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Discussant for the session:

"Do We Know Enough About Global Change to Justify Action?"

Models of global warming vary widely in their complexity and detail, but they all depend on the greenhouse effect of atmospheric gases for their forcing. Forcing for present conditions is well known. Without it, Earth would be too cold to be habitable. *Increases* in the greenhouse warming, not the warming itself, are the cause for concern. If you add heat to the system—corresponding to that from a doubling of carbon dioxide—and had no atmosphere at all, you would expect to get something like 1°C warming. That figure approximately doubles by adding the water vapor in the atmosphere. Water vapor is an additional greenhouse gas that increases with warmer temperature. Clouds in the global warming models act to further amplify the warming by as much as 4°C. The climate modeling community does not yet know how to realistically generate clouds in climate models. They have just tried it in several possible ways and have shown their results. Nobody has any confidence in any of the cloud simulations thus far presented. The latest assessment, the Intergovernmental Panel on Climate Change ("IPCC") report that came out last year, gives 1.5°C to 4.5°C as the expected warming caused by doubled CO_2. With all likelihood the changes will be in the lower end of the range.

The question of this session is whether we know enough about global change to justify action. We're emphasizing global climate change, but there are other global change issues as well, such as decreasing ozone. The international community has done about as much as could be done over the last few years to initiate action in that area. To address the climate change question, we must recognize that there are a number of important greenhouse gases that are increasing in quantity, carbon dioxide being the most important.

Carbon dioxide has been documented as having increased from 280 parts per million ("ppm") up to about 355 ppm today. It is increasing at about half the rate at which people produce it and put it in the atmosphere. Where the rest goes is not well known, so there is a possibility that the fraction going into the atmosphere will become larger in the future. Methane and nitrous oxide are strongly linked with natural biological processes, and trying to sort out why their quantities are increasing continues to be relatively difficult, although their increase is believed to result from human activities.

Another indication of the relative importance of the different greenhouse gases is indicated in Figure 1 taken from the table in the IPCC report. Again,

CO_2 makes up a little more than half of the greenhouse gases. Science, like everything else, changes with time. When we did the Charney Report in the late 1970s, we were thinking only about CO_2 and we thought that the equivalent doubling of then existing CO_2 levels was likely to occur between the years 2030 and 2050. Now, present projections of all the greenhouse gases going up equivalent to a doubling of CO_2 come up with about the same date. The projections of CO_2 growth greatly decreased in studies in the early 1980s. This was the result of economists looking more critically at what was the most plausible future as opposed to just drawing straight lines through the existing data. It's these two changes that make non-scientists and people not involved in the debate take a step back and question whether the science is known well enough.

But uncertainties tend to go in both directions. The ozone question, for example, was first raised with the issue of supersonic transports. Going back to the early 1980s or even late 1970s, the initial answers were not very different from those currently accepted. However, many significant factors were initially left out that tended to cancel each other. If one has an approximate description of the system, from a physical viewpoint, I think it is safe to say that it is not going to completely go away. Conclusions will change as we understand the science better, but they can change in both directions.

Taking all the greenhouse gases and projecting them into the future, one gets a climatic forcing in watts per meter squared. Earth's heating from the sun, that is, how much solar energy is absorbed averaged over day/night and summer/winter and so on, comes out to be about 240 watts per meter squared. So 1% of that is about 2.4 watts per meter squared, which is just where we are now in 1991 in terms of greenhouse forcing. When you double the CO_2, you come up with a figure representing about twice that amount of forcing.

The reason we talk about doubling CO_2 is historical. Climate models first used this as a simple assumption to put in models, as equivalent to about a 2% increase of solar constant. The increase of greenhouse gases up to now is equivalent to a 1% increase in the output of the sun. A solar physicist who looks at the output of the sun would like it to be variable in these models because that would help the physicist be a part of the climate change debate. Observations of the sun over more than the last decade indicate that solar output has varied by about 0.1%. The climate change of a few hundred years ago, called the little ice age, could possibly be explained by a variable sun having reduced its output by as much as 0.3% or 0.4% or maybe half a watt per meter squared. But there's no way now that we can imagine a decrease of solar output to cancel the increase resulting from the greenhouse gases.

The climate forcing from the greenhouse gases acts on a system that is very complex. We must consider the land systems, the ocean systems and ice, the atmosphere including the clouds, and all the trace gases in the atmosphere. Will changing the temperature of the atmosphere in turn change concentrations of ozone, a greenhouse gas? The science community is learning how to better cope with such questions, but we face great uncertainties when we try to project in detail what will happen to the climate system. For example, I do not think we can say very much at all about the predicted global average of 1.5°C to 4.5°C warming expected to result from doubling CO_2. What we would really like to know is how climate will change in a particular region, but that requires using global forcing in models well enough established to respond to the individual weather systems over a region.

In addressing the greenhouse effect, two kinds of radiation in the atmosphere are important: solar and infrared. Solar radiation is absorbed except for the thirty percent (30%) that is reflected. The thermal infrared, or the so called "outgoing long wave," is the radiation of concern for the greenhouse effect. The addition of more gases traps more radiation which can be shown to be quantitatively equivalent to adding more solar radiation. For example, changing reflection of solar radiation as a result of changing clouds may complicate the picture. [See Figure 2]

Recent simulations indicate how much the uptake of heat by the ocean might slow the warming. Over the continental areas, the uptake is as much as 80% of that calculated for equilibrium conditions. Certain oceanic areas, especially the southern ocean, hardly warm up at all. Thus, even if global warming could melt the ice caps, it would not be expected to happen for a very long time because of the rate at which the ocean is taking up the heat. This is the steady state of warming of 2°C to 3°C in low to middle latitudes and warm and higher latitudes.

Turning to the issue of a rising sea level, five to ten years ago we were worried about the possibility of a rapid rise of greater than one meter. Current projections suggest that as an upper limit by the year 2100. It could be as little as a few tens of centimeters by the year 2100. If we just look to the year 2030, which is as far as planning projections go, we're talking about a possible sea level rise of 10 to 30 centimeters.

The details of local/regional projections that come out of the models are still given little credibility. It is necessary to consider only global features before we expect some correspondence between the data and the models. If a straight line is fit to the global temperature record for the last 100 years, a rise of about 0.5°C appears, which is more or less at the lower end of what models now predict. The disagreement between the models and data is not totally out of range of known uncertainties, so some feel comfortable taking the position that there is no disagreement between the models. Others feel uncomfortable with that position, and still others believe that the disagreement itself is telling us something.

In the 1940s, the northern hemisphere was almost as warm as it is now, but then it cooled considerably into the 1960s, until finally, global temperatures started increasing relatively rapidly in the last decade. Solar variability cannot offer an explanation. But there is a hypothesis for anthropogenic cooling that can be quantified, though not nearly as precisely as the heating from the greenhouse gases. That is, the increased solar reflection resulting from the addition of sulfate aerosols to the atmosphere, also a result of burning fossil fuels, may contribute significantly to global cooling.

There is between 1% and 3% sulfur in fossil fuel that gives us acid rain and covers the eastern United States with haze much of the time. Knowing the sources of this, we can estimate how much loading is in the atmosphere and how this will reflect radiation. The exact amount is uncertain, but it comes out about 1 watt per meter squared cooling. These aerosol particles are also important for the formation of clouds. More particles generate more cloud drops for the same amount of water, and this causes more solar reflection. This is even a more imprecise calculation, but the results are an additional one watt per meter squared.

Much smoke results from biomass burning, especially in the tropics. Trying to quantify how much smoke is in the atmosphere and what that might be doing to the atmosphere is an uncertain calculation, but it suggests climate effects comparable to that of sulfate aerosol. Thus, if you add smoke to the climate effects from sulfur aerosol, an essentially complete cancellation of greenhouse warming can be argued. However, any current estimates of this aerosol cooling are much more uncertain than the present calculations of greenhouse gas warming. From the energy viewpoint, this particular twist on the greenhouse warming issue is likely to become very important over the next few years.

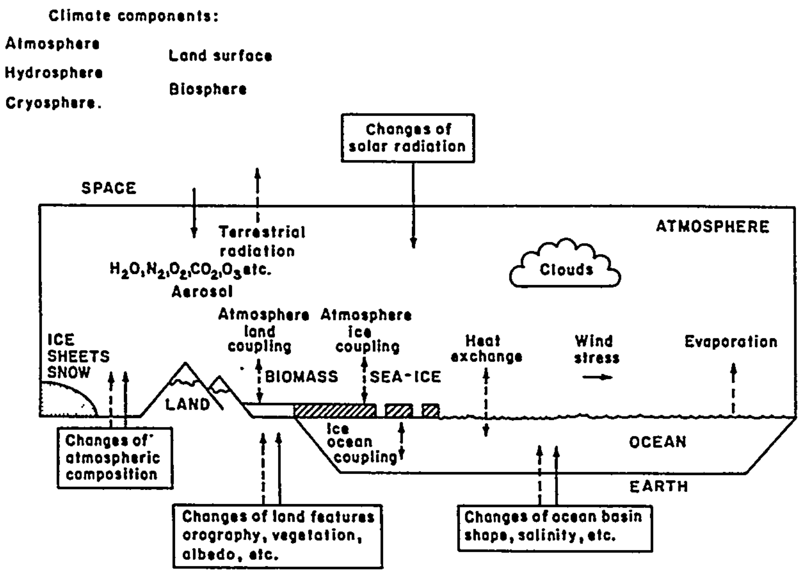

Figure 1.

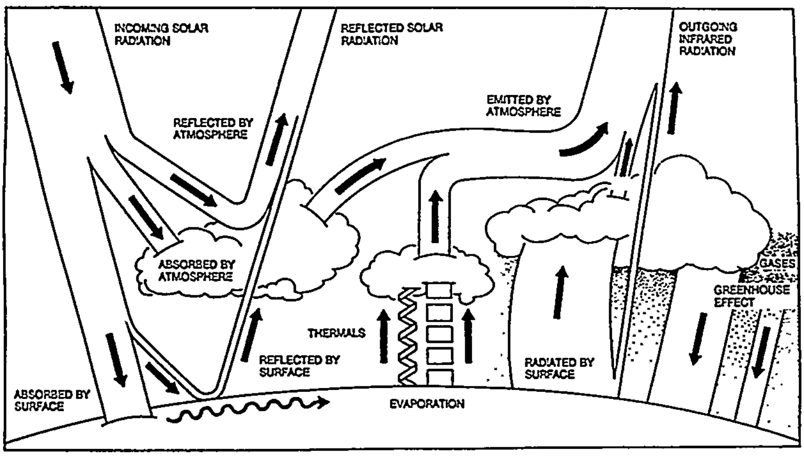

Figure 2.