U.S. Senate Committee on Commerce, Science and Transportation
Hearing on "The Case for Climate Change Action"
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Introduction and Personal Perspective. If I may indulge in a personal note at the outset: it is a pleasure to appear again in front of both Senators McCain and Lieberman on climate change issues, having had that honor on several occasions since the mid-1980s with Senator McCain and the mid-1990s with Senator Lieberman. As these hearings today are about the "case for action" on climate change based on sound science assessment, I will try to emphasize aspects of the science of climate change less exhaustively covered by other witnesses, such as Dr. Tom Wigley of the National Center for Atmospheric Research, whose testimony on climate change science I fully associate myself with. Instead, I will focus more on climate change impacts. The problem was well-stated by Senator Lieberman when I commented to the Senate Environment and Publics Works Committee, chaired by the late Senator Chaffee, in July 1997. At that time, Senator Lieberman said:

> Changes in climate have major implications for human health, water resources, food supplies, infectious diseases, forests, fisheries, wildlife populations, urban infrastructure, and flood plain and coastal developments in the United States. Although uncertainties remain about where, when, and how much climate might change as a result of human activities, the changes —when they happen—may have severe impacts on many sectors of the U.S. economy and on the environment. These are serious risks that we must start considering (p. 15).

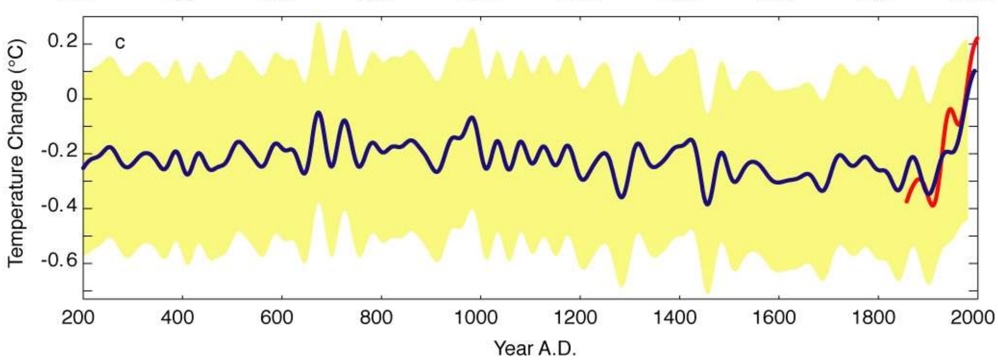
This statement is equally valid today and can be further supported by substantially more scientific studies pointing out potentially serious climate impacts. I will briefly review some of these and put them in the context of climate change cost-benefit analyses. But first, a brief statement about the climate change science itself.

While testifying to this Committee on May 8, 1989—when Senator McCain was a member of the Committee—I recall a discussion about the problem of uncertainties surrounding climate change and the question of how long we should wait before taking action. Some debaters had asserted that there wasn't enough direct evidence of human-induced climate change for strong policy actions. In response to Senators from this committee on that point, I agreed that "Most of our confidence that the future will change is based on literally millions and millions of observations which tell us about the heat trapping properties of gases, not based so much on the performance of the planet this century. If we insist on waiting for the planet to catch up to what we expect it to do, it is another 10 to 20 years to prove that beyond doubt" (p.150).

Well, it is now 14 years since I said that. I believe the work of the Intergovernmental Panel on Climate Change (IPCC), the U.S. National Academy of Sciences (NAS), and others has amply demonstrated that, indeed, nature has "caught up" with our expectations of warming and in fact added a few surprises like rapid changes in polar regions and devastating heat-wave-induced deaths, even in modern, highly developed countries, with the more than 15,000 mortalities occurring in France this summer as a result of the extreme heat serving as a prime example.

Surface warming trends are solidly grounded in observational science and consistent with human-induced pressures. It is scientifically well established that the Earth's surface air temperature has warmed significantly, by about 0.6 ° Celsius (C) since 1860, and that an upward trend can be clearly discerned by plotting historical temperatures. Such a graph would show a rapid rise in temperature at the end of the twentieth century. This is supported by the fact that all but three of the ten warmest years on record occurred during the 1990s. But what has been learned only in the past five years is that this unusual warmth in recent years is not just an anomaly in temperature records of the last 140 years, but the past 2000, as Figure 1 displays.

Figure 1. 2,000-year reconstruction of global temperature changes in degrees Celsius



The blue line represents the temperature reconstruction, with 95% confidence band shown in yellow and the instrumental record in red. Notice that the last several decades of the 20th century exceed the range of temperatures over the past 2000 years. (Source: Mann and Jones, 2003.)

The probability that the radical upward swing in temperature at the tail end of the 20th century is just a natural quirk of nature—as some "contrarians" and their political supporters contend—is exceedingly low. If, as some assert, "the sun did it", then what was the sun doing over the previous 2 millennia? It is rather perverse to expect such radical behavior from the sun just now, at the same time that we have clear evidence of human-induced pressures coincident with the warming. While the possibility (at some low probability) that natural factors are responsible for the unusual warmth of the Earth's surface at the end of the 20th century cannot be ruled out completely, a much more likely explanation is that the warming is the result of a mix of natural and human-induced (anthropogenic) factors. While this alone is cause for worry, more disquieting still are climate change projections for the 21st century, especially if we assume that greenhouse gas emissions follow a business-as-usual path.

It is for these reasons that I express my personal satisfaction for having, over the past two decades, had the opportunity to testify to the Senators currently leading this effort to establish a meaningful climate change policy for the United States that will actually result in emissions reductions. In my personal opinion, it is essential that we get on with the job of providing (mandatory) incentives to push the amazing industrial and intellectual capacity of our country to fashion cost-effective solutions. I thank the Senators for having pursued this issue over the long term.

As mentioned, nature has cooperated with theory in the past few decades, as evidenced by the record warming. In addition, it is well-established that human activities have caused increases in radiative forcing, with radiative forcing defined as a change in the balance between the radiation coming into and going out of the surface-atmosphere system. In the past few centuries, atmospheric carbon dioxide has increased by more than 30 percent, and virtually all climatologists agree that the cause is human activities, and the burning of fossil fuels in particular.

Despite the many well-established aspects of the science of climate change (e.g., anthropogenic forcing of global warming), other aspects (e.g., specific regional changes) are still being vigorously debated. In fact, the climate change debate is characterized by deep uncertainty, which results from factors such as lack of information, disagreement about what is known or even knowable, linguistic imprecision, statistical variation, measurement error, approximation, subjective judgment, and disagreement about structural models, among others (see Moss and Schneider, 2000). These problems are compounded by the global scale of climate change, which produces varying impacts at local scales, long time lags between forcing and its corresponding responses, very long-term climate variability that exceeds the length of most instrumental records, and the impossibility of before-the-fact experimental controls or empirical observations (i.e., there is no experimental or empirical observation set for the climate of, say, 2050 AD, meaning all our future inferences cannot be wholly "objective," data-based assessments — at least not until 2050 rolls around). Moreover, climate change is not just a scientific topic but also a matter of public and political debate, and degrees of uncertainty may be played up or down (and further confused, whatever the case) by stakeholders in that debate.

Can We Define "Dangerous" Climate Change? Article 2 of the UN Framework Convention on Climate Change (UNFCCC) states that: "The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". The Framework Convention on Climate Change further suggests that:

"Such a level should be achieved within a time frame sufficient

- to allow ecosystems to adapt naturally to climate change,
- to ensure that food production is not threatened and
- to enable economic development to proceed in a sustainable manner."

Thus, the term "dangerous anthropogenic interference" may be defined or characterized in terms of the consequences (or impacts) of climate change outcomes, which can be related to the levels and rates of change of climate parameters. These parameters will, in turn, be determined by the evolution of emissions and consequent atmospheric greenhouse gas concentrations. Evaluating the consequences of climate change outcomes to determine those that may be considered "dangerous" is a complex undertaking, involving substantial uncertainties as well as value judgments. In this context, the role of scientists is to assess the literature with a view to providing information that is policy-relevant, without being policy prescriptive.

Climate Sensitivity and Climate Scenarios to 2100 and Beyond. By how much will humans and natural changes in the Earth each contribute to future climate disturbance? The IPCC has attempted to tackle this controversial question in its Special Report on Emission Scenarios (SRES), which contains a range of possible future climate scenarios based on different assumptions regarding economic growth, technological developments, and population growth, arguably the three most critical determinants of future climate change. Together, the fan of possible climate scenarios and the probability distributions of possible climate sensitivities determine what policy makers often want to know—by how much will it warm in, say, 2100 (or any other time), depending on what policies we choose to change emissions scenarios (e.g., Schneider, 2002).

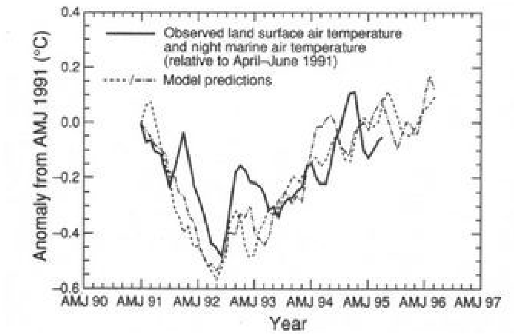
The SRES scenarios and other climate change projections depend on detailed modeling. The most typical way scientists codify knowledge is by constructing models made up of the many subcomponents of the climate system that reflect our best understanding of each subsystem. The most comprehensive models of atmospheric conditions are three-dimensional, time-dependent simulators known as general circulation models (GCMs). Because of the complexity and computational costs of GCMs, simpler models are often constructed to explore the sensitivity of outcomes to plausible alternative assumptions (e.g., Wigley's, testimony to this session). The system model as a whole cannot be directly tested before the fact — that is, before the future arrives — but it can be verified against historical situations that resemble what we believe will be analogous to what will occur in the future (see "Model Validation" below).

While modeling has become both more complex and more accurate as computing abilities have advanced and more is understood about the climate problem, scientists still have to deal with an enormous amount of uncertainty, as mentioned above. In modeling, a major uncertainty is climate sensitivity, the amount by which the global mean surface air temperature will increase for a doubling of CO_2 concentrations from pre-industrial levels. Many scientists have done extensive modeling and observational research on this subject over the past 20 years, and most agree that climate sensitivity probably falls somewhere within the IPCC's range of 1.5-4.5 ^{o}C. However, that old consensus is changing, as several recent studies (e.g., Andronova and Schlesinger, 2001; Forrest et al, 2001) have estimated that climate sensitivity could be an alarming 6 ^{o}C or higher. (To give a sense of the magnitude, a 5-7 ^{o}C ***drop*** in temperature is what separates Earth's present climate from an ice age.)

Model Validation. In the presence of so much uncertainty, how can modelers be more confident in their model results? How do they know that they have taken into account all economically, ecologically, and/or climatologically significant processes, and that they have satisfactorily "parameterized" processes whose size scales are below that of their models' grid cells? The answer lies in a variety of model validation techniques, most of which involve evaluating a model's ability to reproduce — in the case of climate models — known climatic conditions in response to known forcings.

Volcanic eruptions are one good form of model validation. Major volcanic eruptions inject so much sulfuric acid haze and other dust into the stratosphere that they exert a global cooling influence that lasts several years. Such eruptions occur somewhat randomly, but there is typically one every decade or so, and they constitute natural "experiments" that can be used to test climate models. The last major volcanic eruption, of the Philippine volcano Mt. Pinatubo in 1991, was forecast by a number of climate modeling groups to cool the planet by several tenths of a degree Celsius. That is indeed what happened.

Figure 2. Predicted and observed changes in global temperature after the 1991 eruption of Mt. Pinatubo



Solid curve is derived from measured air temperatures over land and ocean surfaces. Broken curves represent climate model runs with slightly different initial conditions. In both cases the models included the effect of dust injected into the atmosphere by the volcanic eruptions. (Source: Hansen et al, 1996.)

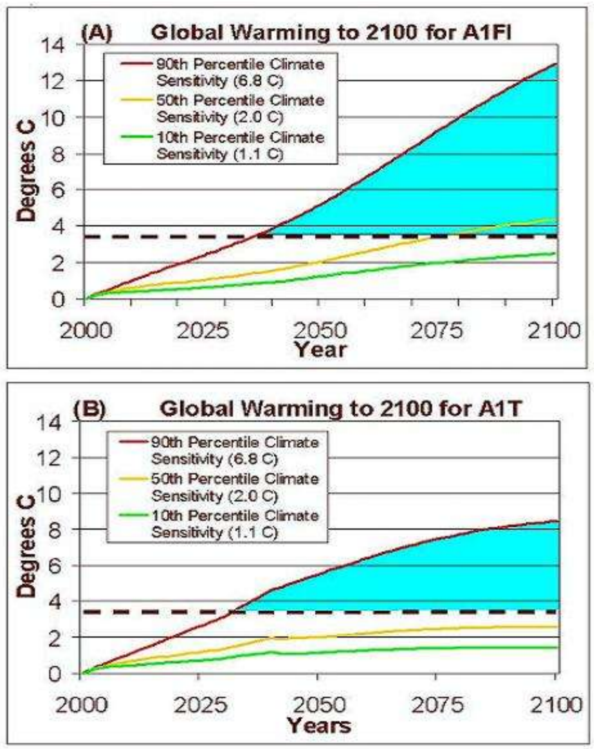
Figure 2 shows a comparison between actual global temperature variations and those predicted by a climate model for a period of five years following the Mt. Pinatubo eruption. Now, a drop in temperature of a few tenths of a degree Celsius is small enough that the observed variation just could be an unusual natural fluctuation. However, earlier eruptions, including El Chichón in 1983 and Mt. Agung in 1963, were also followed by a marked global cooling of several tenths of a degree Celsius. Studying the climatic effects from a number of volcanic eruptions shows a clear and obvious correlation between major eruptions and subsequent global cooling. Furthermore, a very simple calculation shows that the negative forcing produced by volcanic dusts of several watts per square meter is consistent with the magnitude of cooling following major volcanic eruptions. Viewed in light of these data, the graph above suggests that climate models do a reasonably good job of reproducing the large-scale climatic effects of volcanic eruptions over a time scale of a few years.

Seasonality provides another natural experiment for testing climate models. Winter weather typically averages some fifteen degrees Celsius colder than summer weather in the Northern Hemisphere and five degrees Celsius colder in the Southern Hemisphere. (The Southern Hemisphere variation is lower because a much larger portion of that hemisphere is water, whose high heat capacity moderates seasonal temperature variations.) Climate models do an excellent job reproducing the timing and magnitude of these seasonal temperature variations, although the absolute temperatures they predict may be off by several degrees in some regions of the world. However, the models are less good at reproducing other climatic variations, especially those involving precipitation and other aspects of the hydrological cycle. Of course, being able to reproduce the seasonal temperature cycle alone — since it comes full circle in only one year — does not guarantee that a model will accurately describe the climate variations resulting from other driving factors (such as increasing anthropogenic greenhouse gas concentrations) that will likely occur over decades or centuries. On the other hand, the fact that models do so well with seasonal variations is an assurance that the models' climate sensitivity is unlikely to be off by a factor of 5 - 10, as some contrarians assert.

Joint Probability Estimation. The combined effects of uncertainties in emissions and uncertainties in climate sensitivity are also known as a “joint probability” (i.e., sensitivity and emissions varied jointly). How do we approach this question of the joint probability of temperature rise to 2100 *and* crossing some “dangerous” warming threshold, to use the language of the UNFCCC—which, by the way, was signed by President Bush in 1992 and ratified by the Senate. Instead of using two probability distributions, an analyst could pick a high, medium, and low range for each factor and plot the results, as I will demonstrate. For example, a glance at Andronova and Schlesinger’s (2001) calculations shows that the 10 percentile value for climate sensitivity is 1.1 ºC for a doubling of CO_2 (i.e., 4 W/m^2 of radiative forcing). 1.1 ºC is, of course, below the IPCC's lower limit climate sensitivity value of 1.5 ºC. However, this merely means that there is a 10 percent chance climate sensitivity will be 1.1 ºC or less — that is, a 90% chance climate sensitivity will be 1.1 ºC or *higher*. The 50th percentile result — that is, the value that climate sensitivity is as likely to be above as below — is 2.0 ºC. The 90th percentile value for climate sensitivity from Andronova and Schlesinger (2001) is 6.8 ºC, meaning there is a 90% chance climate sensitivity is 6.8 ºC or less, but there is still a very uncomfortable 10% chance it is even higher than 6.8 ºC — a value well above the 4.5 ºC figure that marks the top of the IPCC's range. Using these three values to represent a high, medium, and low climate sensitivity, we can produce three alternate projections of temperature over time, once an emissions scenario is decided on.

In Schneider (2003), the three climate sensitivities just explained were combined with two SRES storylines: A1FI, the very high emissions, fossil fuel-intensive scenario; and A1T, the high technological innovation scenario, in which development and deployment of advanced technologies dramatically reduces the long-term emissions. This comparison pair almost brackets the high and low ends of the 6 SRES representative scenarios’ range of cumulative emissions to 2100, and since both are for the “A1 world,” the only major difference between them is the technology component. This component should be viewed as a “policy lever” that could be activated through the implementation of policies to encourage decarbonization, for example—like the bill before this committee. Therefore, studying how different the evolution of projected climate is to 2100 for the two different scenarios is a very instructive exercise and can help in exploring the different likelihoods of crossing “dangerous” warming thresholds.

Figure 3. Three climate sensitivities and two scenarios (source: Schneider, 2003)



As noted in Figure 3 above, the three climate sensitivities — 10th, 50th and 90th percentiles — designated by Andronova and Schlesinger (2001) are combined with the radiative forcings for the A1FI and A1T scenarios laid out in the SRES. The dashed horizontal lines in both graphs represent the 3.5 °C cut-off — a very conservative number picked by me as the threshold value for "dangerous" climate change — and the blue shaded area marks the extent to which each temperature change scenario exceeds that 3.5 °C threshold. As shown, these scenarios produce similar projections of warming for the first several decades of the 21st century, but diverge considerably— especially in the high-sensitivity 90th percentile case — after mid-century. The 50th and 90th percentile A1FI cases both exceed the threshold of 3.5 °C warming before 2100, and the area shaded in blue is much more dramatic in the fossil-intensive scenario than the technological innovation scenario. In fact, at 2100, when the A1T curves are stabilizing, the A1FI curves are still upwardly sloped — implying even greater warming in the 22nd century. In order to fully assess "dangerous" climate change potential, simulations that cover well over 100 years will be necessary, since it is widely considered that warming above a few degrees Celsius is likely to be much more harmful than changes below a few degrees (see Figure 4 below).

How Long is a "Long View"? The most striking features of both scenarios in Figure 3 are the top (red) lines, which rise very steeply above the two lines below them. That is because of the peculiar shape of the probability density function for climate sensitivity in Andronova and Schlesinger (2001). [For those concerned with the technical details, that is because the probability density function has a long tail on the right-hand side, representing the possibility that aerosols have been holding back not-yet-realized warming and the rise in temperature could be much higher than currently expected.] Also striking is that both the 10th and 50th percentile results for both the A1FI and A1T scenarios don't differ much in 2050, but then diverge considerably by 2100. This has led some to declare (erroneously, in my view) that there is very little difference in climate change across scenarios or even among different climate models with different sensitivities. This is clearly wrong, for although both A1FI and A1T have emissions, and thus CO_2 concentration, projections that are not very different for the first several decades of the 21st century, they diverge after 2050, as does the temperature response. For the 90th percentile results, both the A1FI and the A1T temperature projections exceed the "dangerous" threshold of 3.5 °C at roughly the same time (around 2040), but the A1FI warming not only goes on to outstrip the A1T warming, but is still steeply sloped at 2100, implying warming beyond 13 °C in the 22nd century, which would undoubtedly leave a dramatic legacy of environmental damage for distant posterity and great ecological stress for nature.

Figure 3 shows, via a small number of curves (6 in all), the probability of temperature changes over time for three climate sensitivity probabilities, but it does not give probabilities for the emissions scenarios themselves; only two are used to "bracket uncertainty," and thus no joint probability can be gleaned from this exercise. This is the next step that needs to be taken by the research community. An MIT integrated assessment group (Webster et al, 2003) has already attempted to fashion a probability distribution for future climate using a series of different models and expert judgments. Like other assessments, their work also suggests a wide range of possibilities, with some representing quite "dangerous" potential outcomes. That approach, I predict, will be the wave of the future in such analyses, but given the heavy model-dependence of any such results, individual "answers" will remain controversial and assumption-bound for a considerable time to come.

The likelihood of threshold-crossing is quite sensitive to the particular selection of scenarios and climate sensitivities used. However, in these bracketing studies, the probability of crossing "dangerous" thresholds of climate change is typically around ten percent—a risk society will have to weigh against the costs of climate mitigation activities. As will be discussed shortly, that is a high risk indeed.

If conventional economic discounting were applied, some present-day "rationalists" might argue that the present value of damages postponed for a century or so is virtually nil. But what if our behavior were to trigger irreversible changes in sea levels and ocean currents or the extinction of species (on generational time scales)? Is it fair to future generations for us to leave them the simultaneous legacy of more wealth and severe ecosystem damage? That is the dilemma thoughtful analysts of the climate policy debate have to ponder, since the next few generations' behaviors will precondition to a considerable extent the long-term evolution of the climate and the planetary ecosystems.

Climate Impacts. Let us consider some of the effects that might occur in the next century if the SRES emissions *do* occur. We can use models to calculate the climatic consequences of those scenarios unfolding, which then allow us to estimate potential impacts of climate changes, and in turn, the benefits of avoiding some of those potential damages through mitigation and/or other measures.

Table 1 shows the IPCC's summary of a number of such projected impacts. These effects have been consolidated into five major reasons for concern and represented graphically, as shown in Figure 4.

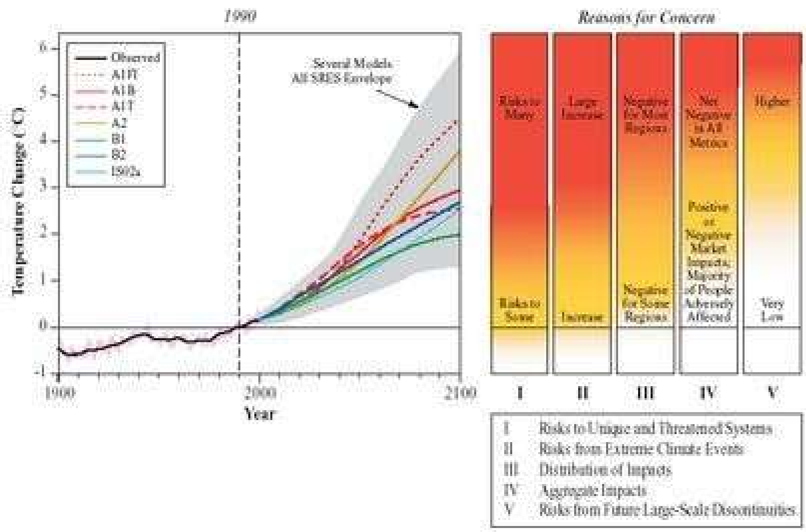
Table 1— Projected effects of global warming during the 21st Century (adapted from IPCC 2001b, table SPM-1)

Projected Effect	Probability estimate	Examples of Projected Impacts with high confidence of occurrence (67 – 95% probability) in at least some areas
Higher maximum temperatures, more hot days and heat waves over nearly all land areas	Very likely (90-99%)	Increased deaths and serious illness in older age groups and urban poor Increased heat stress in livestock and wildlife Shift in tourist destinations Increased risk of damage to a number of crops Increased electric cooling demand and reduced energy supply reliability
Higher minimum temperatures, fewer cold days, frost days and cold waves over nearly all land areas	Very likely (90-99%)	Decreased cold-related human morbidity and mortality Decreased risk of damage to a number of crops, and increased risk to others Extended range and activity of some pest and disease vectors Reduced heating energy demand
More intense precipitation events	Very likely (90-99%) over many areas	Increased flood, landslide, avalanche, and mudslide damage Increased soil erosion Increased flood runoff increasing recharge of some floodplain aquifers Increased pressure on government and private flood insurance systems and disaster relief

Increased summer drying over most mid-latitude continental interiors and associated risk of drought	Likely (67-90%)	Decreased crop yields Increased damage to building foundations caused by ground shrinkage Decreased water resource quantity and quality Increased risk of forest fire
Increase in tropical cyclone peak wind intensities, mean and peak precipitation intensities	Likely (67-90%) over some areas	Increased risks to human life, risk of infectious disease epidemics and many other risks Increased coastal erosion and damage to coastal buildings and infrastructure Increased damage to coastal ecosystems such as coral reefs and mangroves
Intensified droughts and floods associated with El Niño events in many different regions	Likely (67-90%)	Decreased agricultural and rangeland productivity in drought- and flood-prone regions Decreased hydro-power potential in drought-prone regions
Increased Asian summer monsoon precipitation variability	Likely (67-90%)	Increase in flood and drought magnitude and damages in temperate and tropical Asia
Increased intensity of mid-latitude storms	Uncertain (current models disagree)	Increased risks to human life and health Increased property and infrastructure losses Increased damage to coastal ecosystems

Figure 4 — Reasons for concern about climate change impacts (source: IPCC Working Group 2 Third Assessment Report, figure SPM-2)

Reasons for Concern About Climate Change Impacts.



In Figure 4 above, the left part of the figure displays the observed temperature increase up to 1990 and the range of projected increases after 1990, as estimated by IPCC Working Group I (IPCC, 2001a). The right panel displays conceptualizations of five reasons for concern regarding climate change risks evolving through 2100. White indicates neutral or small negative or positive impacts or risks, yellow indicates negative impacts for some systems, and red means negative impacts or risks that are more widespread and/or greater in magnitude. This figure shows that the most potentially dangerous impacts (the red colors on the figure) typically occur after a few degrees Celsius of warming — thus, my use of 3.5 ºC as a tentative "threshold" for serious climate damages in Figure 3 is very conservative. (The European Union has suggested the "dangerous" threshold is about 2 ºC.) The risks of adverse impacts from climate change increase with the magnitude of climate change.

Despite uncertainties surrounding emissions scenarios and climate sensitivity, the IPCC has projected that, if its latest estimate that the Earth's atmosphere will warm somewhere between 1.4 and 5.8 ºC by 2100 is correct, likely effects will include: more frequent heat waves (and less frequent cold spells); more intense storms (hurricanes, tropical cyclones, etc.) and a surge in weather-related damage; increased intensity of floods and droughts; warmer surface temperatures, especially at higher latitudes; more rapid spread of disease; loss of farming productivity and/or movement of farming to other regions, most at higher latitudes; species extinction and loss of biodiversity; and rising sea levels, which could inundate coastal areas and small island nations (see Table 1).

The threat of rising sea levels has been studied in great detail. It is thought that warmer atmospheric temperatures would lead to warming of ocean water (and corresponding volumetric expansion) until the heat was well-distributed throughout the oceans — a mixing time known to be on the order of 1,000 years. Instead of only up to a meter of sea level rise over the next century or two from thermal expansion of warmed ocean waters— and perhaps a meter or two more over the five or so centuries after that — significant global warming would likely trigger nonlinear events like a deglaciation of major ice sheets near the poles. That would cause many additional meters of rising seas for many millennia, and once started, might not be reversible on the time scale of thousands of years.

It is important that scientists continue to develop stronger models and probe the issue of climate sensitivity, as improvements in the science will lead to improvements in our understanding of the potential impacts of various levels of temperature change.

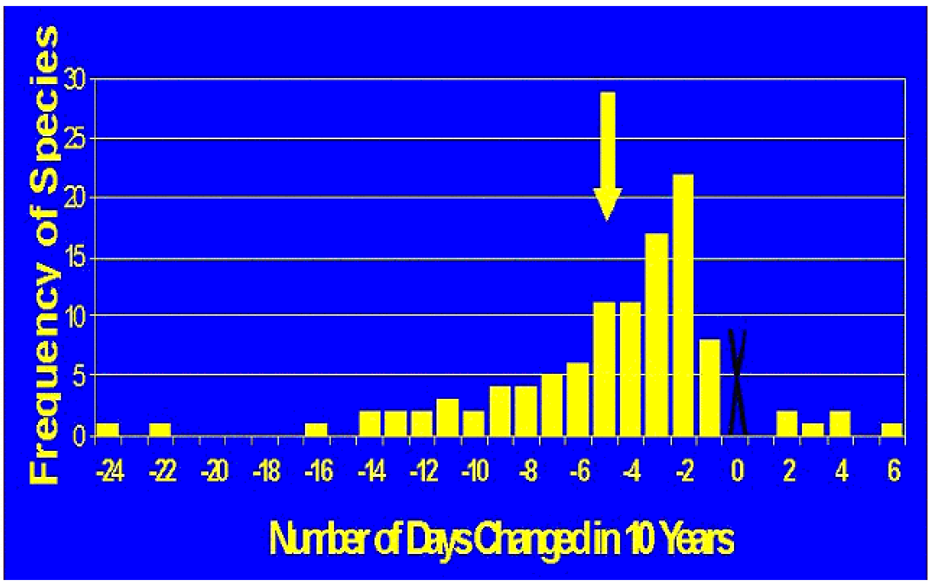
In What Units Can We Measure Climate Damage? Schneider, Kuntz-Duriseti, and Azar (2000) have argued that the best way to estimate the full extent of the climate change-induced damages described above is by examining not just monetarily-quantifiable ("market") damage, but the "five numeraires": monetary loss (market category), loss of life, quality of life (including coercion to migrate, conflict over resources, cultural diversity, loss of cultural heritage sites, etc.), species and/or biodiversity loss, and distribution/equity. Assessing climate impacts in all these categories should ensure a fairer, more accurate assessment of the actual costs of global warming.

The last numeraire, the issue of equity in climate change, is, and will likely continue to be, contentious. Climate change inequality will likely come in two forms. First, it will produce inequity in effects. Some countries or sectors within countries will benefit from a certain degree of warming, whereas others will be harmed by it. The developed countries, who are responsible for most of the greenhouse gases emitted into the atmosphere thus far may not be affected as much as the developing countries for two reasons: first, there is usually higher adaptive capacity in richer, cooler countries than in poorer, warmer ones. Second, developing countries that have not yet experienced the economic fruits of an industrial revolution and want their chance to emit and industrialize fear that policies to restrict emissions will deny them their “fair share” of the atmospheric commons to use—quite literally—as a waste dump. One strategy to solve this problem is “technology leapfrogging,” the transfer or development of cleaner technologies to developing countries on a much-accelerated time schedule (relative to the developments that have emerged over a century in now-rich countries).

Moreover, as there are disparities in countries’ abilities to pay for global warming-related problems, once again, the developing countries will be affected more yet have less of an ability to pay than the rich nations. While I agree it is essential to deal with climate policy at home—and thus personally applaud this bill before the committee today—we will have to join with other countries to fashion joint solutions in the near future if we are to make progress on the climate change problem.

Nature Is Already Responding. Another numeraire mentioned above was the loss of biodiversity. Very recent studies (e.g., Root et al, 2003; Parmesan and Yohe, 2003) have shown that nature is already responding to climate trends of the past several decades. Figure 5 (below), for example, shows the activities of many plants and animals — such as the flowering of trees and the migrating of birds in the spring — have been occurring earlier due to observed climate trends. That warmer weather would make flowers bloom earlier is hardly surprising, but that "only" 0.6 ºC of warming to date has already caused a statistically significant "discernible impact" on plants and animals is surprising. Moreover, it is sobering to consider what major movements — and extinctions — would likely take place in plant and animal communities if the climate changes by several degrees or more.

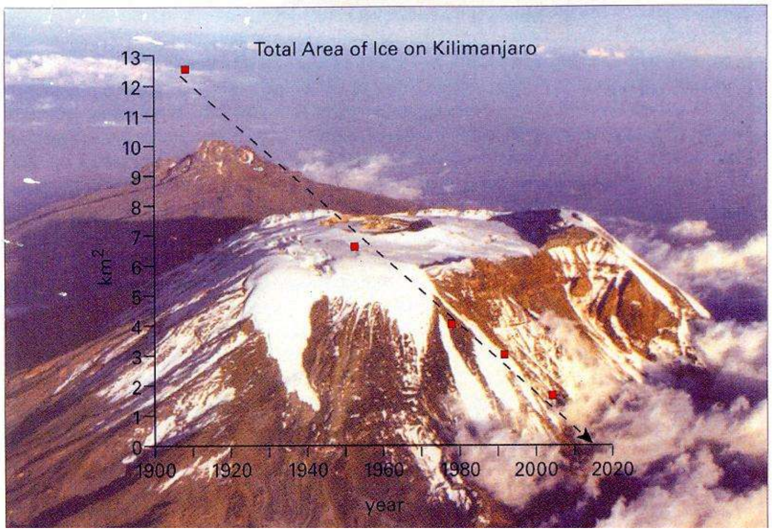
Figure 5. Frequency of species and groups of species with a temperature-related trait changing by number of days in 10 years for data gathered primarily since 1960



The arrow indicates the mean and the "x" indicates no data were tabulated for species showing no clear trait changes. This is a highly statistically significant result demonstrating that there has been a discernible impact of recent climate trends on plants and animals. Their vital activities that are linked to temperature are occurring earlier, in concert with global warming trends. (Source: Root et al, 2003.)

Another clear climate impact is the retreat of mountain glaciers. This problem goes beyond just the disruption of scenic beauty as glaciers in places like Glacier National Park continue to disappear; it can be damaging to societies that are flooded during the glacier-melting stage and will later suffer from lack of water as their current supplies disappear with the glaciers. Figure 6 shows the dramatic disappearance of Mt. Kilimanjaro's glaciers, which have decreased in size by 80-90% relative to 100 years ago.

Figure 6. What will happen to the snows of Kilimanjaro?



The extent of ice cover on Mt. Kilimanjaro decreased by 81% between 1912 and 2000. Disappearing paleoclimate archives such as this are a priority target of the Global Paleoclimate Observing System currently being proposed by the Past Global Changes (PAGES) scientists.

Climate Surprises? The IPCC and others have stated that "dangerous" climate change, including surprises, is more likely to occur with more than a few degrees Celsius of additional warming. Surprises, better defined as "imaginable abrupt events", could include deglaciation and/or the alteration of ocean currents, the most widely-used example of the latter being a slowdown of the Thermohaline Circulation, or THC, system in the North Atlantic Ocean. Ecosystems, especially those already stressed by land use pressures, are particularly vulnerable to rapid climate changes.

Estimating climate damages that are expected to occur gradually and their effects is simple relative to forecasting "surprise" events and their consequences. But rather than being ignored as unlikely, surprises and other irreversibilities like plant and animal extinctions should be treated like other climate change consequences by scientists performing risk assessments, where ***risk*** is defined as ***probability x consequence***. While the possible consequences of climate change have been discussed thoroughly, they are often not accompanied by probabilities. The probability component of the risk equation will entail subjective judgment on the part of scientists, but this is far preferable to overlooking the risk equation entirely.

Policymakers will be better able to determine what is "dangerous" and formulate effective legislation to avoid such dangers if probabilities appear alongside scientists' projected consequences. These probabilities and consequences will vary regionally. In general, temperature rises are projected to be greatest in the subpolar regions, and to affect the polar winter more dramatically than the summer. Hotter, poorer nations (i.e., developing nations near the equator) are expected to suffer more dramatic effects from climate change than their developed neighbors in the North. This is partly due to the lower expected adaptive capacities of future societies in developing nations (when compared with their developed country counterparts), which depend on their resource bases, infrastructures, and technological capabilities. This implies that damages may be asymmetrically felt across the developed/developing country divide. The scenario in which climate change brings longer growing seasons to the rich northern countries and more intense droughts and floods to the poor tropical nations is clearly a situation ripe for increasing international tensions and could cause developing nations to feel increasing resentment towards the most-polluting nations in the twenty-first century. That scenario has clear security implications for the United States.

Regardless of the different levels of vulnerability and adaptive capacity that future societies are expected to have and the need for regional-level assessments that that implies, all people, governments, and countries should realize that "we're in this together." In all regions, people's actions today will have long-term consequences. Even if humanity completely abandons fossil fuel emissions in the 22nd century, elevated CO_2 concentrations are projected to remain for a millennium or more. The surface climate will continue to warm from this greenhouse gas elevation, with a transient response of centuries before an equilibrium warmer climate is established. How large that equilibrium temperature increase is depends on both the final stabilization level of the CO_2 and the climate sensitivity.

Implications for Climate Policy Choices. In the face of such uncertainty, potential danger, and long-term effects of present actions, how should climate change policy be confronted? As discussed previously, climate change, like many other complex socio-technical issues, is riddled with "deep uncertainties" in both probabilities and consequences. They are not resolved today and may not be resolved to a high degree of confidence before we have to make decisions regarding how to deal with their implications. With imperfect, sometimes ambiguous, information on both the full range of climate change consequences and their associated probabilities, decision-makers must decide whether to adopt a "wait and see" policy approach or follow the "precautionary principle" and hedge against potentially dangerous changes in the global climate system. Since policymakers operate on limited budgets, they must determine how much to invest in climate protection versus other worthy improvement projects — like new nature reserves, clean water infrastructure and other health improvement, and better education.

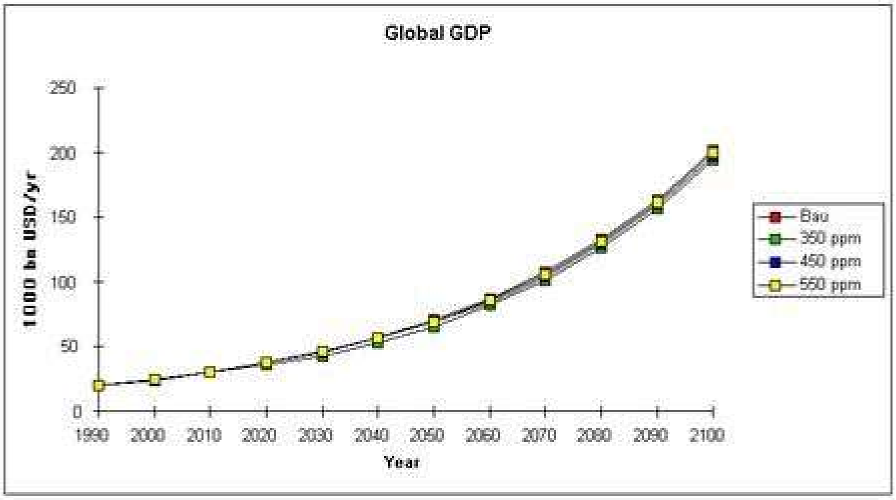
Ultimately, the decision on whether or not to take action on climate change entails a value judgment on the part of the policymaker regarding what constitutes "dangerous" climate change, ideally aided by complete risk assessments provided by scientists. Cost-benefit analyses (CBAs) are also useful in deciding the ifs and whats of climate change policy, but uncertainties and the need for multiple metrics (e.g., the "five numeraires") make this exercise difficult as well, especially when attempting to estimate the costs of surprise and other catastrophic events.

Any policies that are implemented should encourage, and possibly even go so far as to subsidize, technological change. Encouraging technological change through energy policies, in particular, is of critical importance when addressing climate change. As Figure 3 shows, alternate energy-technology scenarios could dramatically lower the risk of "dangerous" climate change.

Is It Really Too Expensive To Mitigate Global Warming? Christian Azar and I (Azar and Schneider, 2002) developed a simple economy model and estimated the present value (discounted to 1990, expressed in 1990 USD, and assuming a discount rate of five percent per year) of the costs to stabilize atmospheric CO_2 at 350 parts per million (ppm), 450 ppm, and 550 ppm to be 18 trillion USD, 5 trillion USD, and 2 trillion USD, respectively. Obviously, 18 trillion USD is a huge cost; the output of the entire global economy in 1990 amounted to about 20 trillion USD. Seen from this perspective, these estimates of the costs of abatement tend to create the impression that we would, as critics suggest, have to make draconian cuts in our material standards of living in order to reduce emissions and achieve the desired levels of CO_2 concentration. These same critics view the cost estimates as unaffordable and politically impossible.

However, viewed from another perspective, an entirely different analysis emerges. In the absence of emission abatement and without factoring in any damages from climate change, GDP is assumed to grow by a factor of ten or so over the next 100 years, which is a typical convention used in long-run modeling efforts. (The plausibility of these growth expectations is not debated here, but the following analysis will show how GDP is expected to grow with and without climate stabilization policies.) If the 350 ppm target were pursued, the costs associated with it would only amount to a delay of two to three years in achieving this aforementioned tenfold increase in global GDP. Thus, meeting a stringent 350 ppm CO_2 stabilization target would imply that global incomes would be ten times larger than today by April 2102 rather than 2100 (the date the tenfold increase would occur for the no-abatement-policies scenario). This trivial delay in achieving phenomenal GDP growth is replicated even in more pessimistic economic models. These models may be very conservative, given that most do not consider the ancillary environmental benefits of emission abatement (see Figure 7 below).

Figure 7. Global income trajectories under business-as-usual (BAU) and in the case of stabilizing the atmosphere at 350 ppm, 450 ppm, and 550 ppm



Observe that we have assumed rather pessimistic estimates of the cost of atmospheric stabilization (average costs to the economy assumed here are \$200/ ton Carbon (tC) for 550 ppm target, \$300/tC for 450 ppm, and \$400/tC for 350 ppm) and that the environmental benefits in terms of climate change and reduction of local air pollution of meeting various stabilization targets have not been included. (Source: Azar & Schneider, 2002.)

Representing the costs of stringent climate stabilization as a few short years of delay in achieving monumental increases in wealth should have a strong impact on how policymakers, industry leaders, and the general public perceive the climate policy debate. Similar results can be presented for the Kyoto Protocol: the drop in GDP below "baseline" levels that would occur if the Kyoto Protocol were implemented ranges between 0.05% and 1%, depending on the region considered and the model used (see IPCC Working Group III, chapter 8, IPCC 2001c, p. 537-538). The drops in the growth rates for OECD countries over the next ten years would likely fall in the range of 0.005-0.1 percent per year below baseline scenario projections under the Kyoto Protocol. (It should be kept in mind that the uncertainties about baseline GDP growth projections are typically much larger than the presented cost-related deviations.) Returning to the analysis Azar and I did, assuming a growth rate of two percent per year in the absence of carbon abatement policies, implementation of the Kyoto Protocol would imply that the OECD countries would get 20 percent richer (on an annual basis) by June 2010 rather than January 2010, assuming the high-cost abatement estimate.

Similar statements could well be made about the costs associated with this bill that is before the Committee. Although I have not analyzed it myself, I strongly suspect that the loss of GDP from the costs incurred as a result of implementing this measure would be such a small fraction of typically-projected US GDP growth rates that only months of delay in growth would occur, nowhere enough to prevent large increases in personal income from occurring. Thus, this bill is likely to be an inexpensive “insurance premium” to slow down global warming and lower the likelihood of “dangerous” climate impacts.

Whether the costs mentioned are big or small is, of course, a value judgment, but in any case, it is difficult to reconcile the long-term climate benefits of a short-term delay in GDP growth with the strident rhetoric of contrarians like Lindsey (2001) who states in a speech to a colloquim on Science and Technology Policy (organized by the American Association for the Advancement of Science, or AAAS) that “the Kyoto Protocol could damage our collective prosperity and, in so doing, actually put our long-term environmental health at risk” (p.5). Others have made similar statements about this bill, and they have been refuted by careful economic analyses (Pizer and Kopp, 2003; Paltsev et al, 2003). Clearly, such balanced quantitative economic assessments, rather than pessimistic and often politically-motivated exaggerations should guide the evaluations of making bills like this one the laws of the land.

I thank the Committee for asking for my views on this important piece of legislation.

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