenario.

The climate is also going to change. If modelers assume the same response to changes in atmospheric composition as has occurred in the past, then there would be a temperature increase of about 1 to 3 1/2 degrees Centigrade. While this range seems quite broad, half of the range is due to uncertainty about how the climate will respond and the range of estimates in the climate simulation. The other half of the range is due to uncertainties in the socioeconomic assumptions – how the world will develop and what kind of energy we will use. Thus, although it sounds like a big range, it is important to understand that there are mainly two main contributors to the range.

Other changes that could occur include a potential over many centuries for intensified rates of loss of polar ice sheets in Greenland and the West Antarctic. There is a lot of ice tied up in those ice sheets – and a lot of sea level equivalent (loss of one of these ice sheets over several centuries would result in 15 feet of sea level rise). So, there are a lot of potential changes that could happen to the climate. We are getting better at modeling gradual changes, but there is also the possibility of unpredictable, sudden changes.

Consequences will Result from the Changing Climate

Most research over the past 20 to 30 years has been focused on *if climate is changing* and *is it due to human activities?* The IPCC findings are also giving a clear indication that climate is going to be changing much more in the future. Although we don't know the details, the climate will be changing. Now, the issue for some has become "So what! Who cares if it changes?" Here in Ann Arbor, in the winter you might like the temperature to be a few degree warming. On the other hand, if you are a farmer in Nebraska, a few degree warming in the summer may not be helpful at all. And so the questions have become, "What are the types of impacts that could occur?" I am

going to give a brief overview of the kinds of impacts that could occur.

It is important to recognize that when you look at the impacts of fossil fuels, that they are not only the cause of these changes, but provide a tremendous benefit to society that sustains our standard of living. Thus, if we are going to justify making changes with respect to fossil fuel use, we ought to be comparing the impacts of fossil fuel cutbacks with the major types of impacts that might occur.

One category of the effects of changes in temperature, precipitation and sea level rise, are human health. It is important to look at potential impacts as well as potential coping mechanisms. For example, warmer conditions in cities that exacerbate thermal stress may be offset with air conditioning of living quarters. There may be situations where disease vectors for infectious diseases are not killed off by the frost in the winter. For instance, some were concerned that the earlier spring that has occurred this year because of the El Niño will allow some of these vectors to become active earlier in the year. There are also health-related issues about air quality that should be given attention.

A second category of potential major consequences is agriculture. Agriculture in some regions may well benefit because CO₂ is a plant nutrient. If plants have enough water, sunlight and nutrients, increasing the CO₂ concentration can actually produce agricultural benefits. In particular, the technologically advanced countries may be able to get a significant benefit from the fertilization and the increased water use efficiency that occurs. The situation is more problematic in some of the developing nations because they have much less flexibility to move crops around because they rely more on traditional kinds of one-crop economies. Another potential issue are the consequences of impacts on species and the destruction of natural habitat.

There are shifts in various species and ecosystems that are expected with a change in climate. Forests tend to be very tightly attuned to the climate, so the

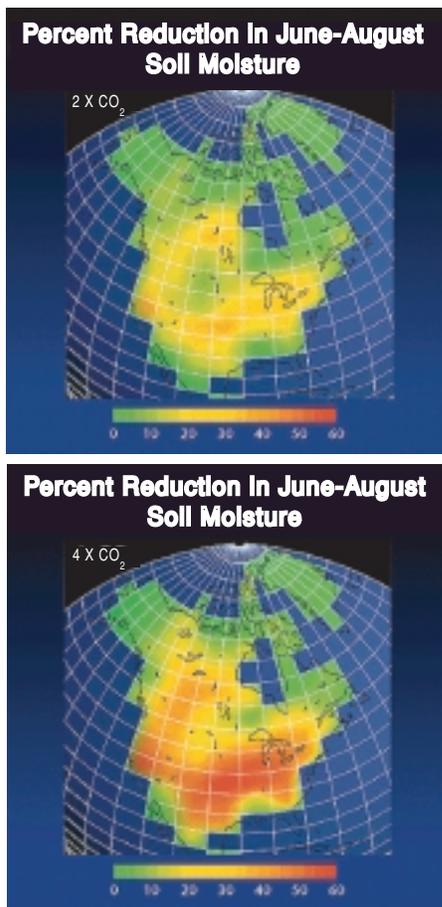


Figure 8: Percent reduction in June-August soil moisture, 2 X CO₂ and 4 X CO₂. Source: Manabe & Stouffer, 1994, NOAA Geophysical Fluid Dynamic Laboratory, Princeton, NJ.

forest composition will change in various ways – different species moving in different ways. Wildlife tends to be dependent on the particular timings of various ecosystem activities, and so there could, for example, be significant disruption to migrating species. Ecosystems tend not to move as a whole. Different parts have different sensitivities and they each move at different rates. They are likely to get torn apart, and the question is “What will happen with respect to how ecosystems move?”

Water resources are absolutely critical for society and the distribution of storms and rainfall are very important to determining water resources. This graph (Figure 8) is from a model calculation trying to give an *indication* of what may happen to soil moisture in various regions in the U.S. The

Figure shows consequences for two times CO₂ at the left and four times CO₂ on the right. All of these colors are showing significant percentage drops and reduction of soil moisture in the summertime. The farmers will need to cope with a range of effects as a result of reduced soil moisture — to do this, farmers may change planting times, rotate their crops, or they may have to start to irrigate (assuming that there are water resources and aquifers available). Changes in soil moisture may also provide the opportunity to try novel crops, although farmers would also need different management strategies to cope with an increased incidence of pests, weeds and disease.

Impacts on coastal regions are likely to be very important. Sea level is estimated to go up by about a foot to maybe as much as three feet over the next hundred years. This range depends, to a large extent, on what happens to the polar ice sheets. The expectation is that polar ice sheets will build up some snow for a while and keep the sea level rate from rising too fast. Eventually, we would expect to get sufficient warming for melting to begin. The main lingering uncertainty in scientist’s minds is that we can’t fully account for the sea level rise that occurred in the last hundred years without there having been some melting of the polar ice sheets. So, with limited knowledge about the magnitude of the projected sea level changes, it is difficult to project what sea level rise will mean for particular regions around the country and around the world.

For many regions of the country, a sea level rise is going to be particularly problematic. The coast in the mid-Atlantic region around Washington, D.C. is a particularly interesting area for some of us. There are many locations where businesses and residents are within three feet of sea level – there is a lot of coastal property that is right at sea level. A couple of years ago the Chesapeake Bay had major damage due to hurricane and storm surges. Local officials looked at historical records of sea levels and concluded that sea levels are rising about

a foot per century with about half of that due to global warming and about half due to the land sinking. They were very concerned. They had a conference and invited some Dutch engineers over to talk about it. The Dutch engineers turned out to be flabbergasted that the states of Maryland and Virginia didn't have a plan for building a levee across (the) Chesapeake Bay to protect them!

The Challenge of Slowing Global Warming

Given all these potentially important impacts, an important question to ask is how hard it is to do something about it? The nations of the world did agree at the Rio Summit and set the objective of trying to stabilize the climate so these kinds of impacts would not occur. This is rather an ambitious goal – to stabilize the greenhouse gas *concentrations*, not *emissions*, thereby to prevent dangerous anthropogenic interference on the climate. They set the qualification that needs to be done rapidly enough to slow down climate change and not disrupt ecosystems. However, we want to make sure that emissions are not cut so fast that food production is disrupted. We also want to do it in such a way that the cutback does not threaten sustainable economic development. This is quite a list of conditions – trying to figure out a pathway is quite a challenge.

To get a sense of what it takes to stabilize the climate system, we can estimate the reductions in emissions that are needed. If we want to stabilize the greenhouse gas concentration at today's level, we would have to reduce emissions to about two billion tons of carbon per year over the next century. That is one third of our present level, even though the population is increasing. That would be extremely difficult to do. If we want to stabilize at twice the preindustrial concentration, (about 550 ppm), we would need to limit the average emission rate for the next century to about eight billion tons of carbon. And remember what I said – the IPCC predicted that carbon emissions are projected to go from a level of 6 up to about 20

billion tons of carbon per year over the next century, or an average of maybe 12 or 13 billion tons per carbon a year for the next century, or an average of maybe 12 or 13 billion tons per carbon a year for the next century. To get the 8 billion tons of carbon per year in order to stabilize concentrations at two times preindustrial levels, we would need a 30-40% cutback globally below the projections.

Cutting the emissions too rapidly would endanger the global economy, whereas cutting emissions too slowly risks environmental damage and risks disrupting the climate. One approach might be to focus on technological options of improved efficiency and low-cost energy strategies. That requires risking some money now to invest in those kinds of strategies. What the nations are proposing to do is to take a series of steps to try and move forward. The nations of the world tentatively agreed last December to the Kyoto Agreement as a first step. I want to point out that, to achieve stabilization, this can be viewed as really only a first step. The negotiators proposed to reduce greenhouse gas emissions by 2010 from the developed countries, reaching to 5-8% below their 1990 levels. Even if this is implemented economic growth around the world will cause the concentrations and emissions to both continue to go up.

Even though this is only a beginning and it is one that has not been accepted by everyone, countries are starting to move in that direction. While there may be shortcomings in the agreement, if the world does not take some sort of first step, the question becomes at what point we do take a first step? The alternative is that the concentrations will continue upward.

The real issue is whether we can sustain ourselves through the next couple of generations, and then through the next century? The most important thing to understand for this workshop is that there is really no way that cutbacks in emissions are going to stop climate change in the near future. We

are going to have to figure out how to cope with climate change – plan in advance to minimize the adverse impacts and to take advantage of any opportunities presented. What this workshop is about is looking at the changes that are projected, understanding our vulnerability, and trying to figure out if there are some win-win approaches for all of us, so we can minimize the adverse impacts that occur.