Global Warming and All That

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Full text, 44 minutes. With cuts [], 35 minutes

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1. Land Management and Climate

I am grateful to the organizers for inviting me to the meeting, but I have to tell you that I am not an expert in the technical problems that we will be discussing. My only qualification for talking today is that I used to work on carbon dioxide and climate with Alvin Weinberg at the Oak Ridge National Laboratory before the subject became fashionable. I will be talking this morning about land management and climate. I belong to the group of people who are called by the newspapers "climate skeptics". That means that I do not agree with the official dogmas promulgated by the International Panel on Climate Change [IPCC, 2001]. As a skeptic, I am not saying that the IPCC dogmas are wrong. I am saying that we don't know whether they are right or wrong. Since the dogmas may be right, it makes sense to support research on the sequestration of carbon dioxide produced in power-stations. Since the dogmas may be wrong, it would make sense to explore vigorously the actual fluxes of carbon between the atmosphere and the oceans and land vegetation and topsoil.

The IPCC makes predictions of the effects of fossil-fuel burning on climate. I disagree with the predictions because they come from computer models of the atmosphere and ocean which are in many ways unrealistic. The predictions ignore the dominating effect of biology on the carbon dioxide and other greenhouse gases in the atmosphere. The computer models are based on the equations of fluid dynamics and describe correctly the fluid dynamics of the atmosphere and ocean. They do a good job with fluid dynamics. That is why they are able to predict the weather with good accuracy up to five days ahead. They do not do a good job with chemistry and biology, which become important when you try to model the atmosphere and ocean over a longer time. They do not do a good job with modeling the movements of carbon as it is chemically transformed and transported through living plants and animals into soil and atmosphere and ocean.

To understand the movement of carbon through the atmosphere and biosphere in detail, we need to measure a lot of numbers. I do not want to confuse you with a lot of numbers, so I will ask you to remember just one number. The number that I ask you to remember is one hundredth of an inch per year. Now I will explain what this number means. Consider the half of the land area of the earth that is not desert or ice-cap or city or road or parking-lot. This is the half of the land that is covered with soil and supports vegetation of one kind or another. Every year, it absorbs and converts into biomass a certain fraction of the carbon dioxide that we emit into the atmosphere. We don't know how big a fraction it absorbs, since we have not measured the increase or decrease of the biomass. The number that I ask you to remember is the increase in thickness, averaged over one half of the land area of the planet, of the biomass that would result if all the carbon that we are emitting by burning fossil fuels were absorbed. The average increase in thickness is one hundredth of an inch per year.

The point of this calculation is the very favorable rate of exchange between carbon in the atmosphere and carbon in the soil. To stop the carbon in the atmosphere from increasing, we only need to grow the biomass in the soil by a hundredth of an inch per year. Good topsoil contains about ten percent biomass, [Schlesinger, 1977], so a hundredth of an inch of biomass growth means about a tenth of an inch of topsoil. Changes in farming practices such as no-till farming, avoiding the use of the plow, cause biomass to grow at least as fast as this. If we plant crops without plowing the soil, more of the biomass goes into roots which stay in the soil, and less returns to the atmosphere. If we use genetic engineering to put more biomass into roots, we can probably achieve much more rapid growth of topsoil. I conclude from this calculation that the problem of carbon dioxide in the atmosphere is a problem of land management, not a problem of meteorology. No computer model of atmosphere and ocean can hope to predict the way we shall manage our land.

Instead of calculating world-wide averages of biomass growth, we may prefer to look at the problem locally. Consider one possible future, with China continuing to develop an industrial economy based largely on the burning of coal, and the United States deciding to absorb the resulting carbon dioxide by increasing the biomass in our topsoil. The quantity of biomass that can be accumulated in living plants and trees is limited, but there is no limit to the quantity that can be stored in topsoil. To grow topsoil on a massive scale may or may not be practical, depending on the economics of genetically engineered crop-plants. It is at least a possibility to be seriously considered, that China could become rich by burning coal, while the United States could become environmentally virtuous by accumulating topsoil, with transport of carbon from mine in China to soil in America provided free of charge by the atmosphere, and the inventory of carbon in the atmosphere remaining constant. We should take such possibilities into account when we listen to predictions about climate change and fossil fuels. If biotechnology takes over the planet in the next fifty years, as computer technology has taken it over in the last fifty years, the rules of the climate game will be radically changed.

2. Physics and Biology

When I listen to the public debates about climate change, I am impressed by the enormous gaps in our knowledge, the sparseness of our observations and the superficiality of our theories. Many of the basic processes of planetary ecology are poorly understood. They must be better understood before we can reach an accurate diagnosis of the present condition of our planet. When we are trying to take care of a planet, just as when we are taking care of a human patient, diseases must be diagnosed before they can be cured. We need to observe and measure what is going on in the biosphere.

[Many of the non-living processes governing weather and climate, such as clouds and rainfall and turbulent convection, thunderstorms and hurricanes, are difficult enough to understand. The living processes governing the fertility of forests and oceans are even more difficult. Here are two examples to illustrate the difference between living and non-living processes. The two major environmental agreements of the last twenty years were the Montreal Protocol of 1987 and the Kyoto Protocol of 1997. The Montreal Protocol is concerned with the protection of the ozone layer in the stratosphere. The ozone shields the earth from harmful ultraviolet radiation, but it is destroyed by man-made industrial chemicals that have been released into the atmosphere. The Montreal Protocol forbids the production and sale of the ozone-destroying chemicals. The Protocol was signed and ratified by the major producing countries and is a shining example of international cooperation on a global scale. After the discovery in 1984 of the Antarctic Ozone Hole, a drastic loss of ozone that occurs in the Antarctic stratosphere each year at the end of winter, it took the international community only three years to negotiate the Protocol and put it into operation. For fifteen years since it was signed, the Protocol has been pretty well maintained and has effectively stopped the further decrease of stratospheric ozone. Once scientists could agree about causes, politicians could agree about remedies.

Because the destruction of ozone is a non-living process, governed by the exact science of chemistry, it is also politically tractable.]

[The Kyoto Protocol of 1997 tried to deal with carbon dioxide as the Montreal Protocol dealt with ozone, but its history has been very different. The Kyoto Protocol attempts to slow the increase of carbon dioxide in the atmosphere by putting limits on the burning of fossil fuels. In reality it has achieved very little. Technically, it fails to limit the growth of carbon dioxide to a significant extent. And politically, it fails to unite mankind in a common cause. Why did the Kyoto Protocol fail where the Montreal Protocol had succeeded? There are many reasons for the failure of Kyoto, but the main reason is the lack of a solid scientific basis. Whereas the Montreal Protocol rested on facts of chemistry, the Kyoto Protocol rested on beliefs about the biosphere which many people do not share. Planetary ecology is not an exact science like chemistry. When we are dealing with living creatures, and with complicated networks of living creatures, exact prediction of consequences of actions is impossible. The carbon dioxide problem is mixed up with problems of plant physiology and ecology that are still poorly understood. When scientists disagree about facts, it is not to be expected that politicians will be able to agree about remedies.]

Everyone agrees that the increasing abundance of carbon dioxide in the atmosphere has two important consequences, first a change in the physics of radiation transport in the atmosphere, and second a change in the biology of plants on the ground and in the ocean. Opinions differ on the relative importance of the physical and biological effects, and on whether the effects, either separately or together, are beneficial or harmful. The physical effects are seen in changes of rainfall, cloudiness, wind-strength and temperature, which are customarily lumped together in the misleading phrase “global warming”. The phrase “global warming” is misleading because the increase in temperature caused by increasing carbon dioxide is not evenly distributed. In humid air, the effect of carbon dioxide on radiation transport is unimportant because the transport of thermal radiation is already blocked by the much larger greenhouse effect of water vapor. The effect of carbon dioxide is only important where the air is dry, and air is usually dry only where it is cold. Hot desert air may feel dry but often contains a lot of water vapor. The warming effect of carbon dioxide is strongest where air is cold and dry, mainly in the arctic rather than in the tropics, mainly in winter rather than in summer, and mainly at night rather than in daytime. The warming is real, but it is mostly making cold places warmer rather than making hot places hotter. To represent this local warming by a global average is misleading.

The biological effects of carbon dioxide on plants are seen in changes of rate-of-growth, root-to-shoot ratio, and water requirement, which are different for different species and may result in shifts of the ecological balance from one kind of plant community to another. Effects on plant communities will also cause effects on dependent communities of microbes and animals. Biological effects are difficult to measure but are likely to be large. Experiments in greenhouses with an atmosphere enriched in carbon dioxide show that the yield of many crop-plants increases roughly with the square-root of the carbon dioxide abundance. If this were true for the major crop-plants grown in the open air, it would mean that the thirty-per-cent increase in carbon dioxide produced by fossil-fuel burning over the last fifty years would have resulted in a fifteen percent increase of the world’s food supply. We do not know whether the greenhouse results are true for open-air agriculture. Agricultural yields are limited by many factors other than carbon dioxide abundance. One factor that we know to be often limiting for plant growth is water. If water is limiting, as it often is in times of drought, then increased carbon dioxide can still be helpful. The little pores in the leaves of plants have to be kept open for the plant to acquire carbon dioxide from the air, but the plant loses a hundred molecules of water through the pores for every one molecule of carbon dioxide that it gains. This means that increased carbon dioxide in the air allows the plant to partially close the pores and reduce the loss of water. In dry conditions, increased carbon dioxide becomes a water-saver and allows the plant to keep on growing.

The fundamental reason why carbon dioxide abundance in the atmosphere is critically important to biology is that there is so little of it. A field of corn growing in full sunlight in the middle of the day uses up all the carbon dioxide within a meter of the ground in about five minutes. If the air were not constantly stirred by convection currents and winds, the corn would stop growing. The total content of carbon dioxide in the atmosphere, if converted into biomass, would cover the surface of the continents to a depth of less than an inch. About a tenth of all the carbon dioxide in the atmosphere is actually converted into biomass every summer and given back to the atmosphere every fall. That is why the effects of fossil-fuel burning cannot be separated from the effects of plant growth and decay. There are five reservoirs of carbon that are biologically accessible on a short time-scale, not counting the carbonate rocks and the deep ocean which are only accessible on a time-scale of thousands of years. The five accessible reservoirs are the atmosphere, the land plants, the top-soil in which land plants grow, the surface layer of the ocean in which ocean plants grow, and our proved reserves of fossil fuels. The atmosphere is the smallest reservoir and the fossil fuels are the largest, but all five reservoirs are of comparable size. They all interact strongly with one another. To understand any of them, it is necessary to understand all of them. That is why planetary ecology is not an exact science like chemistry.

As an example of the way different reservoirs of carbon dioxide may interact with each other, consider the atmosphere and the top-soil. Greenhouse experiments show that many plants growing in an atmosphere enriched with carbon dioxide react by increasing their root-to-shoot ratio. This means that the plants put more of their growth into roots and less into stems and leaves. A change in this direction is to be expected, because the plants have to maintain a balance between the leaves collecting carbon from the air and the roots collecting mineral nutrients from the soil. The enriched atmosphere tilts the balance so that the plants need less leaf-area and more root-area. Now consider what happens to the roots and shoots when the growing season is over, when the leaves fall and the plants die. The new-grown biomass decays and is eaten by fungi or microbes. Some of it returns to the atmosphere and some of it is converted into topsoil. On the average, more of the above-ground growth will return to the atmosphere and more of the below-ground growth will become topsoil. So the plants with increased root-to-shoot ratio will cause an increased net transfer of carbon from the atmosphere into topsoil. If the increase in atmospheric carbon dioxide due to fossil-fuel burning has caused an increase in the average root-to-shoot ratio of plants over large areas, then the possible effect on the top-soil reservoir will not be small. At present we have no way to measure or even to guess the size of this effect. The aggregate biomass of the topsoil of the planet is not a measurable quantity. But the fact that the topsoil is unmeasurable does not mean that it is unimportant.

At present we do not know whether the topsoil of the United States is increasing or decreasing. Over the rest of the world, because of large-scale deforestation and erosion, the topsoil reservoir is probably decreasing. We do not know whether intelligent land-management could increase the growth of the topsoil reservoir by four billion tons of carbon per year, the amount needed to stop the increase of carbon dioxide in the atmosphere. All that we can say for sure is that this is a theoretical possibility and ought to be seriously explored.

3. Oceans and Ice-ages

Another problem that has to be taken seriously is a slow rise of sea level which could become catastrophic if it continues to accelerate. We have accurate measurements of sea level going back two hundred years. We observe a steady rise from 1800 to the present, with an acceleration during the last fifty years. It is widely believed that the recent acceleration is due to human activities, since it coincides in time with the rapid increase of carbon dioxide in the atmosphere. But the rise from 1800 to 1900 is probably not due to human activities. The scale of industrial activities in the nineteenth century was not large enough to have had measurable global effects. So a large part of the observed rise in sea level must have other causes. One possible cause is a slow readjustment of the shape of the earth to the disappearance of the northern ice-sheets at the end of the ice age twelve thousand years ago. Another possible cause is the large-scale melting of glaciers, which also began long before human influences on climate became significant. Once again, we have an environmental danger whose magnitude cannot be predicted until we know more about its causes, [Munk, 2002].

The most alarming possible cause of sea-level rise is a rapid disintegration of the West Antarctic ice-sheet, which is the part of Antarctica where the bottom of the ice is far below sea level. Warming seas around the edge of Antarctica might erode the ice-cap from below and cause it to collapse into the ocean. If the whole of West Antarctica disintegrated rapidly, sea-level would rise by five meters, with disastrous effects on billions of people. However, recent measurements of the ice-cap show that it is not losing volume fast enough to make a significant contribution to the presently observed sea-level rise. It appears that the warming seas around Antarctica are causing an increase in snowfall over the ice-cap, and the increased snowfall on top roughly cancels out the decrease of ice volume caused by erosion at the edges. There is also an increase in snowfall over the East Antarctic Ice-cap, which is much larger and colder and is in no danger of melting. This is another situation where we do not know how much of the environmental change is due to human activities and how much to long-term natural processes over which we have no control.

Another environmental danger that is even more poorly understood is the possible coming of a new ice-age. A new ice-age would mean the burial of half of North America and half of Europe under massive ice-sheets. We know that there is a natural cycle that has been operating for the last eight hundred thousand years. The length of the cycle is a hundred thousand years. In each hundred-thousand year period, there is an ice-age that lasts about ninety thousand years and a warm interglacial period that lasts about ten thousand years. We are at present in a warm period that began twelve thousand years ago, so the onset of the next ice-age is overdue. If human activities were not disturbing the climate, a new ice-age might already have begun. The big question that we do not know how to answer is, do our human activities in general, and our burning of fossil fuels in particular, make the onset of the next ice-age more likely or less likely?

There are good arguments on both sides of this question. On the one side, we know that the level of carbon dioxide in the atmosphere was much lower during past ice-ages than during warm periods, so it is reasonable to expect that an artificially high level of carbon dioxide might stop an ice-age from beginning. On the other side, the oceanographer Wallace Broecker [Broecker, 1997] has argued that the present warm climate in Europe depends on a circulation of ocean water, with the Gulf Stream flowing north on the surface and bringing warmth to Europe, and with a counter-current of cold water flowing south in the deep ocean. So a new ice-age could begin whenever the cold deep counter-current is interrupted. The counter-current could be interrupted when the surface water in the Arctic becomes less salty and fails to sink, and the water could become less salty when the warming climate increases the Arctic rainfall. Thus Broecker argues that a warm climate in the Arctic may paradoxically cause an ice-age to begin. Since we are confronted with two plausible arguments leading to opposite conclusions, the only rational response is to admit our ignorance. Until the causes of ice-ages are understood, we cannot know whether the increase of carbon-dioxide in the atmosphere is increasing or decreasing the danger.

4. Measuring Carbon Fluxes

Here is another glaring example of our ignorance. We know that only about half of the carbon dioxide produced by the burning of fossil fuels stays in the atmosphere. The other half somehow disappears, but we do not know how or where it goes. Until the existing fluxes of carbon in and out of the atmophere are accurately measured and understood, it is absurd to claim that we can predict future fluxes with any degree of confidence.

At present the best tool that we have for measuring fluxes of carbon dioxide and other greenhouse gases in and out of the atmosphere is the Eddy Diffusion Tower invented fifteen years ago by Steven Wofsy of Harvard University, [Wofsy et al. 1993]. The tower is built high enough to carry instruments above the tops of trees or other vegetation. Besides standard instruments with slow response to measure the local temperature and pressure and humidity, there are two special instruments with extremely rapid response to measure instantaneously two properties of the air in a small volume. The two rapid-response instruments measure the vertical velocity of the air and the concentration of carbon dioxide at the same place and the same time. The local vertical velocity is obtained from a clever device measuring the phase shift between ultrasonic waves traveling a few inches up and down through the moving air. The carbon dioxide concentration is obtained by sucking air from the same place into a nozzle connected to an infrared absorption spectrometer. Measurements of velocity and carbon dioxide concentration are made every quarter of a second.

It usually happens in daytime, and also at night when there is some wind, that the air around the tower is turbulent with eddies moving the air up and down. If there is a flux of carbon dioxide out of the atmosphere into the vegetation or into the soil, the concentration of carbon dioxide will be less when the air is moving up and greater when the air is moving down. If the flux is upward then the carbon dioxide concentration is larger when the air is moving up. To measure the flux, all you have to do is to multiply the concentration by the vertical velocity at each instant and then take an average over time. Although the concentration and the vertical velocity are varying rapidly in a random way, the variations are highly correlated, so that the time-average of the product of the two quantities gives a measurement of the flux which is almost all signal with very little noise.

The eddy diffusion tower has two defects, one minor and one major. The minor defect is that it does not work when the air is still at night and there is a temperature inversion near the ground. When that happens, the vertical velocity of the air is zero and the carbon dioxide emitted from the vegetation does not rise. So the measurement fails. This is a minor defect, because night-time fluxes are usually small and can be estimated from measurements made on similar nights when the air is turbulent. The major defect of the method is that it does not measure fluxes occurring as a result of catastophic events such as forest-fires or volcanic eruptions. Forest fires and eruptions cause sudden large fluxes of carbon dioxide into the atmosphere. These fluxes do not appear in eddy diffusion measurements and must be estimated separately. The important uncertainties come from large fires in remote places which are difficult and expensive to study. Satellite observations provide only rough estimates of the carbon dioxide output from such fires.

A few dozen eddy diffusion towers have been installed in various places around the globe, mainly in forested areas, to measure the carbon dioxide fluxes flowing in and out of the forest as the seasons change. The measurements are consistent, and the total yearly fluxes are probably correct with uncertainties of the order of ten percent. Typical total fluxes are plus 3 flux-units for temperate deciduous forest, plus 0.5 flux-unit for tropical rain-forest, minus 0.5 flux-unit for boreal coniferous forest. Here a flux-unit means a ton of carbon per hectare per year, plus means carbon flowing down from atmosphere to forest, minus means carbon flowing up from forest to atmosphere.

Of course we should expect the fluxes to vary from place to place and from year to year, depending on the age of the forest, the species of the trees, the local rainfall and other environmental conditions. The towers now operating are far too few and too sparse to give us any reliable measure of the total carbon dioxide fluxes going in and out of the atmosphere over the whole planet. All that we can conclude from the existing measurements is that the local fluxes are of the right order of magnitude to have a major effect on the total carbon dioxide content of the atmosphere. For example, if we take the 3 flux-units measured for one small piece of deciduous forest in Massachusetts and multiply it by the area 1.3 billion hectares of all the temperate deciduous forests on the planet, the result is 4 gigatons of carbon per year, which is about half the amount put into the atmosphere by burning fossil fuels. We do not know whether the Massachusetts forest is typical of deciduous forests all over the world. To find out whether that is so or not, we need to have thousands of eddy diffusion towers making local measurements all over the world. We need to measure local fluxes not only over forests but over farmlands and grasslands and wetlands too. Eddy diffusion towers are today tricky and labor-intensive to install and operate. If they are to be deployed in large numbers, they must be made fully automatic and packaged so that they can be handled by unskilled labor.

The essential point that needs to be understood by the public is that the burning of fossil fuels is only one way in which human activities affect the atmosphere. Our management of the land has effects which are of the same magnitude and might be arranged to be of the opposite sign. We might manage the land in such a way as to convert all the carbon dioxide produced by fossil fuel burning into vegetation and topsoil. To see whether this is possible, we need first of all to do field experiments with various kinds of vegetation, using eddy diffusion towers to measure the fluxes of carbon dioxide produced by various kinds of forestry and various kinds of farming. Only after such experiments have been done, we can make economic comparisons to see whether the control of atmospheric carbon dioxide by land management is better or worse than control by physical sequestration or by restricting the burning of fossil fuels. I remember almost thirty years ago reading the paper of Cesare Marchetti [Marchetti, 1976] with the title, "On Geoengineering and the Carbon Dioxide Problem". He proposed that we sequester the carbon dioxide produced in power-stations and dispose of it in liquid form at suitable places in the deep ocean. At deep ocean temperatures and pressures, the carbon dioxide is a liquid heavier than water. It will sink to the ocean bottom and stay there for a long time. When I read that paper, I thought, there must be a better way to do it, and I made some calculations about growing trees to absorb carbon dioxide from the atmosphere [Dyson, 1977]. Not much has changed in the thirty years since then. We still do not know whether physical sequestration or land-management is the better way to do the job.

[5. Fertilizing the Oceans]

[Another way of absorbing carbon dioxide from the atmosphere has been proposed more recently by Ian Jones of the Ocean Technology Group at the University of Sydney in Australia, [Jones and Otaegui, 1997]. Jones points out that the vast areas of the ocean away from coastlines and upwelling currents are deserts with low biological productivity. In most of these areas the limiting nutrient that keeps productivity low is nitrogen. He proposes that we fertilize the ocean deserts with urea (CON_2H_4) which is non-toxic and has little effect on the PH of the water. The fertilization will be far away from the coastal waters that already have too much nitrogen. The concentration of nitrogen in the fertilized areas will not be high enough to produce symptoms of eutrophication. The nitrogen will be metabolized by floating phytoplankton which absorbs carbon dioxide from the atmosphere, and then recycled as the phytoplankton dies or is eaten by other creatures. After being recycled many times, the nitrogen will finally be carried down to the deep ocean in corpses or fecal pellets of various species. Each ton of nitrogen that falls to the deep ocean will carry with it seven tons of reduced organic carbon. The net result of the fertilization is that each ton of nitrogen moves seven tons of carbon from the atmosphere to the deep ocean.]

[If we imagine using ocean fertilization to stop the growth of carbon dioxide in the atmosphere, we would need to spread about half a gigaton of nitrogen per year into the ocean. The spreading could be done by a small number of super-tankers or by a system of undersea pipelines. How much this would cost remains to be seen. According to Jones, the costs would be largely offset by the growth of wild fish populations resulting from the fertilization. He claims that the populations of commercially valuable fish would roughly be doubled. Many valuable species that are now suffering from over-fishing would be replenished, and many fishermen around the world who are now strugging to survive would again be profitably employed. I do not know enough about fisheries or about the chemical engineering of large-scale production of urea to judge whether Jones's proposal makes economic or ecological sense.]

6. The Wet Sahara

Another problem that has always fascinated me is the mystery of the wet Sahara. At many places in the Sahara desert that are now dry and unpopulated, we find rock-paintings showing people with herds of animals, [Lhote, 1958]. The paintings are abundant and of amazing artistic quality, comparable with the more famous cave-paintings in France and Spain. The Sahara paintings are more recent than the cave-paintings. They come in a variety of styles and were probably painted over a period of several thousand years. The latest of them show Egyptian influences and must be contemporaneous with early Egyptian tomb paintings. Henri Lhote's book, "The Search for the Tassili Frescoes", has marvelous reproductions of fifty of the paintings. The best of the herd paintings date from roughly six thousand years ago. They are strong evidence that the Sahara at that time was wet. There was enough rain to support herds of cows and giraffes, which must have grazed on grass and trees. There were also some hippopotamuses and elephants. The Sahara then must have been like the Serengeti today.

At the same time, roughly six thousand years ago, there were deciduous forests in Northern Europe where the trees are now conifers, proving that the climate in the far north was milder than it is today. There were also trees standing in mountain valleys in Switzerland that are now filled with famous glaciers. The glaciers that are now shrinking were much smaller six thousand years ago than they are today. Six thousand years ago seems to have been the warmest and wettest period of the interglacial era that began twelve thousand years ago when the last Ice Age ended. I would like to ask two questions. First, if the increase of carbon dioxide in the atmosphere is allowed to continue, shall we arrive at a climate similar to the climate of six thousand years ago when the Sahara was wet? Second, if we could choose between the climate of today with a dry Sahara and the climate of six thousand years ago with a wet Sahara, why should we prefer the climate of today? That is perhaps a philosophical question, but it will not do us any harm to think about it.

[The biosphere is the most complicated of all the things we humans have to deal with. The science of planetary ecology is still young and undeveloped. It is not surprising that honest and well-informed experts can disagree about facts. But beyond the disagreements about facts, there is another deeper disagreement about values. The disagreement about values may be described in an over-simplified way as a disagreement between naturalists and humanists. Naturalists believe that nature knows best. For them the highest value is to respect the natural order of things. Any gross human disruption of the natural environment is evil. Excessive burning of fossil fuels is evil. Changing nature's desert, either the Sahara desert or the ocean desert, into a managed ecosystem where giraffes or tunafish may flourish, is likewise evil. Nature knows best, and anything we do to improve upon Nature will only bring trouble. The naturalist ethic is the driving force behind the Kyoto Protocol.]

[The humanist ethic begins with the belief that humans are an essential part of nature. Through human minds the biosphere has acquired the capacity to steer its own evolution, and now we are in charge. Humans have the right and the duty to reconstruct nature so that humans and biosphere can both survive and prosper. For humanists, the highest value is harmonious coexistence between humans and nature. The greatest evils are poverty, underdevelopment, unemployment, disease and hunger, all the conditions that deprive people of opportunities and limit their freedoms. The humanist ethic accepts an increase of carbon dioxide in the atmosphere as a small price to pay, if world-wide industrial development can alleviate the miseries of the poorer half of humanity. The humanist ethic accepts our responsibility to guide the evolution of the planet.]

[The sharpest conflict between naturalist and humanist ethics arises in the regulation of genetic engineering. The naturalist ethic condemns genetically modified food-crops and all other genetic engineering projects that might upset the natural ecology. The humanist ethic looks forward to a time not far distant, when genetically engineered food-crops and energy-crops will bring wealth to poor people in tropical countries, and incidentally give us tools to control the growth of carbon dioxide in the atmosphere. Here I must conclude by confessing my own bias. Since I was born and brought up in England, I spent my formative years in a land with great beauty and a rich ecology which is almost entirely man-made. The natural ecology of England was uninterrupted and rather boring forest. Humans replaced the forest with an artificial landscape of grassland and moorland, fields and farms, with a much richer variety of plant and animal species. Quite recently, only about a thousand years ago, we introduced rabbits, a non-native species which had a profound effect on the ecology. Rabbits opened glades in the forest where flowering plants now flourish. There is no wilderness in England, and yet there is plenty of room for wild-flowers and birds and butterflies as well as a high density of humans. Perhaps that is why I am a humanist.]

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