A Pocket Model of Global Warming for Policy and Scientific Debate

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Abstract

The global climate system is a large complicated system with many feedback loops connecting the different sub-systems. In recent years there has been an increase in the public's awareness of global warming and the greenhouse effect. The public understands that there is some connection between the human emission of greenhouse gases and global climate change. Experts in this field have been analyzing these connections for years and are still unable to give definitive answers to questions concerning the direct link between emissions and temperature change. Policy makers have a desire to intervene in order to limit the amount of emissions. At this point in time available answers are under debate and are unclear, or the models used by the scientific community are too complicated for policy makers to understand.

The purpose of this global warming model is to be small, conceptually clear, and accessible to nonscientists. This model contains all of the feedback loops hypothesized in the scientific literature. However due to its small size it is aggregated to a global level. This level of aggregation will help to make the model more understandable for policy makers. The global aggregation will allow policy makers to focus upon the global effects rather than the details of the climate system.

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The global climate system is a large complicated system with many feedback loops connecting the different sub-systems. In recent years there has been an increase in the public's awareness of global warming and of the greenhouse effect. The public understands that there is some connection between human emission of greenhouse gases and global climate change. Policy makers, therefore, have a desire to intervene in order to limit the adverse climate effects of emissions.

When the public refers to the greenhouse effect what is generally meant is simply warming above the current average temperature. This generalization is not true. The greenhouse effect is a true effect. It is the feedback mechanisms causing this effect which are uncertain. Experts in the field of climatology have been analyzing these connections for years and are still unable to give definitive answers to questions concerning the direct link between emissions and temperature change. There is still some debate in the scientific community concerning the degree to which human emissions are responsible for increasing the effect upon global warming. Policy makers are dependent upon the scientific community for answers to this question because they do not understand the models used by the scientific community. These models are generally too large and complicated for policy makers to understand.

The purpose of this paper is to introduce a global climate simulation model that is scientifically accurate but understandable for policy makers. The model is small, conceptually clear, and accessible to nonscientists. It contains all of the feedback loops hypothesized in the scientific literature. Due to its small size it is aggregated to a global level. The global aggregation will allow policy makers to focus upon the global effects of human intervention rather than the details of climatology.

Sub-systems in the global warming model

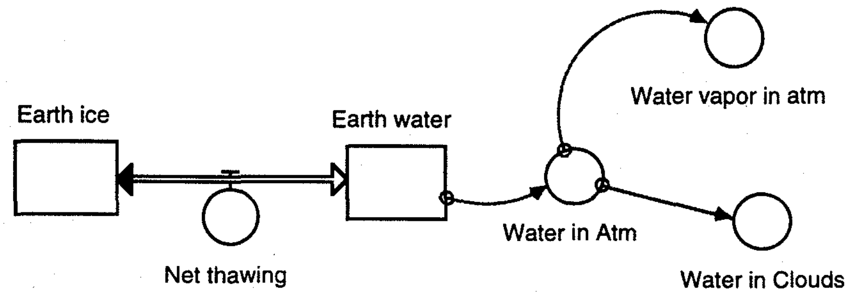
Three major sub-systems affecting world climate are represented in the model: water; heat; and carbon. Two of the sub-systems, water and carbon, are conserved systems. These two sub-sytems are closed loop systems (no water or carbon leaves the system). In climatology literature the water and carbon systems are described as cycles. Heat is described as the heat budget for the planet. In the global warming model heat received from the sun is exogenous. This is consistent with the literature.

There is disagreement in the scientific community about the strength of the feedback effects within and among these sub-systems. The true effects or the relative strengths of effects are unknown. Some of these feedback effects are crucial to global warming, while others thought to be important may not be.

The water sub-system:

Water flow is simplified so that water exists in four places: earth ice; earth water; water vapor in the atmosphere; and water in clouds. Due to the short residence time of water in the atmosphere, the model has water in two levels, water or ice. Total water in the atmosphere is based upon temperature, with water vapor and water in clouds each a fraction of this level. The fraction for the division of water in the atmosphere into water vapor and water in clouds is assumed to be a constant. Water in the atmosphere is a level but the relatively short average residence time of water in the atmosphere made it possible to approximate the value of this stock with a auxiliary (Richardson and Pugh 1980).

Figure 1: the water sub-system



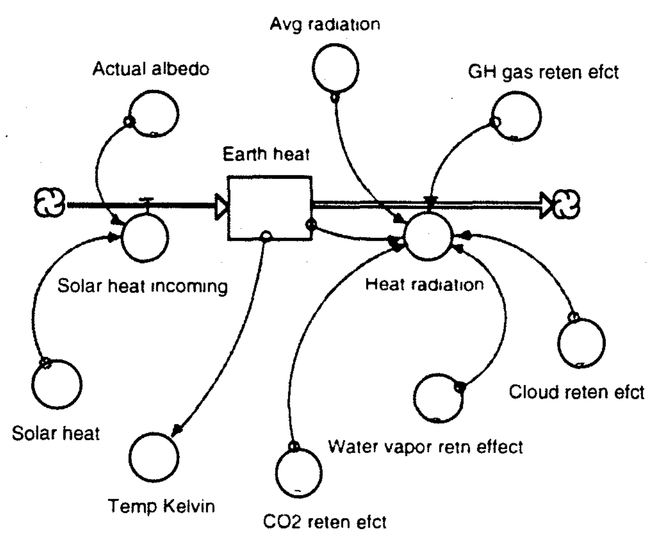
Water is stored in ice and the assumption is that warming will cause net melting, whil cooling will cause net freezing. This net melting or freezing will change the balance between eartl ice and earth water. Earth water evaporates and becomes water vapor, which condenses into wate in clouds, and this turns into precipitation.

The amount of water in the atmosphere is based upon the global average temperature. Th scientific literature estimates that for each one degree rise in temperature the amount of wate vapor increases by 6% (Manowitz 1990). Earth ice makes up about 2% of total water, earth wate almost 98%, while water vapor and water in clouds together are .0009%. All the water vapor i the atmosphere is enough to cover the entire planet with approximately 2.5 cm of water. Tota world wide precipitation is almost one meter per year. The average residence time of water vapo in the atmosphere is about 9.5 days (Nierenberg 1992).

The heat sub-system

The global warming model assumes that incoming solar heat is constant. The rate of sola heat reaching the earth is affected by the total amount of earth albedo (reflectivity). World wid albedo -- the fraction of solar heat that is reflected back into space - is about 30% (Trenbertl 1992). In the global warning model albedo effects are simplified to three sources: aerosols in th atmosphere; ice (and snow); and clouds. Albedo is increased when the level of aerosols in th atmosphere increases or when ice and cloud covers increase. These will increase actual albedo reduce the ability of the earth to absorb solar heat, and therefore reduce global averag temperature. The total amount of heat stored in the ocean and atmosphere is earth heat. This leve determines the global mean temperature or the temperature in degrees Kelvin.

Figure 2: the heat sub-system

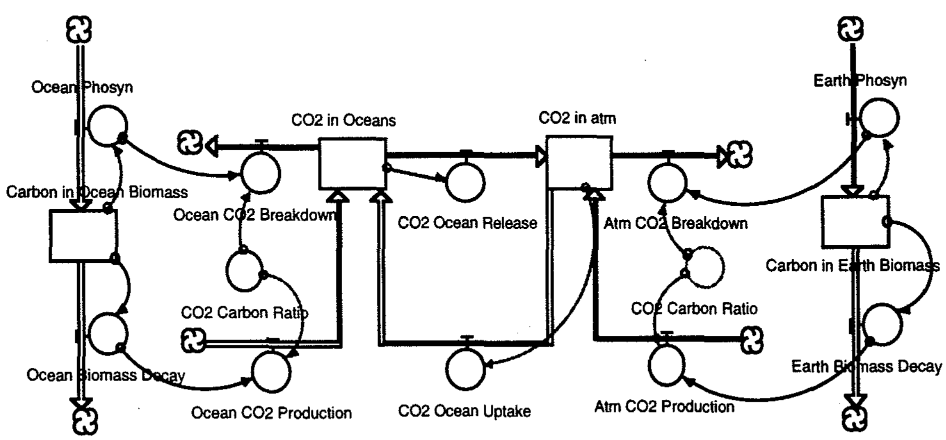


The earth has an average rate of heat radiation. In equilibrium this rate is equal to the amount of radiation received from the sun. Given the theories on radiative equilibrium the earth should have a temperature of minus 18 Celsius. The current global average temperature is about 15 Celsius (Trenberth 1992). The difference in temperature (33 degrees Celsius) is heat trapped by the atmosphere through the greenhouse effect. In the global warming model heat radiation reduces the level of earth heat. This rate is simplified into four effects upon the rate of heat radiation. These are the atmospheric concentrations of: water vapor; CO_2; other greenhouse gases (an average of methane, nitrous oxide, fluorocarbons, and ozone); and clouds (reflecting heat heat back to the earth).

The carbon sub-system

In the model the carbon sub-system is not modeled as a closed system. This is due to the relatively long residence period of carbon inside of the earth. What is left out is the absorption of carbon into the ground. Humans extract carbon products from the earth. In the global warming model these appear only as an exogenous variable, human fossil burning. Because the model is constructed this way the amount of carbon appears to be increasing. Actually carbon is a conserved system and there is no net gain in the world wide level of carbon. The only change is in its place of residence.

Figure 3: the carbon sub-system



In the model carbon is stored in four levels: earth biomass; ocean biomass; CO_2 in the ocean; and CO_2 in the atmosphere. Carbon in earth biomass is increased by the rate of earth photosynthesis. It is reduced by the rate of biomass decay. The structure for carbon in ocean biomass has a parallel structure.

In the global warming model the level of CO_2 in the ocean is increased by two rates:.ocean CO_2 production; and CO_2 ocean uptake. Ocean CO_2 production is the CO_2 released by ocean biomass decay. CO_2 ocean uptake is the absorption of CO_2 from the atmosphere. The level of CO_2 in the ocean is decreased by two rates: CO_2 ocean release; and ocean CO_2 breakdown. CO_2 ocean release is the rate of absorption of CO_2 into the atmosphere from the ocean. Ocean CO_2 breakdown rate is ocean photosynthesis removing CO_2 from the water.

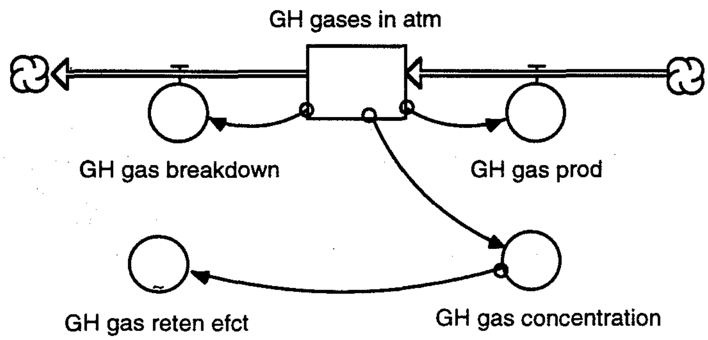
The level of CO_2 in the atmosphere is increased by two rates:.atmospheric CO_2 production; and CO_2 ocean release. It is decreased by two other rates: atmospheric CO_2 breakdown; and CO_2 ocean uptake. The rates for CO_2 ocean release and CO_2 ocean uptake are discussed above. Atmospheric CO_2 production is the CO_2 released by earth biomass decay. Atmospheric CO2 breakdown is earth photosynthesis removing CO_2 from the atmosphere.

Carbon dioxide in the atmosphere is one of the known greenhouse gases. The release and absorption of carbon and CO_2 between these four levels is important in the analysis of the greenhouse effect.

Other greenhouse gases and aerosols

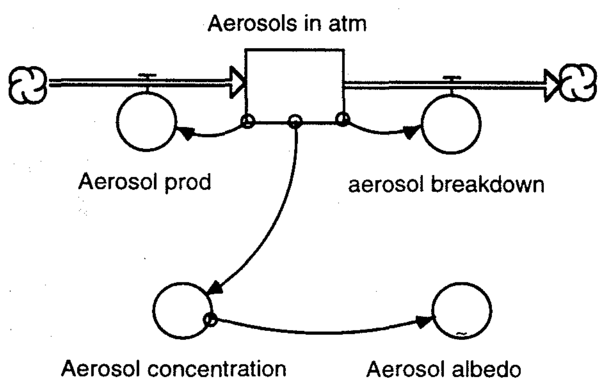
In addition to CO_2 and water vapor there are other greenhouse gases which affect he radiation. As mentioned previously an average of methane (CH4), nitrous oxide (N2C fluorocarbons (F11 and F12), and ozone (O3) are used in the global warming model as oth greenhouse gases. These are the important greenhouse gases and together with water vapor aı CO_2 make up approximately 99% of the total greenhouse effect (Bolin 1986).

Figure 4: other greenhouse gases



In the global warming model other greenhouse gases are treated as exogenous. Increas in the atmospheric concentration of greenhouse gases reduce heat radiation. Changes in tl concentrations of other greenhouse gases are assumed to be due to human intervention. Sin 1935 atmospheric concentrations of these gases have increased by approximately 90% and tl temperature change is about 0.3 degrees Celsius (Bolin 1986).

Figure 5: aerosols



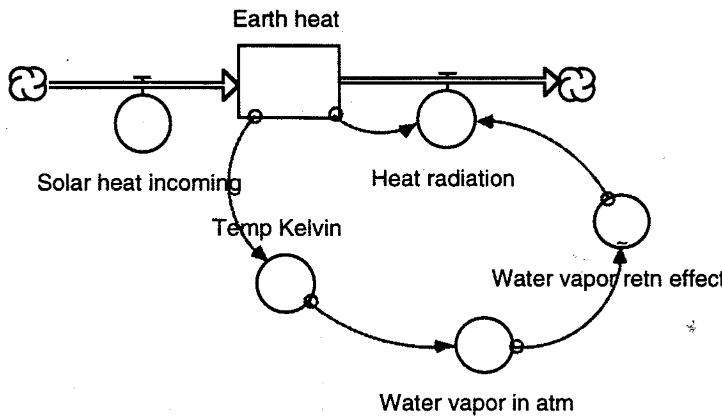
In the global warming model other aerosols are treated as exogenous. Aerosols a assumed to increase the global albedo. Not much is known about the effects of human aeros production upon global albedo. There is research which is interested in the local climatic effe of human aerosol production. It is estimated that naturally occurring aerosols lower the glot temperature by 1.5 degrees Celsius (Bolin 1986).

Part of the problem with estimating the effects of aerosols upon global climate is th somewhat like clouds, aerosols increase both albedo and heat retention effects. Also similar clouds it is assumed that aerosols reflect more heat back to space than they retain. These factc make it difficult for researchers to determine the amount of cooling due to human aeroso Consequently the level of aerosols and their effects upon the global warming model have been lı in equilibrium.

Major feedback loops affecting global heat

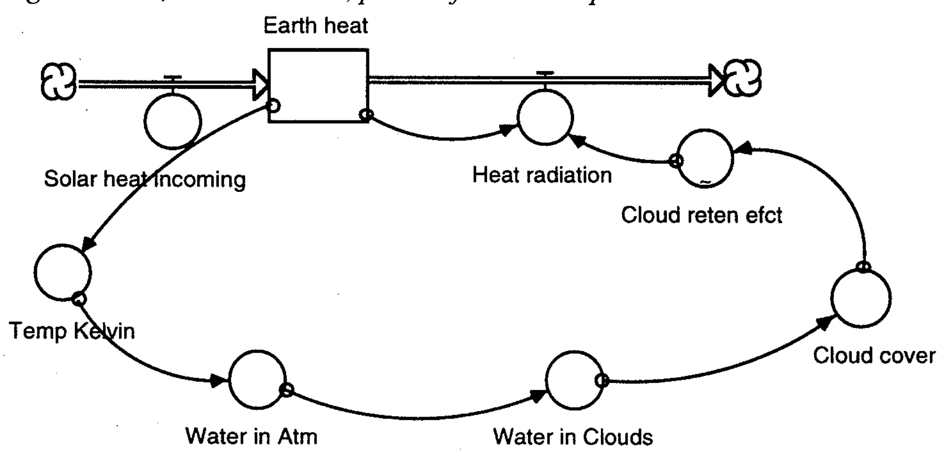
Water vapor in the atmosphere produces the largest greenhouse effect. It is estimated that 80 to 90% of the greenhouse effect is due to water vapor in the atmosphere. There is a positive feedback loop between temperature and the amount of water in the atmosphere. This is represented in the model with temperature affecting evaporation. Increased evaporation leads to more water in the atmosphere, water vapor increases the heat retention effect, and this increases the ability of the earth to store heat. The level of heat in turn increases the average earth temperature. This is a positive feedback loop.

Figure 6: heat, water vapor, positive feedback loop



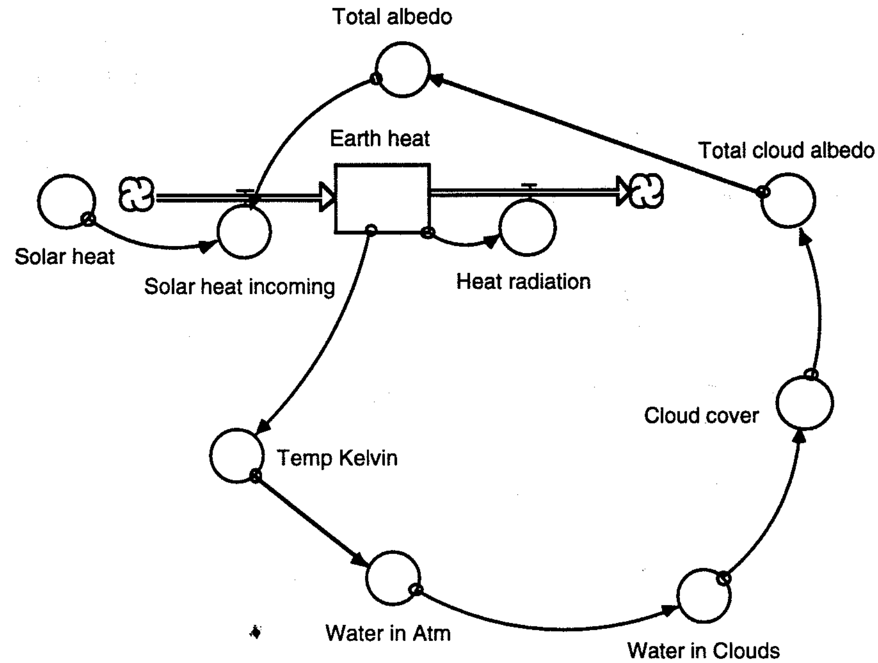
Clouds in the atmosphere produce both positive and negative feedback loops. As the level of earth heat increases, temperature increases, water vapor in the atmosphere increases and cloud cover increases.

Figure 7: heat, water in clouds, positive feedback loop



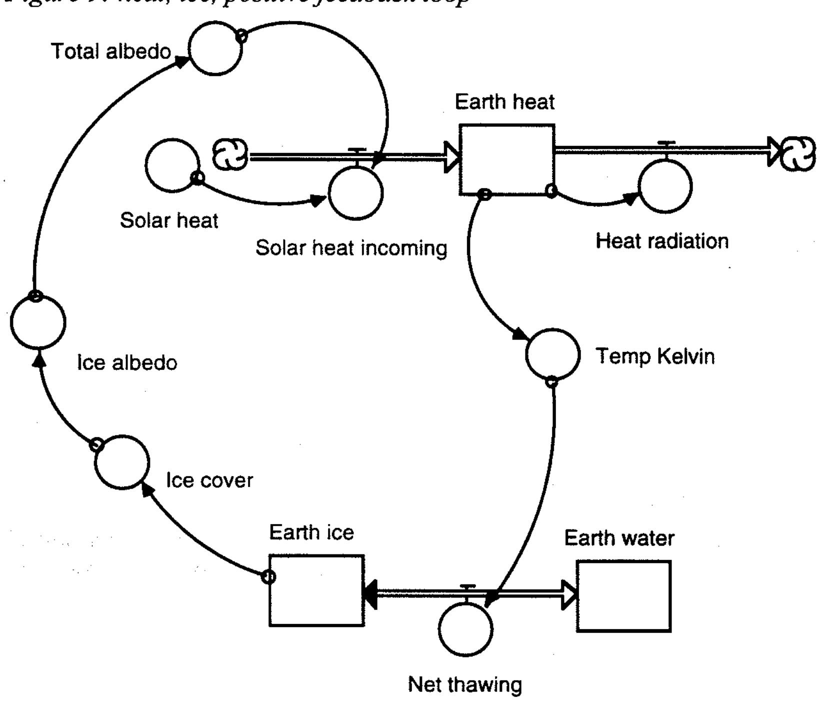
Clouds reflect heat back to the earth's surface, increasing the heat retention effect. This is the positive feedback loop connecting earth heat, water and clouds as shown in the diagram above.

Figure 8: heat, water in clouds, negative feedback loop



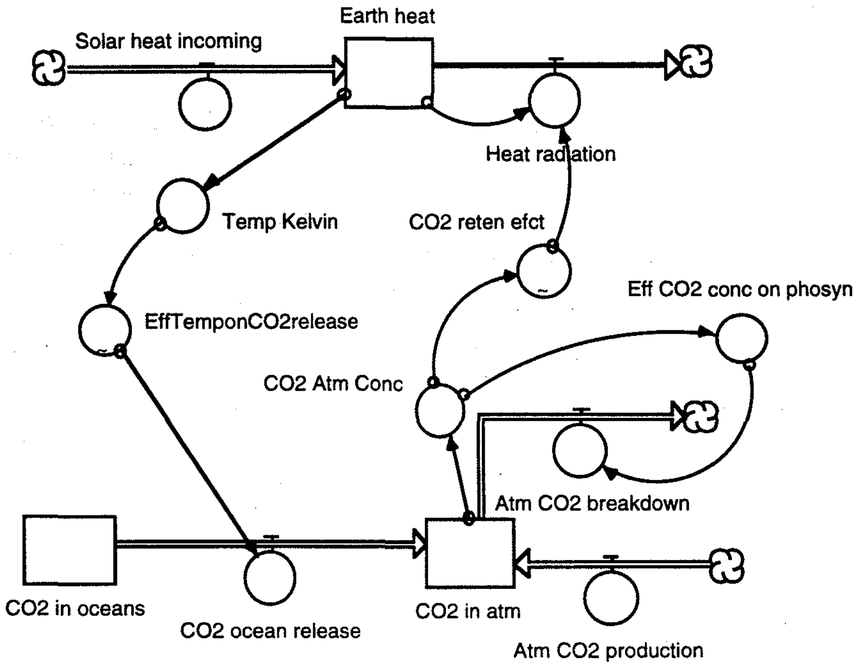
The same effect which produces a positive feedback effect also creates a negati feedback effect. Clouds not only reflect heat back to the earth but can reflect sun light back space. Increases in cloud cover raise the global cloud albedo and result in an increase of planeta albedo.

Figure 9: heat, ice, positive feedback loop



A positive feedback loop links temperature to net ice thawing. As ice thaws, ice co shrinks and this reduces global ice albedo. As ice albedo is reduced, total albedo is reduced a more solar heat is absorbed by the earth resulting in increased temperatures.

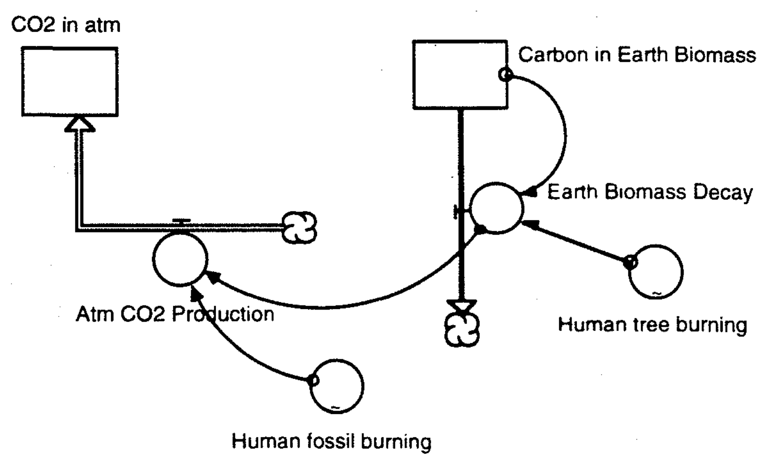
Figure 10: heat, CO_2, positive feedback loop



There is a positive feedback effect connecting the levels of CO_2 in the atmosphere and earth heat. The global warming model assumes that increases in CO_2 concentration will increase the heat retention effect, reducing the rate of earth heat radiation. This will result in increased temperature which will increase the rate of CO_2 release from the ocean into the atmosphere. It is assumed that increases in CO_2 concentration will increase the rate of photosynthesis. This minor negative feedback loop will dampen the positive feedback effect of atmospheric CO_2 concentration upon temperature.

Human intervention in the carbon cycle is represented by two exogenous variables in the greenhouse model.

Figure 11: human CO_2 emissions



One variable is human fossil burning. This represents the burning of fossil fuels and the resulting emissions of CO_2. The other variable used is human tree burning. This represents the burning of earth biomass which is contributing to the destruction of rain forests, decreasing the amount of photosynthesis, and increasing the concentration of CO_2 in the atmosphere. Together these sources have increased the concentration of CO_2 in the atmosphere by about 17% since 19 (derived from Bolin, 1986).

Base run

The focus of the following base model runs are the estimated increases in CO_2 and otl greenhouse gases over the 50 year period from 1985 to 2035. In the base run an attempt was ma to duplicate the literature in the field. In actuality three base cases were tested: low; middle; a high range increases in levels of CO_2 and other greenhouse gases in the atmosphere. Exogeno variables for human greenhouse gas production, fossil fuel burning and biomass burni (estimated by weight, Bolin 1986) were included in the model. These variables are hum emissions (for greenhouse gases and fossil burning) or burning of biomass (resulting in emission These variables are graph functions formulated as mass over time.

The low scenario has about a 15% increase in CO_2 levels and a 20% increase in otl greenhouse gases. The result is an increase of 1.7 degrees Celsius.

The mid-range estimated increase is a 31% increase in the amount of CO_2 in t atmosphere and a 60% increase in the amount of other greenhouse gases. The temperatu increase for this level of change is approximately 2.2 degrees Celsius.

The high scenario has a 62% increase in CO_2 levels and a 100% increase of other GH g levels. The result is an increase of approximately 3.0 degrees Celsius.

<u>Scenario Table, percent increase for 1985 to 2035:</u>

	Low	Middle	High
CO_2	15%	31%	62%
GH gases	20%	60%	100%
Temp. Ch.	1.5	2.0	2.7

The policy implications are that to achieve the low scenario very tight restrictions w have to be placed upon CO_2 and other greenhouse gas production. If the atmosphe concentrations of CO_2 are to rise only 15% over the next 40 years, CO_2 output must st increasing by 2005 and must decline steadily thereafter. It is assumed that by 2035, CO_2 outp will be down close to the 1980 levels. It is not within the scope of this paper to examine the poli issues necessary to limit greenhouse gas output.

Climate theory uncertainty

The purpose of this section is to explore areas of uncertainty in the literature and to t where future research should be focused.

Changes in cloud albedo

The greatest area of uncertainty is the effect of clouds on the global climate system. I clear that clouds have albedo which reflects solar radiation and retains heat. It is uncertain wh effect is stronger and if increases in water in the atmospheric will increase cloud albedo. In model the effect of increased humidity upon cloud albedo was assumed to be relatively weak. T assumption was changed to a strong effect.

The stronger the effect of cloud density is upon cloud albedo the stronger is the dampi effect upon temperature increases. Simulation results indicate that if this effect is increas sufficiently there will be almost no global warming. This effect alone cannot reverse warmi effects, only reduce the increase in temperature due to rising levels of greenhouse gases.

Aerosol albedo

In the absence of any global data on the effect upon aerosols in the atmosphere due to human intervention, the base run did not include any exogenous human effects. Intuitively this could not be true. Human pollution must have changed the level of aerosols in the atmosphere.

The assumption in the literature is that aerosols only dampen the greenhouse effect. Another important assumption is that the aerosol albedo effect is greater than the retention effect. However given the lack of research on the global effects of aerosols there is no certainty about these effects. Large increases in the global level of aerosols can lower global temperature even with large increases in global warming gases.

Lindzen's theory, water vapor has a negative feedback effect

In the global warming debate there are many opponents to the idea that human intervention is having a significant affect upon global warming. In the field of climatology one of the respected scholars is Richard Lindzen.

Contrary to most researchers in the field he thinks that there is a negative feedback effect between temperature and water vapor in the atmosphere. He think that current researchers are misinterpreting some of the data. Lindzen concludes this because most of the warming in this century occurred before 1940. There was a slight reduction in temperature between 1940 and 1970, with a rapid rise since. The drop in temperature occurred in spite of the introduction of minor greenhouse gases. In addition most models overestimate the amount of warming. According to Lindzen this is due to the error in interpreting the feedback effects of water vapor. If they were interpreted as a negative feedback this would reduce the rates of temperature change, reflecting current realities.

This theory was tested using the global warming model. The results were a 20% lowering in the estimated temperature increase. This is consistent with Lindzen's assertion that this reduces the estimated temperature due to increases in the levels of greenhouse gases.

Reproducing historical global temperature trends similar to Lindzen's results

In order to test Lindzen's theory the base model was run with the addition of aerosol cooling effects. The results suggest that it is possible to reproduce historical global temperature trends which are similar to Lindzen's findings. This does not disprove Lindzen's theory but it does illustrate the range of uncertainty regarding the greenhouse effect and global warming.

Future tests

It should be clear that there is uncertainty about the changes in cloud albedo due to changes in the level of water in the atmosphere.

Due to the desire to keep the model simple there are some areas open to future tests. There are a number of auxiliaries in this model which are constants but could be variables affected by CO_2 concentrations or temperature. For example the residence time of carbon in earth and ocean biomass is a constant. It is possible that increases in global temperature will increase the rate of photosynthesis and will also reduce the residence time in biomass.

Further research on the global effects of human aerosol production would lend itself to this model. With this model it is possible to speculate about these effects but testing climatology theory would be more interesting.

Finally, solar heat was assumed to be constant. Slight changes in the earth's orbit and variations in solar output do exist. These changes, if long term, do affect the global climate. It might be interesting to test changes of solar output in this model.

Conclusions

Policy makers need to know more about the global climate system if they are going to make rational decisions concerning greenhouse gas emissions. They are not about to spend years learning about the details of climate systems before making these decisions. If the research community is concerned we must find ways to accurately inform policy makers without losing them in the details of the knowledge. Any model used for this purpose must be at a level that laypeople can understand and scientists can trust. The global warming model does both of these.

This is a scientifically accurate model. The global climate is a large feedback system and the global warming model contains all of the important hypothesized feedback effects in th climatology literature. It is possible to run simulations which reflect the disagreement in th scientific community. This model permits its users to test different theories of global warming by changing some of the auxiliary values.

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