Improving the Assessment and Valuation of Climate Change Impacts for Policy and Regulatory Analysis

Sponsored by

United States Environmental Protection Agency

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Workshop Report:

Improving the Assessment and Valuation of Climate Change Impacts for Policy and Regulatory Analysis – Part 2

Research on Climate Change Impacts and Associated Economic Damages

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I. Introduction

This report summarizes the January 27-28, 2011 workshop, *Research on Climate Change Impacts and Associated Economic Damages*, sponsored by the U.S. Environmental Protection Agency (EPA) and U.S. Department of Energy (DOE). This was the second in a series of two workshops, titled *Improving the Assessment and Valuation of Climate Change Impacts for Policy and Regulatory Analysis.*

This report is organized as follows:

- The first section provides an introduction to the report and the workshop, including context and workshop format.
- The second section provides a summary of the findings and potential improvements to climate change impacts and damages assessment, as identified by workshop participants. This section summarizes and categorizes the wide variety of cross-cutting and sector-specific recommendations highlighted by individual participants over the course of the two-day workshop.
- The third section provides a chronological presentation of the workshop proceedings, including a summary of each presentation and discussion section.
- The appendix to the report provides the final workshop agenda, charge questions, participant list, and extended abstracts of most speaker presentations.

This report serves as the EPA and DOE planning committee's summary of the workshop. It has not received official endorsement from the workshop speakers and other participants.

Context

In 2009 and early 2010, EPA and DOE participated in the interagency working group on the social cost of carbon (SCC). The interagency group used the DICE, FUND, and PAGE integrated assessment models (IAM) to estimate a range of values for the SCC from 2010 to 2050 for use in U.S. government regulatory impact analyses (RIA). The SCC working group reported their findings in February 2010 and the estimated SCC values were first used in the analysis of DOE's Energy Conservation Standard for Small Electric Motors.[1] In preparation for future iterations of this process, EPA and DOE seek to improve the natural science and economic understanding of the potential impacts of climate change on human well-being. This enhanced understanding is also intended to inform ongoing work of the U.S. government to improve regulatory assessment and policy analysis related to climate change.

To help inform this work, EPA's National Center for Environmental Economics and Climate Change Division and DOE's Office of Climate Change Policy and Technology sponsored a pair of invitational workshops in late 2010 and early 2011. The first workshop took place on November 18-19, 2010 and focused on conceptual and methodological issues related to modeling and valuing climate change

[1] See http://go.usa.gov/3fH.

impacts. It also addressed the implications of these estimates for policy analysis. The second workshop, which is the focus of this report, took place on January 27-28, 2011, and reviewed recent research that examines the physical impacts and associated economic damages for a variety of impact categories (e.g., human health, agriculture, sea level rise), with a particular focus on knowledge that might be used to improve IAMs.

Workshop Format

The workshop took place over two days, January 27-28, 2011, at the Capital Hilton Hotel in Washington, DC. The workshop was attended by approximately 100 individuals, including representatives from several U.S. federal government agencies, non-governmental organizations, academia, and the private sector. A full list of workshop participants is available in the Appendix.

The workshop began with opening remarks about recent progress in estimating climate change impacts and valuing climate damages. The vast majority of the workshop consisted of plenary sessions covering research on the following specific impact categories:

- Storms and Other Extreme Weather Events
- Water Resources
- Human Health
- Agriculture
- Sea Level Rise
- Marine Ecosystems and Resources
- Terrestrial Ecosystems and Forestry
- Energy Production and Consumption
- Socio-economic and Geopolitical Impacts

Most sessions included presentations by at least one natural scientist and at least one economist, followed by an open discussion with the audience. The workshop concluded with a panel discussion about incorporating the research on climate change impacts into integrated assessment modeling and brief summary comments by representatives of EPA and DOE.

II. Findings and Potential Improvements Identified by Workshop Participants

Over the course of the two-day workshop, a number of research findings and suggestions for improving the assessment of climate change impacts and damages were identified by the workshop participants. This section aims to summarize and categorize those suggestions.

The participants' suggestions related to impacts and damages assessment both generally and within specific impact categories. As such, the section is organized into two broad categories of comments: cross-cutting comments and sector-specific comments.

The potential improvements and key findings outlined below represent the perspectives of one or more participants but, importantly, do not represent a consensus since none was sought at this workshop.

Cross-Cutting Comments

Throughout the workshop, several participants made comments or suggestions related to impact and damage assessment that apply to more than one impact category. This section is organized into three types of comments:

- Comments related to impact assessment and valuation within sectors
- Comments related to combining impact assessment and valuation from different sectors
- Comments related to research and collaboration priorities

Comments related to impact assessment and valuation within sectors

Throughout the course of the workshop, the participants' comments and suggestions related to impacts assessment and valuation within sectors spanned a wide range of topics, including the following:

- **Clearly incorporate the human response.** Throughout the two-day workshop, numerous participants emphasized the importance of clearly incorporating the human response to climate change when estimating climate change impacts. The human response includes both adaptation and technology development. Many participants emphasized that modeling needs to explicitly account for the human response to climate change impacts, which will greatly affect the magnitude of damages. Participants further emphasized that it is important to clearly articulate what is assumed and included regarding the human response.

- **Build on knowledge of non-climate change impacts and responses.** During the conference, several participants emphasized that climate change impacts (e.g., storms, health impacts) and the corresponding management responses are not without analog. Participants noted that, in many cases, climate change will simply enhance or reduce impacts of other anthropogenic stressors, rather than introduce entirely new stimuli. Participants encouraged the assessment and valuation communities to build on knowledge of existing impacts when modeling future climate change impacts and responses.

- **Use appropriate concepts to measure welfare impacts.** Numerous participants emphasized that GDP is not a measure of welfare, and recommended that alternate measures be used. For example, one participant suggested that consumer surplus is a better measure of welfare. Another participant suggested that direct costs of damage provide a reasonable estimate for global welfare losses.

- **Use appropriate scale and level of detail.** Several participants discussed the importance of scale and level of detail in impacts assessment. Participants suggested that the scale and level of detail required to model each sector is somewhat unique.

  - **Consider both top-down and bottom-up approaches.** Participants noted that both top-down and bottom-up approaches should be considered to estimate climate change impacts. One participant noted that estimates from the two approaches should converge, confirming the accuracy of the estimates.

- **Better estimate non-linear impacts and damages.** Workshop participants identified several potential improvements related to the assessment of non-linear impacts and damages, including threshold effects, non-linear scaling, and unprecedented changes.

    - **Incorporate threshold effects of physical and biological impacts.** Numerous participants highlighted the thresholds that characterize physical and biological impacts. Participants emphasized the importance of accounting for thresholds, which pervade almost every sector, to robustly estimate impacts. One participant noted that aggregate representations of the natural science can lead to neglect of important threshold effects.

    - **Recognize non-linear character of damages.** Workshop participants emphasized that climate change damages do not necessarily scale linearly with socio-economic variables (e.g., population, income). Several participants highlighted examples of climate damages that relate inversely or non-proportionally with socio-economic variables such as population and income (e.g., sea level rise or health damages). Participants emphasized that it is not appropriate to automatically assume linear scaling of damages.

    - **Use mechanistic approaches.** Several participants recommended the use of mechanistic and process models since statistical extrapolation may not capture non-linear effects of unprecedented levels of change. Participants suggested that impacts modelers rely on basic principles (e.g., plant biophysiology, ocean chemistry) to predict the responses to new climate conditions. However, in cases where climate change impacts are expected to be within or close to the range of past variations, statistical models are appropriate. Participants noted that statistical modeling is more appropriate in some sectors (e.g., agriculture, wildfire impacts) than others.

- **Increase focus on extreme climate events.** Several workshop participants highlighted the need for impacts and valuation assessment to examine the impacts and damages from extreme climate events for incorporation in IAMs and the SCC. Several participants noted that impact studies tend to examine temperature changes of 2.5 to 3 degrees Celsius, neglecting to evaluate the impacts at higher temperature changes. Furthermore, impacts assessment has tended to focus on the means of the probability distribution of impacts, neglecting to evaluate the low-probability, high impact tails of the distribution. Participants emphasized the importance of these high-impact events (e.g., extreme temperature increase, sea level rise) on IAM results.

- **Account for very long-term (beyond 2100) impacts.** Several participants noted the need for impacts and valuation assessment to examine the damages from very long-term (e.g., beyond 2100) impacts. Participants emphasized the importance of these long-term impacts (e.g., ice sheet melting, possible deep ocean anoxia) for IAM results. Participants noted that impact and damage assessments tend to focus on more near-term impacts. They explained that it is critical to model long-term impacts, despite the great uncertainty associated with doing so. Characterization of that uncertainty is important.

- **Distinguish between committed and projected impacts.** Several workshop participants highlighted a need to distinguish between committed and projected impacts in models. Participants emphasized that models need to correctly account for this notion of irreversibility in terms of both positive and negative impacts and damages. They explained that due to the inertia of natural systems, mitigation will not lead to an immediate cessation of some impacts. For example, mitigation can stabilize the rate of sea level rise but cannot prevent the realization of significant, already committed sea level rise.

- **Fully account for non-market and non-use values.** Several participants emphasized the importance of fully incorporating non-market and non-use values to build robust estimates of damages. Several participants recommended that revealed and stated preference estimates and benefit-transfer methods be improved to value these impacts. One participant suggested that problems with both revealed preference and stated preference methods can be mitigated by joint estimation of revealed preference and stated preference data. Another participant recommended collaboration between natural scientists and economists so that impacts assessment endpoints correspond to the items assessed in valuation exercises.

- **More fully incorporate uncertainty**. Throughout the conference, several participants recommended that scientists attempt to characterize the great uncertainty in impacts assessments. IAMs can be used to evaluate the impact of some aspects of sector-specific uncertainty on the SCC.

- **Rigorously evaluate impact models**. Several workshop participants emphasized the importance of rigorously testing, comparing, and evaluating impact models. Several participants noted the important role of Model Intercomparison Projects (MIPs) in improving physical climate models, and suggested that these types of approaches be utilized for a wider range of models. One example of an ongoing impact MIP is the Agricultural Model Intercomparison and Improvement Project (AGMIP).

- **Recognize the potential for unexpected and unpredictable events.** Several participants highlighted the fact that there will likely be unexpected impacts from climate change. For example, one participant described an unexpected outbreak of a shellfish-caused gastrointestinal disease in Alaska due to increases in water temperatures above a previously unknown threshold. Another participant noted that new agricultural pests with unknown characteristics will likely develop as a result of climate change.

Comments related to combining impact assessment and valuation from different sectors

Participants also suggested potential improvements in modeling interactions between different natural and economic systems. These suggestions include the following:

- **Incorporate interactions between sectors.** Throughout both days of the workshop, numerous participants highlighted the importance of including interactions between sectors when estimating impacts. Participants highlighted several examples of interacting sectors, including sea level rise and extreme storms, heat-related health effects and space cooling demand, and water resources and energy demand, among others. Participants noted that interactions and feedbacks may be synergistic or antagonistic, additive, multiplicative, or subtractive. As a result, the cumulative impacts may be larger or smaller than the sum of the individual impacts. Participants further noted the importance of avoiding double-counting when integrating the climate change impacts across sectors.

- **Keep climate change in context.** Over the course of the workshop, several participants emphasized that climate change is only one of many other global, anthropogenic changes impacting the sectors discussed. Participants highlighted the need to incorporate interactions with non-climate stressors and to account for the risk of climate change in relation to other global changes. For example, one participant presented the impacts of water allocation policy on water resources; another participant highlighted needs (e.g., education) other than climate-related health issues competing for investment in developing countries; and, a third participant highlighted coastal management decisions that affect the impacts from relative sea level rise.

Comments related to research and collaboration priorities

Finally, participants made suggestions related to framing a research agenda. These suggestions include the following:

- **Focus research efforts on impacts with greatest magnitude.** Several workshop participants recommended that future research efforts focus on the impacts and damages with potentially the greatest magnitude. One participant noted that it is more important to estimate a high cost damage with some quantified but sizable measure of error, than a lower cost damage with high precision. This recommendation applies both within and among sectors. For example, one participant suggested that it is more important to improve estimates of mortality impacts than to improve estimates of morbidity impacts since the monetized value of mortality impacts tends to overwhelm the monetized value of morbidity impacts. Another participant suggested that IAMs can be used to evaluate the relative magnitude of impacts in different sectors. Research can then be targeted on improving estimates of those impacts with the greatest effect on the SCC.

- **Foster interaction between natural scientists, economists, and modelers.** Throughout the workshop, participants highlighted the importance of increasing collaboration between natural scientists, economists, modelers, and all those involved in impacts assessment, damages valuation, and integrated assessment modeling.
    - **Encourage trans-disciplinary review of IAM damage functions.** Multiple participants recommended that IAM data sources, damage functions, and outputs be reviewed by relevant members of the Impacts, Adaptation, and Vulnerability (IAV) and economic

valuation communities. In this way, the communities could ensure that IAMs reflect the current state of the primary literature for each of the impact categories

  - **Link into existing efforts.** One participant recommended that impacts assessment and valuation efforts be coordinated among existing efforts such as the National Climate Assessment, the United Nations Environment Programme (UNEP) Programme of Research on Climate Change Vulnerability, Impacts and Adaptation (PRO-VIA), and other international efforts to improve knowledge on impacts and valuation.

- **Use consistent scenarios.** Workshop participants suggested that consistent climate scenarios should be used in impact and damage assessment. This would facilitate intercomparison of impacts and damages estimates, and would also aid in the integration and combination of these estimates into IAMs.

- **Increase capacity to address challenges.** Numerous participants highlighted a need for additional funding and staff to help address existing impacts and damages assessment challenges. A couple of participants highlighted that IAM development is severely understaffed and underfunded, particularly as compared to general circulation model (GCM) development. One participant highlighted discrepancies in funding between different impact sectors, noting the relative lack of funding for climate change health impacts.

Sector-Specific Comments

The vast majority of the workshop proceedings focused on the current state of research in nine impact categories. This section aims to highlight the key research findings and recommendations for future research for each of the nine impact categories, as identified by workshop participants. The summaries below are based directly on the workshop presentations, and are not intended to be comprehensive.

Storms and Other Extreme Weather Events

- Fewer tropical storms are expected in the future, but the average wind speeds and precipitation totals of the storms that do occur are expected to increase. The intensity of the strongest storms is expected to increase.

- Estimates in the literature for increases in cyclone property damages due to climate change range from 0.002 to 0.006% of Gross World Product (GWP). Increases in property damages from all extreme events (including cyclones) due to climate change, according to one study, range from $47-$102.5 billion (2008 dollars) per year, or 0.008-0.018% of GWP, by 2100.

- Fatalities may increase or decrease due to climate change impacts on extreme events, as deaths from tropical cyclones may decrease more than deaths from other extreme events (e.g., heat waves) increase. Tropical cyclones are expected to continue to be the dominant cause of extreme event-related damages.

Water Resources

- Water demand, supply, and management must be modeled on a river basin scale in order to effectively estimate climate change impacts.

- National estimates from the literature of climate change damages to water resources range from $11.5-$60 billion (2009 dollars) per year for the United States.

- Coupling approaches that model changes using regional hydrologic models and approaches that model changes using regional economic models could help to bridge some gaps in water resources damage estimation.

Human Health

- The most significant health effects from climate change result from diarrhea, malnutrition, and malaria.

- The World Health Organization (WHO) estimates that the costs to treat climate change-related cases of diarrhea, malnutrition, and malaria in 2030 would be $4 to $13 billion. This would be a 3% increase in diarrhea cases, a 10% increase in malnutrition cases, and a 5% increase in malaria cases.

- Health impact valuation depends largely on mortality valuation, particularly in developing countries, and particularly among children. Appropriately adjusting the value of a statistical life for income is critical for accurate valuation.

- Health impacts in developing countries must be considered in the context of other stressors.

Agriculture

- Estimates in the literature project the global range of yield changes in the 2050s to be approximately -30 to +20%, compared with 1990, under an A2 SRES emission scenario, which corresponds to a 2.3°C mean global temperature increase from base temperatures (1961-1990).

- Global effects of climate change on agriculture are expected to be positive on average in the short term and negative in the long term. The location of the inflection points, with respect to climate change severity over time, where impacts change from positive to negative are unknown.

    - CO_2 fertilization from increasing carbon dioxide concentrations will benefit some plants (C_3 plants) more than others (C_4 plants). Elevated CO_2 concentrations especially benefit weeds, which are particularly good at taking advantage of high CO_2 concentrations.

- Agriculture's contribution to only 2-3% of U.S. GDP is due, in part, to the paradox of value and price, where rare, nonessential goods cost more than essential goods. However, the highly inelastic nature of agricultural demand means that even a small reduction in agricultural production from climate change could result in large price changes and large welfare losses.

- Adaptation and technology change can help to mitigate the impacts of climate change on agriculture. A key challenge will be producing heat and drought tolerant plants with high yields.

Sea Level Rise

- Climate-induced sea level rise will be compounded by subsidence in many densely-populated coastal areas.

- The greenhouse gases emitted so far have committed the planet to a significant amount of sea level rise that will be fully realized over coming centuries. Emissions abatement may stabilize the *rate* of sea level rise, but not reduce the globe's current commitment to sea level rise.

- The valuation of sea level rise damages depends heavily on wetland values and on adaptation.

Marine Ecosystems and Resources

- Increasing atmospheric CO_2 concentrations cause ocean CO_2 concentrations to increase, decreasing ocean pH, and decreasing saturation states for calcite and aragonite, which are used by marine animals to produce calcareous parts (e.g., shells).

- Damages from decreased mollusk harvest revenues due to a 0.1-0.2 ocean pH decrease are estimated at $1.7 to $10 billion in net present (2007) value losses through 2060.

- Assessments using the following three approaches would be beneficial to estimate marine impacts: a bio-climate envelope, which evaluates species tolerance to changing environmental variables, to provide key first pass estimate; minimum realistic models, which represent only the most important components of a specific system, on high value fisheries; and ecosystem and food web models to assess component interactions.

- A wide variety of studies to estimate damages is needed, using both revealed and stated preferences, to estimate total economic value of marine ecosystems and resources. Analyzing the results available from multiple existing studies could be used in a benefit transfer study to estimate economic value by transferring available information into the appropriate context.

Terrestrial Ecosystems and Forestry

- Three major types of terrestrial ecosystem impacts are expected: changes in vegetation distribution and dynamics, wildfire dynamics, and species extinction risks. Predicted global extinctions range from relatively low levels up to 60% of species.

- Understanding changes in pest outbreaks, interior wetlands, and snow pack are important gaps in impacts assessment.

- Natural scientists and economists need to work together to identify biophysical impacts assessment endpoints that correspond to the items assessed in valuation exercises.

Energy Production and Consumption

- Energy impacts may be beneficial for small to modest climate change, but are expected to be dominated by negative impacts in the long-run.
- In the U.S. and across the group of industrialized countries, energy use and expenditures for space conditioning is expected to decrease due to near-term warming, since decreases in energy demand for heating are likely to be greater than increases in energy demand for cooling. Net demand changes may be quite different from this conclusion over the long-term and for other regions.
- More data and research are needed to evaluate wildfire and sea level rise impacts on power sector infrastructure, and temperature impacts on electricity production, transmission, and distribution.

Socio-economic and Geopolitical Impacts

- Climate change-induced natural disasters, migration caused by sea level rise and other climate factors, and increasing resource scarcity may promote conflict.
- Estimates for the number of future environmental refugees range from 50 million by 2010 to 1 billion by 2050. These estimates include numerous environmental causes for displacement, including climate change.
- The policy debate regarding socio-economic and geopolitical impacts from climate change is running well ahead of its academic foundation, and sometimes even contrary to the best evidence.

III. Chronological Presentation of Workshop Proceedings

This section presents the proceedings of the workshop in chronological order, including the following components: workshop introduction; session presentations and discussion sessions; panel discussion; and closing remarks. The following summary represents statements from one or more workshop participants but, importantly, represents neither the views of EPA or DOE, nor a consensus, since none was sought at this workshop.

Workshop Introduction

The workshop introduction included a welcome from Dr. Elizabeth Kopits of EPA, followed by opening remarks from Dr. Michael Oppenheimer of Princeton University and Dr. William Cline of the Peterson Institute for International Economics, as well as questions about the opening remarks.

Welcome

The workshop commenced with a welcome by Dr. Elizabeth Kopits. She noted that this workshop was the second of two EPA- and DOE-sponsored workshops in preparation for future efforts to estimate the social cost of carbon. She mentioned the previous meeting focused on integrated assessment models, the 2009-2010 SCC process, and broad conceptual issues associated with integrated assessment. She explained that the second workshop would focus on a more detailed review of the quantitative research on climate change impacts and associated damages, which underpins integrated assessment models. She noted that in some sectors, the science and economics may have evolved enough to indicate ways in which IAM damage functions can be improved; while in other sectors, it may only be possible to enumerate research gaps and priorities. She highlighted the desire to facilitate increased dialogue and coordination between natural scientists and economists, noting that each session of the workshop would pair a natural scientist with an economist and would include interdisciplinary dialogue.

Opening Remarks

Progress in estimating climate change impacts

Following Dr. Kopits' introduction, Dr. Michael Oppenheimer of Princeton University presented opening remarks on past and potential future progress in estimating climate change impacts. He noted that the systematic assessment and valuation of potential climate change impacts and damages dates back to the 1970s. He explained that there have been recent advances in process-based and statistical modeling of physical exposure and impacts. These advances include improvements in general circulation model resolution and downscaling; statistical modeling of agriculture, migration, and conflict responses; and deployment of GIS data.

In contrast, there has been slow and limited progress in accounting for adaptation capacity and human responses. Dr. Oppenheimer noted that current approaches to incorporate adaptation responses are obscure, that there is little understanding of the gap between adaptation capacity and implementation, and that indirect effects of human responses (e.g., of migration) have not been assessed. He emphasized the importance of incorporating the human response in climate change impacts modeling.

Dr. Oppenheimer then presented five emerging areas in estimating climate change impacts. First, he presented the indirect and remote consequences of human responses, such as human population migration or shifts in human activities (e.g., agriculture) that affect resources and populations at a distance. Second, he presented the interacting effects of adaptation and mitigation, highlighting the biodiversity, food price, and political ramifications of biofuel development and the political reverberations of geo-engineering. Third, he presented the complexity of interacting systems and stressors. For example, he noted how upstream water diversion can cause deltaic subsidence which interacts with sea level rise. Fourth, he presented complexities associated with climate extremes and disasters, such as the local specificity of exposure and vulnerability, and the learning that may occur as rare events become more frequent. Fifth, he presented the dynamic nature of vulnerability, which evolves with development and changes as learning competes with mal-adaptive and risk-shifting behavior. He noted the complexities associated with diverse potential development pathways and the existing gap between top-down and bottom-up estimates of impacts.

Progress in valuing climate damages

Next, Dr. William Cline of the Peterson Institute for International Economics presented opening remarks on past and future progress in valuing climate damages. He discussed the different historical approaches to estimating the SCC and emphasized the importance of catastrophic risk valuation and discount rate selection. Dr. Cline emphasized the role of the pure rate of time preference in Ramsey discounting, noting the use of a zero pure rate of time preference in several estimates. Dr. Cline also emphasized the effect of uncertainty, noting that insuring against catastrophe would warrant aggressive action even without a zero pure rate of time preference.

Regarding catastrophic risks, Dr. Cline noted that some have been considered in damage valuation, including collapse of the ocean conveyor belt, collapse of the West Antarctic Ice Sheet, and a runaway greenhouse effect from methane release. Dr. Cline then presented the possibility of hydrogen sulfide release from deep ocean anoxia due to anaerobic bacteria buildup caused by sea level rise and shutdown of the ocean conveyor belt. He explained that the resulting elevated hydrogen sulfide levels could be toxic to plants and animals and could cause mass extinction. He noted that this risk should not be ignored, despite the fact that it would likely not occur for 2000 years or more. In order to account for very long term but catastrophic damages, Dr. Cline argued that contingent valuation might be necessary, as the use of even the lowest interagency discount rate produces numbers too low to justify action to prevent a risk so far in the future. He suggested that super-contingent valuation may be helpful to value such catastrophic risks. He noted that the contingent valuation implied by the Copenhagen pledge to reduce emissions from developing countries far exceeds current IAM estimates for the social cost of carbon.

Regarding the discount rate, Dr. Cline noted that a descriptive approach using Treasury Inflation Protected Securities yields a discount rate lower than what was used by the interagency process. Dr. Cline then noted the importance of the elasticity of marginal utility when using a prescriptive approach, suggesting that a value of 1.5 is more appropriate than a value of 1 as proposed by Stern or a value of 2 as proposed by Weitzman.

Dr. Cline noted that, if targets are set, the SCC is defined as the marginal abatement cost along the least cost pathway to achieving the targets. Finally, Dr. Cline suggested that the interagency group should consider an insurance approach to determining the SCC.

Questions

In response to a question from the audience, Dr. Oppenheimer noted his interest in statistical approaches. He emphasized that estimates from top-down approaches and bottom-up approaches should converge, thereby giving one indication of their reliability.

During the question and answer session, one participant suggested that the time scale of long-term CO_2 effects is tens of thousands years, two orders of magnitude larger than what is typically considered. Dr. Cline noted that he may have contributed to the use of a scale of hundreds of years, but that typical discount rates imply that what happens after 80 years is of little consequence. A second participant agreed with Dr. Cline in preferring a precautionary or insurance approach over a cost-benefit approach. The participant noted that as the marginal benefit of the abatement curve approaches vertical, the precautionary benefits of abatement increases dramatically.

A third participant suggested that adaptation will occur on a global scale and asked how adaptation could be incorporated into the SCC and U.S. policies. In response, Dr. Oppenheimer first noted the many levels of human response, from individual to international. He then suggested that many studies do not consider the human response at all. Finally, he noted that a comprehensive solution to incorporate adaptation may not yet be available, but that it is important to strive to do better and to incorporate the human response to impacts at whatever level is possible.

Storms and Other Extreme Weather Events

Following the workshop introduction, there were nine sessions, each covering a specific impact category. The first session covered the impacts and damages from storms and other extreme weather events. The session was moderated by Dr. Alex Marten of the U.S. Environmental Protection Agency and included presentations by Dr. Tom Knutson, National Oceanic and Atmospheric Administration (NOAA); and Dr. Robert Mendelsohn, Yale University.

Impact of Climate Change on Storms and Other Extreme Weather Events

Dr. Tom Knutson, of NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), presented the effects of climate change on tropical cyclones. Most of his presentation focused on the findings from a World Meteorological Organization (WMO) study. The study sought to determine two things: whether the human impact on hurricanes is detectable and what future climate change implies for hurricane activity.

Regarding the detection and attribution of climate change in tropical cyclone activity, the study concluded that it remains uncertain whether past changes in tropical cyclone activity exceed natural variability levels. For example, while the frequency of past tropical cyclone activity is correlated with increases in sea surface temperature, the trends disappear when storm counts are adjusted to account for improved storm observation data.

To evaluate the future implications of climate change for tropical cyclone activity, the study considered the changes associated with the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES)[2] A1B scenario. To predict future activity, the study used high resolution atmospheric models, regional dynamical downscaling models, and statistical/dynamical techniques that are able to reproduce historic interannual variability. The WMO expert team made five general conclusions regarding the effect of future climate change on tropical storm activity.

First, the models almost unanimously predict that there will likely be fewer tropical storms globally, with predictions ranging from no change in frequency to a decrease of 34%. There is greater uncertainty regarding the frequency of storms in individual basins (e.g., the Atlantic), though storms in the southern hemisphere decrease in frequency fairly consistently in the different models.

Second, the experts predict a likely increase in average hurricane wind speeds (intensity) globally, with increases ranging from two to 11 percent. Dr. Knutson noted that this statistic does not necessarily apply to individual basins.

Third, the experts predict that there is a greater than 50% chance that the frequency of very intense hurricanes will increase by a substantial fraction in some basins. Fourth, climate change will likely result

[2] http://www.ipcc.ch/ipccreports/sres/emission/index.htm

in higher rainfall rates in hurricanes. The models predict a roughly 20% increase within 100 km of a storm. Fifth, sea level rise is expected to exacerbate storm surge impacts, even if storms themselves do not change**.**

Dr. Knutson summarized these conclusions by explaining that the experts predict fewer tropical storms overall, but an expanded range of storm intensity. The combination of these two changes will result in an increased number of intense storms. Throughout his presentation, Dr. Knutson emphasized the wide range of estimates and disagreement among different models for various tropical cyclone metrics.

Dr. Knutson finished his presentation by noting several factors that might exacerbate the study's projections. These factors include changes in the vertical profile of warming, the El Nino / La Nina pattern of warming, wind shear, and ocean heat transport.

Global Damages from Storms and Other Extreme Weather Events

Dr. Robert Mendelsohn of Yale University expanded on Dr. Knutson's presentation by discussing the effects of climate change on all extreme events, and by delving into the damages associated with these effects. Dr. Mendelsohn examined cold events, drought, floods, hail, heat waves, tornadoes, thunderstorms, tropical cyclones, and extratropical severe storms. His presentation aimed to describe how climate change affects future extreme events, to reflect any underlying changes in future vulnerability, to estimate damage functions for each type of extreme event, and to describe damages from future extreme events caused by climate change.

First, Dr. Mendelsohn considered the change in damages and deaths due to changes in future income and population, without considering climate change effects. He showed that damages increase greatly due to these socio-economic changes, noting that damages from heat waves increase most dramatically and damages from tropical cyclones are the greatest in magnitude. Next, he showed that deaths do not follow the same pattern, with deaths associated with some extreme events (e.g., heat waves) predicted to increase, while others (e.g., those associated with floods, tropical cyclones) predicted to decrease. He noted that deaths increase with increased population, but decrease with increased income.

Dr. Mendelsohn next summarized estimates of changes in cyclone damages due to climate change. He noted that increases in damages have been estimated at 0.002%-0.006% of Global World Product. He noted that the tropical cyclone generator, which models cyclone development, estimates different results in different basins, but shows a consistent increase in tropical cyclone power in the Atlantic and Northwest Pacific basins.

Dr. Mendelsohn then regressed damages and deaths on different variables to develop damage functions. He noted that, using U.S. data, damages increase with both income and population density, but less than proportionally. Using international data, however damages increase less than proportionally with income, but decrease as population density increases. Dr. Mendelsohn noted that the impacts of climate change due to cyclones will be greatest in North America and Asia. He further noted that the impacts from other extreme events are likely to be less significant by an order of magnitude than those from tropical cyclones.

Dr. Mendelsohn explained several limitations associated with this estimation process, including: uncertainty of non-hurricane impacts; the coarseness (e.g., country-scale) of some of the key data; the need for better data about damages, extreme events, and the relationship between them; the paucity of information on ecosystem impacts; and the lack of explicit incorporation of adaptation in impact models.

Dr. Mendelsohn concluded with a brief summary of results. He noted that predicted climate change impacts from all extreme events (including tropical cyclones) range from $47 to $100 billion per year by 2100. This is equivalent to 0.008-0.018% of GWP by 2100. Finally, he noted that climate change has a mixed effect on fatalities because tropical cyclone deaths may fall more than other deaths increase.

Discussion: Storms and Other Extreme Weather Events

During the question and answer session, a couple of participants asked about intersectoral impacts, particularly the interaction between storms and sea level rise. Dr. Mendelsohn noted that the effects of sea level rise and storms are at least additive, but may be interactive and more than additive.

A couple of participants questioned the result that the additive effects of climate change on tropical storms will result in a decrease in deaths. Dr. Mendelsohn explained that this result is due to the predicted decrease in tropical cyclone intensity in the Indian Ocean due to climate change, where approximately 90% of current tropical cyclone deaths occur. He noted that deaths are predicted to increase in every part of the world except for Southern Asia, but that the magnitude of the increases will be small. He also clarified that his work did not monetize deaths.

Several participants asked about the estimation of deaths from heat waves. Dr. Mendelsohn explained that with heat waves, it is the variance rather than the average temperature that matters, since humans are able to adapt to higher average temperatures. He noted that his work does not include ecosystem effects, such as mammalian die-off due to heat waves, nor does it include empirical work on human labor changes due to temperature increases. One participant challenged the assertion that only variance matters, noting that humans are not able to live at very high temperatures. Dr. Mendelsohn clarified that only variance matters within the context of extreme events.

One participant asked whether a valuation of impacts on agriculture and famine was incorporated. Dr. Mendelsohn noted that agriculture effects are incorporated but famine effects are not. Another participant asked whether the predicted relative contribution to damages from different extreme events will change significantly as more research is conducted. Dr. Mendelsohn noted that damages from floods and perhaps heat waves may prove to be more important than currently predicted. However, he explained that it was unlikely that they would increase by an order of magnitude, thus concluding that tropical cyclones will continue to have the greatest impact.

Water Resources

The second session covered the impacts and damages to water resources. The session was moderated by Dr. Robert Kopp of DOE and included presentations by Dr. Ken Strzepek, University of Colorado at Boulder and Massachusetts Institute of Technology; and Dr. Brian Hurd, New Mexico State University.

Hydrological/Water Resource Impacts of Climate Change

Dr. Kenneth Strzepek of the University of Colorado at Boulder and the Joint Program on the Science and Policy of Global Change at the Massachusetts Institute of Technology commenced the second impact-specific discussion by discussing how impacts to water resources can be incorporated into IAMs. Dr. Strzepek explained that water resources encompass a broad spectrum of issues and appear in 18 of the 30 chapters of the IPCC Working Group 2 report.

He explained that, globally, the largest water use is agriculture, while, in the United States, the largest use is thermal cooling for energy production. Dr. Strzepek emphasized the importance of using the appropriate spatial and temporal scale when modeling impacts to water resources. He noted that disaggregation is necessary in order to properly model water supply and demand. Dr. Strzepek explained that a regional or national scale, as often used in IAMs, is far too course to properly model water resources and crops, since the local location of water is critically important and aggregation averages water excesses and water shortages. Using several examples, he illustrated how aggregation can misrepresent the supply and demand of water resources. Instead, Dr. Strzepek suggested that a river basin scale may be more appropriate.

Dr. Strzepek further suggested that water management systems must be modeled at the basin-level to appropriately describe impacts and, especially, adaptation. He noted that water management systems can adapt to changing water supply by increasing water storage capacity to level supply. He noted that modeling water management is crucial since cross-sectoral impacts are greater than sectoral impacts, since different uses are forced to compete for available water. Dr. Strzepek also explained that the metrics used to model water resources are important. For example, different metrics of drought produce very different results.

Next, Dr. Strzepek explained that flooding and storms are very important when considering climate change impacts to water resources. He noted that a lot of work has been conducted on the effects of drought, but that flooding is particularly harmful as it can cause serious damage to capital investments, including infrastructure such as roadway bridges.

Finally, Dr. Strzepek emphasized that threats to water resources must be considered in the context of other global changes. He illustrated that municipal and industrial water demand and environmental policy threaten agricultural water supply more than climate change. He underscored that the effects of climate change must be considered in relation to other uncertainties and stressors. He also mentioned that addressing uncertainty is important.

In response to a question, Dr. Strzepek explained that water management and technological improvements can ameliorate some impacts (e.g., by leveling supply using dams), however a lack of water due to climate change could still have serious implications.

Estimating the Economic Impact of Changes in Water Availability

Following Dr. Strzepek's presentation, Dr. Brian Hurd of New Mexico State University presented estimates of the economic impacts of climate-related changes in water availability. Dr. Hurd again emphasized the complexity of water and water systems, noting the spatial and temporal variability as well as the variability in uses, infrastructure, and vulnerability. He noted that statistical modeling is nearly impossible and that process models work better for estimating the magnitude of changes outside of historical experience. He highlighted the importance of behavioral aspects such as adaptation and optimization.

Dr. Hurd then presented national-level estimates from the literature of annual economic impacts of climate change on water resources. Estimates in the literature range from $7 billion to $60 billion (2009 dollars), under varying assumptions. These estimates arise both from studies that use a hydro-economic model to aggregate benefits and costs and from studies that use regional economic models to estimate impacts on jobs, income, and GDP. He noted that despite very different methodologies, the estimates are consistent in order of magnitude and share of GDP. He noted the counter-intuitive result from some studies that GDP may increase where impacts are greatest, since disasters can increase the number of jobs in certain sectors and locations.

Dr. Hurd concluded with a list of knowledge gaps that limit current estimates and provide areas for future improvement. These gaps include: understanding changes in extreme events; the role of water rights, and federal and state regulation; administrative constraints in adaptation; projections of market prices and trade flows of agricultural and other water-intensive products; measuring, monitoring, and modeling groundwater; water security and food security issues; and assessing and measuring economic outcomes of water quality. He suggested that coupling approaches that model changes using regional hydrologic models (hydro-economic) and approaches that model changes using regional economic models (dynamic system simulation) approaches could help to bridge some gaps.

Discussion: Water Resources

During the question and answer session, one participant questioned the negative impacts for New York State presented by Dr. Hurd, given her understanding that climate projections indicate that water will increase in New York. Dr. Hurd clarified that the study in question only presented impacts from projected drought scenarios without looking at projected increases in water availability. Dr. Strzepek further noted that models indicate an increase in winter precipitation for New York. Without reservoir capacity, New York would be unable to harness the additional water.

A second participant highlighted an example of non-climate global changes interacting with climate change impacts. He noted that there is a movement by EPA to make closed-cycle cooling the standard for thermoelectric power, which would eliminate the 48% of U.S. water currently used for power plants. A third participant questioned whether water withdrawals or water consumption is more important from a modeling and policy perspective. He noted that cooling towers reduce withdrawals but increase consumption. Dr. Strzepek explained that this is a very complicated issue that is affected by temperature and runoff in addition to consumption. He noted that within the United States the issue is most relevant in the western United States.

A fourth participant asked for global estimates of damages to tie this sector into SCC estimates. Dr. Hurd noted that he had focused the research for his presentation on U.S. impacts. Dr. Strzepek cited a series of studies by the World Bank that estimate adaptation costs for water resources at $80-100 billion per year for developing countries. He noted that additional global work has been funded and is underway.

A fifth participant asked about the importance of variability with regard to water resources. Dr. Strzepek emphasized that variability, as well as seasonality, is crucial. However, he noted that the GCMs have trouble capturing this variability. Dr. Hurd further noted that the literature is not well developed on the real impact and economic estimates of those changes. Another participant asked about the attitude of water managers towards variability. Dr. Strzepek explained that water managers tend not to worry about variability because engineers overbuild infrastructure to withstand 100-year events. Since some water managers believe that the uncertainty about what constitutes the current 100-year event dwarfs the potential effects of climate change, they also believe that if systems are prepared for current variability, they are also prepared for climate change.

Human Health

The third session covered the impacts and damages to human health. The session was moderated by Dr. Charles Griffiths of EPA and included presentations by Dr. Kristie Ebi, Carnegie Institution for Science; and Dr. Maureen Cropper, Resources for the Future and University of Maryland at College Park.

Climate-Associated Changes in Health Conditions/Diseases and Air Pollution

Dr. Kristie Ebi of the Carnegie Institution for Science introduced the third impact category with her presentation on climate-associated changes in health outcomes. Dr. Ebi presented several different health conditions that will be affected by climate change, highlighting malnutrition, diarrheal disease, and malaria. Since climate change is never the direct cause of death, she noted that deaths due to climate change have to be modeled.

Dr. Ebi began by presenting an overview of the direction and magnitude of different climate change health impacts, as presented by the IPCC Fourth Assessment Report (AR4). The only net positive impact predicted by the report is a reduction in cold-related deaths. Meanwhile, the report predicts net negative impacts from increases in malaria; malnutrition; deaths, disease, and injuries from extreme weather events; cardio-respiratory disease from changing air quality; infectious disease; and diarrheal disease.

Dr. Ebi noted that the current impacts of these diseases are enormous. For example, under-nutrition results in 35% of child deaths, 11% of the total global burden of disease, and 21% of disability-adjusted life-years (DALYs) for children younger than 5 years. When all the effects of malnutrition are considered (including loss of cognitive function, poor school performance, and loss of future earning potential), the total estimated costs of environmental risk factors could be as high as 8-9% of a typical developing country's GDP in South Asia or Sub-Saharan Africa. Dr. Ebi noted that the scale of current impacts means that even small increases in the impacts will have significant effects. For example, even small increases in temperature could result in enormous increases in the number of mosquito vectors and thus in the prevalence of malaria.

Dr. Ebi then discussed the major regional differences in impacts and their concomitant equity implications. While diarrheal disease has impacts across the globe, the major burden exists in India and

Africa. The burden of malaria lies almost exclusively in Africa. These distributional differences extend to the country level, with different areas within a country experiencing very different rates of disease.

Dr. Ebi noted that current models do not account for complexities and interactions between different impacts. For example, poor nutritional status promotes infectious disease and vice versa. She also mentioned that higher temperatures can lead to increased ozone formation, which affects anyone with compromised lung function or cardiovascular disease.

Dr. Ebi next presented estimates of the costs to treat climate change-related illness from the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC estimates that the costs to treat climate change-related cases of diarrhea, malnutrition, and malaria in 2030 would be $3,992 to $12,603 million. This accounts for a 3% increase in diarrhea cases, a 10% increase in malnutrition cases, and a 5% increase in malaria cases. Dr. Ebi then noted that there will likely be unexpected climate change health impacts. As an example, she described the unexpected outbreak of a shellfish-caused gastrointestinal disease in Alaska, which was caused by increases in water temperatures above a previously unknown threshold.

Dr. Ebi finished her presentation with an extensive list of research needs emphasizing the significant need for work to understand exposure-response, to model impacts, to take into account other drivers, and to understand adaptation. In response to a question, Dr. Ebi noted the need for research on threshold effects. She noted that the health sector has been severely underfunded with regards to other climate change effects, particularly in the United States.

Estimating the Economic Value of Health Impacts of Climate Change

Dr. Maureen Cropper of the University of Maryland and Resources for the Future built on Dr. Ebi's presentation with a presentation on estimating the economic value of the health impacts of climate change. Dr. Cropper noted that economists should value damages after adaptation, plus the costs of adaptation. However, she focused her presentation on valuing the health impacts themselves.

Dr. Cropper noted that health impact valuation depends largely on mortality valuation, particularly in developing countries, and particularly among children. She emphasized that, by far, the largest damages are due to mortality. She underscored that it is better to estimate a crucial issue with some measure of error (e.g., mortality), than a less important issue with high precision (e.g., morbidity).

Dr. Cropper next discussed two different approaches to valuing increased risks of mortality and morbidity. First, the human capital-cost of illness (COI) approach values increases in mortality risk using the present discounted value of forgone earnings, and values an injury by the associated medical costs and lost productivity. Second, the value of a statistical life (VSL)-willingness to pay (WTP) approach values increases in mortality risk using what people will pay for small reductions in risk of death, and values an injury by adding the willingness to pay to avoid pain and discomfort to the COI value. Dr. Cropper noted that the VSL can be estimated using revealed preference studies (e.g., based on compensating wage differentials, purchase of safety equipment) or stated preference studies.

Dr. Cropper noted that there have been dozens of VSL studies in high-income, and even middle-income countries, but that there has only been one study in a low-income country (Bangladesh). She explained that the VSL can be transferred from one country to another using the income ratio between the two countries and the appropriate income elasticity. Dr. Cropper noted that the income elasticity is usually assumed to be one, however, many other factors that affect the VSL differ between countries, including risk preferences, life expectancy, and consumption. Dr. Cropper showed evidence from the literature that the income elasticity should be greater than one and should increase as income falls. Based on a couple of studies, she suggested that an income elasticity of 1.5 is more appropriate.

Dr. Cropper then discussed the difficulties associated with estimating the VSL for children. She explained that an accepted method is the use of parents' willingness to pay to reduce risks to their children. In high income countries, this method suggested that the VSL for a child is approximately twice that of an adult. However, parents' WTP may be different in countries where one out of five children dies before age five. She suggested that, in the interim, the same VSL be used for adults and children until a sensitivity analysis can be conducted.

Finally, Dr. Cropper discussed valuing morbidity. She noted that most estimates capture the value of lost productivity and the cost of medical treatment but that most estimates neglect the value of discomfort, inconvenience, and pain. She again noted that morbidity damages are significantly smaller than mortality damages, once more suggesting that it is most important to refine mortality estimates. She finished by noting that there may be other relevant health impacts, such as the macroeconomic impacts of malaria or the impacts of malnutrition on human capital formation, which could each affect economic growth.

Discussion: Human Health

During the discussion session, a couple of participants challenged the use of WTP as the most appropriate way to frame and value climate impacts. Instead, the participants suggested that willingness to accept compensation be used. This suggestion is based on the fact that the people that cause climate change (e.g., developed countries, older generations) tend not to be the people that are impacted by climate change (e.g., developing countries, younger generations). Dr. Cropper defended the use of WTP, emphasizing that WTP reflects market preferences.

During the discussion, Dr. Ebi and Dr. Cropper emphasized that climate change is just one of many stressors on developing countries. Dr. Cropper suggested that it is important to keep climate change in context and acknowledge that developing countries may prefer to invest in, e.g., education rather than climate change mitigation or adaptation. She suggested that viewing climate change impacts independently would result in over-allocation of resources to climate change issues. One participant asked whether countries should invest in mitigation or in current health impacts. Dr. Ebi suggested that the money for the two different issues does not tend to come from the same sources. In response to another question, she emphasized that the smallest portfolio of funding is directed towards climate change health issues, since it is difficult to attribute health impacts to climate change.

One participant asked how demographic transitions affect health impacts of climate change. Dr. Ebi explained that the issue is complex. She noted that many countries are already undergoing a demographic transition. However, she further noted that there are limits on how much wealth can address health impacts. As an example, Dr. Ebi explained that malaria and dengue control is extremely difficult and requires discovering the right balance of components and maintaining efforts.

A participant asked about impacts on labor productivity. Another participant explained that he used a biophysical model of the human body to estimate how much labor a person can produce at different temperatures and humidity levels. He explained that normal non-air conditioned labor is not possible above certain thresholds. He concluded that without adaptation, labor productivity could fall by 30 percent and GDP could fall by 10 to 15 percent. A final participant asked what reference case should be used when evaluating the SCC and asked if and how current adaptation efforts will affect the reference case. Dr. Ebi agreed that current adaption would change the reference case.

Agriculture

The fourth session covered the impacts and damages to agriculture. The session was moderated by Dr. Charles Griffiths of EPA and included presentations by Dr. Cynthia Rosenzweig, National Aeronautics and Space Administration (NASA) Goddard Institute of Space Studies; and Dr. Wolfram Schlenker, Columbia University.

Biophysical Responses of Agro-ecosystems to Climate Change

Dr. Cynthia Rosenzweig of the NASA/Goddard Institute for Space Studies introduced the fourth impact category by presenting the biophysical climate change effects on agro-ecosystems. Dr. Rosenzweig began by presenting observed climate change impacts on agriculture, which include high temperature effects on rice yield, earlier planting of spring crops, increased forest fires, change in pests, and declines in livestock productivity.

Dr. Rosenzweig explained that studies show insects are emerging earlier, including agriculturally beneficial insects such as bees, as well as pests such as the potato beetle. She noted that climate change may cause new pests to emerge, one of the potential climate change surprises. Next, Dr. Rosenzweig showed that increasing carbon dioxide concentrations benefit C_3 plants (e.g., wheat, rice, soybean, barley) more than C_4 plants (e.g., corn, sorghum, sugarcane), as C_4 plants are already able to concentrate CO_2. She emphasized that increasing CO_2 concentrations benefit weeds in addition to crops, noting that weeds are favored as they are particularly good at taking advantage of high CO_2 concentrations.

Next, Dr. Rosenzweig explained that increasing temperatures can speed up growth cycles. This acceleration negatively impacts yields, as crops have less time to accumulate carbohydrates. She further noted that high temperature stress during critical growth periods (e.g., pollination) could have detrimental effects. Dr. Rosenzweig then described the effects of changes in precipitation. She noted that both drought stress and excess water can be damaging to yields.

Dr. Rosenzweig presented temperature maps that show warming is expected to be greatest over land and at the highest northern latitudes. Similarly, she showed maps that indicate increases in precipitation are very likely in the high latitudes, while decreases are likely in most subtropical land regions. She showed that the most negative yield effects are expected in the lower latitudes, where developing countries are, while the less negative or more positive effects will be in the higher latitudes.

Dr. Rosenzweig noted that globally, the literature consistently estimates the range of yield changes to be approximately -30 to +20 percent. The estimates of the most negative effects range from -32 to -35 percent, while the estimates of the most positive effects range from 19 to 25 percent. Dr. Rosenzweig then showed that global effects of climate change are expected to be positive in the short term and negative in the long term. She noted that the location of the inflection points where impacts change from positive to negative are unknown.

Dr. Rosenzweig then presented the three main approaches to model agricultural impacts, along with advantages and disadvantages, data requirements, spatial resolution, and level of uncertainty for each approach. First, statistical approaches use historical data to estimate statistical relationships between crop and climate variables. These relationships are then used to project climate impacts on yield. Second, expert system approaches use statistical relationships between observed crop yields and observed climate variables to estimate production potential. Third, dynamic process crop models use data and modeled relationships to explicitly simulate the various processes affected by climate. She noted that the graphs that show increasing yield responses to low levels of warming were assembled using largely incomparable data points from very different models and studies, using different coefficients.

Following her presentation of modeling approaches, Dr. Rosenzweig discussed the ability of adaptation and technology to modulate the biophysical impacts. She presented three levels of adaptation, each with increasing benefit, as well as increasing complexity, cost, and risk. The first level includes adjusting varieties, planting times, and spacing. The second level includes actions such as diversification and risk management. The third level includes transformation from land-use or distribution change. She demonstrated that adaptation is not always possible or complete.

Finally, Dr. Rosenzweig finished with a list of gaps and uncertainties related to the biophysical climate change impacts on agriculture. She emphasized the importance of precipitation impacts, which are critical but relatively unknown. Other gaps and uncertainties include: simulating extreme weather events; interactions between warmer temperatures, CO_2, and ozone; interactions between evapotranspiration, soil moisture, crop yield, and water availability; pests; scale effects; yield gaps and plateaus; and multi-model comparisons and assessments. She emphasized the importance of rigorously testing and comparing models, and noted AGMIP, the Agricultural Model Intercomparison and Improvement Project, which is a relatively new effort to assess and ultimately improve agricultural models.

Estimating the Economic Impact of Climate Change in the Agricultural Sector

Next, Dr. Wolfram Schlenker of Columbia University and the National Bureau of Economic Research gave his presentation on estimating the economic impact of climate change in the agricultural sector. First, Dr. Schlenker presented the fact that U.S. agriculture only accounts for two to three percent of U.S. GDP, which might be interpreted to mean that agricultural impacts are negligible. He explained that the low contribution to GDP results from the paradox of value and price, where rare, nonessential goods cost more than essential goods. Through a series of graphs he showed that GDP is not a welfare measure and suggested that consumer surplus is a better option. He showed that because agricultural demand is highly inelastic, a small reduction in agricultural production (e.g., from climate change) results in large price changes and could lead to large welfare losses (i.e., reductions in consumer surplus).

Then, Dr. Schlenker discussed the global importance of U.S. agriculture. He explained that corn, rice, soybeans, and wheat contribute 75 percent of the calories consumed by humans worldwide. World caloric production has been trending upward, resulting in falling real prices over the 20th century. Dr. Schlenker explained that the U.S. share of caloric production has been roughly constant at around 23 percent for the last 50 years. He noted that this share is larger than Saudi Arabia's share of oil production, which means that impacts on U.S. yields have the potential to influence world markets.

Next, Dr. Schlenker presented a statistical analysis examining the link between temperature and yields. He explained the highly non-linear relationship between yields and the number of exposures to particularly cold or warm days (above 84-86°F). He noted that the negative slope of impacts at high temperatures is ten times greater than the slope at low temperatures, which implies large yield declines if maximum temperatures increase significantly. He concluded that the driving force behind climate change impacts on agriculture is extreme heat, with impacts depending on both the baseline temperature and the predicted increase.

Dr. Schlenker then explored the ability of technological progress to mitigate climate impacts. Through a series of graphs, Dr. Schlenker presented the historic evolution of heat tolerance using data from Indiana. He showed that while corn yields have increased continuously in the second half of the 19th century by a total factor of three, the evolution of heat sensitivity is highly nonlinear, growing with the adoption of double-cross hybrids in the 1940's, peaking around 1960, and then declining sharply as single-cross hybrids were adopted. However, Dr. Schlenker questioned whether future innovation could increase both yield and heat tolerance. He suggested that genetically modified crops may have the most potential.

Dr. Schlenker then discussed the role of agriculture and land use change in contributing to or mitigating climate change. He noted that land use change is responsible for approximately 20% of CO_2 emissions. Dr. Schlenker specifically discussed ethanol, which converts agricultural land from food production to energy production in an effort to mitigate climate change. He explained that the estimated food supply elasticity is roughly twice as large as the demand elasticity. As a result, one third of the caloric input diverted to biofuel production would be compensated with a reduction in food consumption while two thirds would be compensated with increases in food production. He noted that the U.S. ethanol mandate is predicted to lead to a decrease in food consumption of 1%, an increase in commodity prices of 20%, and a possible expansion of agricultural areas.

Discussion: Agriculture

During the discussion session, a couple of participants asked questions about CO_2 fertilization effects. One participant asked how CO_2 fertilization should be incorporated into reduced-form models, such as those used to develop the SCC. Dr. Rosenzweig explained that AGWIP would hopefully be able to isolate the CO_2 effects for incorporation. She expressed her belief that an average of current estimates is correct. She believes that the high- and low- (zero) ends of current estimates are both incorrect. Dr. Schlenker noted that there is a wide range of estimates found in the literature. Dr. Rosenzweig suggested that a risk management approach is most appropriate, where ranges and uncertainties are estimated and used, instead of a single number. Another participant asked whether CO_2 fertilization effects are non-linear and characterized by plateaus. Dr. Rosenzweig noted that there are bursts and ebbs in some processes but that effects continue up to concentrations of 700, and possibly even 800ppm.

One participant asked about the biophysical basis for climate change effects and whether biophysical barriers might pose a limit to adaptation efforts. Dr. Rosenzweig first outlined the biophysical effects of climate change, including temperature-caused speed up of the lifecycle, damage at critical growth periods, and water stress. She reiterated that the easiest adaptation efforts include management actions such as planting earlier. She noted that crop breeders are optimistic about the potential of genetic improvements, though there is not a lot of plasticity in the genes controlling for certain growth stages. Dr. Rosenzweig emphasized the challenge of pairing heat tolerance with high yields.

Another participant asked whether the speakers thought current estimates are optimistic (meaning incomes will likely be worse than predicted) or pessimistic, particularly considering the existence of known and unknown unknowns. Dr. Schlenker acknowledged that the unknowns pose a difficult question. Dr. Rosenzweig suggested current estimates may be overly optimistic. She emphasized the need for collaboration between climate scientists, agronomists, and economists. A different participant suggested the need for greater interaction between economic models and crop models. Dr. Rosenzweig agreed, noting that AGMIP facilitates a trans-disciplinary interaction and dialogue.

A final participant asked to what extent Dr. Schlenker's current statistical results could be used to improve IAMs. He noted the need to separate the effects of temperature, CO_2, and precipitation in IAMs. Dr. Schlenker emphasized the uncertainty in modeling precipitation, particularly extremes. He concluded that using currently available estimates of extreme precipitation would not necessarily improve agricultural impact estimates.

Sea Level Rise

The fifth session concluded Day 1 of the workshop and covered the impacts and damages from sea level rise. The session was moderated by Dr. Robert Kopp of DOE and included presentations by Dr. Robert Nicholls, University of Southampton; and Dr. Robert Tol, Economic and Social Research Institute.

Sea Level Impacts of Climate Change

Dr. Robert Nicholls of the School of Civil Engineering and the Environment and the Tyndall Centre for Climate Change Research at the University of Southampton introduced the last impact category of Day One, the sea-level impacts of climate change. Dr. Nicholls began by emphasizing the importance of sea level rise, despite the coasts being a small proportion of the earth's surface. He showed that population and economic density in the coastal zone is significantly greater than other areas of the earth's surface.

Next, Dr. Nicholls explained that climate-induced sea level rise is caused by the thermal expansion of seawater, as well as the melting of land-based ice (e.g., small glaciers in the Rockies or Alaska, the Greenland ice sheet, the West Antarctic ice sheet). He showed that sea level was fairly stable in the 19th century and that the rate of sea level rise has accelerated recently. He noted the great uncertainty regarding future projections of sea level rise.

Dr. Nicholls emphasized the importance of keeping climate change in context. While climate change is contributing to sea level rise, the coast is also experiencing other changes that contribute to changing sea level (e.g., coastal management, water extraction). Dr. Nicholls emphasized that relative sea level, which is determined by both sea level rise and subsidence, is what matters.

Dr. Nicholls then presented the impacts of sea level rise, which include: inundation, flood, and storm damage; wetland loss and change; erosion; saltwater intrusion; and higher water tables and impeded drainage. He noted that all five impacts are affected by interacting climate and non-climate factors. Dr. Nicholls next showed the links between sea level rise impacts and socio-economic sectors, noting the high number of strong links and lone potential benefit. Dr. Nicholls presented a series of images showing observed impacts from sea level rise (including its interaction with storms) and maps identifying the areas, cities, and assets exposed to future sea level rise.

Next, Dr. Nicholls presented a graph showing the limits of mitigation actions to control sea level rise. He emphasized the globe's current commitment to sea level rise, noting that mitigation efforts are only able to stabilize the *rate* of sea level rise. He emphasized that mitigation is still beneficial, while limited. He noted that the globe's commitment to sea level rise indicates a need for adaptation action.

Dr. Nicholls explained that adaptation can include (planned) retreat from the coasts, accommodation of assets (e.g., raising houses on stilts), and coastal protection using hard or soft barriers. Each impact is associated with multiple possible adaptation responses. He noted that, generally, the relative cost of adaptation is extremely low when compared to the coasts' value. Dr. Nicholls presented the optimistic and pessimistic views of potential impacts from and adaptation to sea level rise. He noted that both views are supported by reasonable arguments.

Dr. Nicholls finished with a series of concluding remarks, including the following. Climate-induced sea-level rise is inevitable; the major uncertainty is its magnitude. Climate-induced SLR will be compounded by subsidence in many densely-populated coastal areas. Risks are already increasing, and this will continue. The worst-case (do nothing) impacts are dramatic. There are widely differing views concerning the success or failure of adaptation. Mitigation of climate change and subsidence is needed to make the problem more manageable. To adapt to dynamic coastal risks, proactive assessment is required.

Following Dr. Nicholls' presentation, one participant suggested that sea level rise studies be combined with studies on storm length and intensity, citing the importance of winter storms in the Netherlands. Dr. Nicholls agreed and suggested that specific drivers and key issues need to be evaluated for each place on the earth's coast.

Estimating the Economic Impact of Sea Level Rise

Dr. Richard S. J. Tol of the Economic and Social Research Institute in Dublin, Trinity College in Dublin, and Vrije Universiteit in Amsterdam, continued the discussion of sea level rise by presenting the economic impact of sea level rise. Dr. Tol presented the economic implications of sea level rise, focusing on direct costs, adaptation, and general equilibrium effects.

Dr. Tol explained that, to estimate direct costs, economists typically estimate a unit cost and multiply the unit cost by the impact estimates provided by natural scientists such as Dr. Nicholls. For example, to estimate the costs of inundation, an economist would multiply the number of acres submerged by the average acre value. Dr. Tol emphasized that average acre values should be used as opposed to beach front values since property markets will adjust to coastal realignment. He noted the difficulty in estimating average acre cost, citing a study that used nonmarket valuation to identify wetland values.

Next, Dr. Tol emphasized the importance of incorporating adaptation into estimates of climate damages. He showed that populations with higher income generally suffer less and are less vulnerable to floods. However, he noted that even fairly sophisticated models are only able to explain 60 to 70 percent of vulnerability, due to a large amount of variation that is not understood. He noted that while optimal adaptation models can be built, historically, adaptation has never been optimally implemented. He showed numerous examples of suboptimal adaptation implementation, where adaptation efforts indicate an under- or over-valuation of damages, as estimated under the IPCC Special Report on Emissions Scenarios (SRES) A1B scenario. For example, the Dutch currently pay approximately 0.2% of GDP for coastal protection while damages are estimated to be less than 0.1% of GDP. One participant questioned the assumptions and results presented, questioning why Holland would be affected by the impacts from the SRES A1B scenario.

Finally, Dr. Tol presented general equilibrium effects of sea level rise. He explained that land loss would affect agriculture, and hence all other markets, and that coastal protection would affect construction and capital. He presented the results from a static computable general equilibrium (CGE) model, first with no protection and then with full protection. He noted that impacts only amount to fractions of a percent and that losing capital is more important than losing land. Dr. Tol emphasized that increases in GDP modeled under full protection are misleading since GDP is a measure of economic activity, not welfare. Instead, Dr. Tol suggested that, globally, direct costs are a reasonable measure of welfare costs.

Dr. Tol finished with a series of conclusions. He noted that sea level rise is one of the better understood impacts even though estimates contain significant uncertainty. He noted that the extent of saltwater intrusion, future storm characteristics, wetland value, and adaptation are some of the largest sources of uncertainties.

Discussion: Sea Level Rise

During the discussion session, several questions touched on the issue of timescales. One participant noted the contradictory conclusions about impacts from warming that have been generated in different studies. For example, politicians have identified 2°C of warming as problematic, FUND has identified net benefits up to 3°C of warming, and other studies indicate that the Greenland ice sheet would collapse with 3°C of warming. He noted that sea level rise is one of the biggest impacts on a long timescale. Dr. Tol clarified that SLR is not a large component of marginal impacts. He explained that the damages from SLR due to melting of the Greenland ice sheet would depend on the timescale of the melting. If complete melting occurred over two to three centuries, with sea level rising at three meters per century or more, it would be very difficult to adapt, causing significant damages. However, if the rate of sea level rise was two meters per century, it would be possible to raise dikes and adapt. He noted that rapid collapse of the West Antarctic Ice Sheet would cause many coastal cities to be largely flooded.

In response to another question, Dr. Nicholls emphasized the importance of evaluating the distribution of impacts over time, rather than focusing on expected annual damages. In particular, he noted the importance of events such as storms. He noted that while climate change may increase storms, storms drive coastal action today and the issues will be fundamentally the same in the future.

Another participant again raised the issue of interacting impacts, expressing his frustration that workshop discussions have focused on storms without sea level rise and sea level rise without storms. He emphasized the non-linear and interactive nature of climate change impacts. Dr. Tol noted that there are other interacting impacts as well, including changes in wind and sedimentation patterns.

Several questions addressed the impacts in the Netherlands. In response to one question, Dr. Tol explained that the Dutch are overprotecting against some predicted impacts. In fact, the speakers noted that the Dutch conducted an economic analysis intending to justify their work, but got results that indicated the work was not justified. In response to another question, Dr. Tol clarified that the Dutch are spending about twice as much as they would have in the absence of predicted sea level rise, to prepare defenses for 60-80 cm of SLR in the SRES A1B scenario. Dr. Nicholls noted that the SRES scenarios are optimistic.

The last group of questions concerned extreme storms. One participant asked the speakers to confirm that the Netherlands were building coastal infrastructure to withstand a 1 in 10,000 year event while New Orleans is building for a 1 in 100 year event. Dr. Nicholls explained that the new defenses in New Orleans are built for a 1 in 100 year event, but would probably withstand a 1 in 500 year event without breach. Another participant asked the speakers to confirm that SLR was not substantively included in rebuilding efforts after Hurricane Katrina. Dr. Nicholls confirmed that New Orleans may have done a little to include SLR, but for the most part, SLR was not included.

Marine Ecosystems and Resources

After brief Day 2 opening comments from Elizabeth Kopits, the sixth session commenced, covering the impacts and damages to marine ecosystems and resources. The session was moderated by Dr. Chris Moore of EPA and included presentations by Dr. Sarah Cooley, Woods Hole Oceanographic Institute; Dr. Paul McElhany, National Oceanic and Atmospheric Administration (NOAA); Dr. David Finnoff, University of Wyoming; and Dr. John Whitehead, Appalachian State University.

Modeling Climate and Ocean Acidification Impacts on Ocean Biogeochemistry

Dr. Sarah Cooley of the Woods Hole Oceanographic Institute initiated the discussion on marine ecosystems and resources by presenting an overview of modeling changes in ocean biogeochemistry due to ocean acidification and climate change. She organized her discussion into four sections.

First, Dr. Cooley presented an overview of the chemistry and observed impacts of ocean acidification. She explained that a quarter of the anthropogenic CO_2 burden dissolves in the ocean, combining with water to produce carbonic acid. She noted that the rate of present change in ocean acidification is too fast to be compensated by rock weathering and other mechanisms. Dr. Cooley presented a series of graphs that show increasing atmospheric CO_2 concentrations are associated with increasing ocean CO_2 concentrations, decreasing ocean pH, and decreasing saturation states for calcite and aragonite, which are used by marine animals to produce hard parts (e.g., shells). She also showed that anthropogenic CO_2 has penetrated to ocean depths of thousands of meters.

Dr. Cooley noted that ocean acidification is likely to cause other changes in ocean biogeochemistry. For example, nitrogen-fixing organisms such as phytoplankton thrive in the higher concentration of CO_2, likely causing a shift in the nitrogen pool towards ammonia. Additionally, changing pH and/or CO_2 concentration will likely change metal ion speciation, increasing both copper (which is toxic) and iron (which is a fertilizer). Dr. Cooley emphasized that ocean acidification is occurring along with numerous other anthropogenic stressors, which could be antagonistic or synergistic to acidification-induced change.

Second, Dr. Cooley discussed Earth system model simulations and their ability to predict future conditions. She noted the use of data-model comparisons to evaluate model skill. She explained that it is crucial to correctly model ocean physics and that biogeochemical parameterizations are under continuous improvement. Dr. Cooley explained the use of model intercomparisons to create and evaluate forecasts, including the Ocean Carbon-Cycle Model Intercomparison Project (OCMIP). She explained that the most significant uncertainty in modeling ocean acidification is identifying future atmospheric CO_2 concentrations.

Third, Dr. Cooley discussed biological responses to ocean acidification. She identified numerous biological groups that will be directly or indirectly affected by ocean acidification, including corals, mollusks, plankton, reef communities, and marine predators. She demonstrated that calcification responses vary significantly among different organisms. She emphasized that individual, population, and ecological implications, including follow-on food web effects, are not yet understood. She presented evidence that calcifiers tend to vacate areas when conditions do not suit them.

Next, Dr. Cooley discussed the valuation of ecosystem services. She noted that most studies focus on market values, but that non-market values, indirect use values, and non-use values must also be incorporated in an informed analysis. She presented an estimate of damages assuming that decreases in pH result in lower mollusk harvests. She estimated annual losses of $75 to $187 million in ex-vessel revenues from a 0.1 to 0.2 pH decrease, amounting to $1.7 to $10 billion in net present value losses through 2060. Dr. Cooley noted that valuation of impacts on coral reefs is driven by tourism effects.

Fourth and last, Dr. Cooley discussed knowledge gaps and needs. She noted the need to properly link three main models: physical, biological, and human/economic. She identified numerous relationships within these models that are not well understood. Finally, Dr. Cooley presented the increasing level of uncertainty associated with the progressing stages of ocean acidification impacts (e.g., changes in ocean pH are more certain than effects on marine organisms, which are more certain than changes in ecosystem services).

In response to a question, Dr. Cooley explained that there are a large number of studies examining the observed impacts of historic ocean acidification. However, she explained that there are no good baselines to ascertain when "normal" conditions are exceeded. She noted that numerous time series stations are currently examining this question, which is high on the international research agenda.

Modeling Climate and Acidification Impacts on Fisheries and Aquaculture

Dr. Paul McElhany of the NOAA Northwest Fisheries Science Center expanded on Dr. Cooley's presentation with a discussion of modeling climate change and acidification impacts on fisheries, aquaculture, and other marine resources.

Dr. McElhany started by enumerating the impacts and impacted resources associated with climate change and ocean acidification. He noted that impacts on capture fisheries will be complicated, while aquaculture has some ability to adapt using relocation, control, and species switching. He further noted that while the direct CO_2 effects on growth and survival are relatively well understood, the effects on stratification and circulation are not known.

Next, Dr. McElhany described nearly a dozen different model types that are used to model impacts on marine resources, including: fishery stock assessments, population viability analyses, food web/ecosystem models, NPZ (nutrients, phytoplankton, zooplankton) models, minimum realistic models, maximum unrealistic models, modeled range maps, individually-based models, life-cycle models, bioenergetics, and expert systems. Dr. McElhany noted that IPCC-class Earth system models must be downscaled to match the near-shore, small-scale processes at the biological scale. He noted that the IPCC avoided modeling coastal ocean impacts due to their complexity. However, he emphasized that biological action is concentrated in coastal regions and that these gaps must be addressed.

Dr. McElhany then presented several examples of marine resources modeling. His examples spanned a wide range of scale and scope. Some examples only examined a single variable or a single species, while other examples examined all climate change impacts or entire ecosystems. Dr. McElhany noted the vast complexities associated with the life cycle of a single species and the greater complexities associated with ecosystems. He emphasized the importance of modeling interactions between species. He highlighted one study's results that indicate a general decline in fisheries, especially with all climate change effects, and that range shifts will be the biggest impact. He noted the ambitious nature of the Atlantis model which attempts to couple oceanography, ecology, and fisheries submodels. He also noted a fairly comprehensive evaluation of fisheries using a bioclimate envelope.

Dr. McElhany provided a "reality check" that identified numerous big questions remaining regarding marine resources. He identified significant unknowns including changes in the Gulf Stream, stratification, upwelling, and decadal oscillations, among others. He noted the possibility for positive changes, such as improved fishing in some areas. Dr. McElhany further noted that details are critical in modeling marine resources. For example, species interactions, phenology, synergistic effects, short-term variability, and local circulation are all critical factors. He noted that lab studies do not necessarily scale to ecosystems.

Finally, Dr. McElhany suggested that coarse-scale impact assessment would be beneficial in the future. He suggested the use of back-of-the-envelope estimates and assessment using three approaches: a bioclimate envelope to provide key first pass estimates, minimum realistic models, which model only the most important components of a specific system, on high value fisheries, and ecosystem and food webs to look for interactions. He emphasized the importance of resolving the big climate questions.

In response to a question, Dr. McElhany noted that he was not aware of any studies examining the effects of changing aragonite saturation states on fish. He noted one observational study that indicates major oyster reproductive failures in the past several years, which are correlated to pH changes. A different participant suggested that the reference case for marine resources needs to be carefully considered and that acidification impacts need to be considered in the context of a variety of other environmental stressors that affect the baseline.

Economic Impact of Climate Change and Ocean Acidification on Fisheries

Following Dr. McElhany's presentation, Dr. David Finnoff of the University of Wyoming commenced the economic portion of the marine resources discussion, with his presentation on the economic impact of climate change and ocean acidification on fisheries. Dr. Finnoff began by describing the potential significance of ocean acidification, citing historic mass extinction events linked to ocean surface pH, challenges for calcifying organisms, and Dr. Cooley's work that calculated net present value losses from decreased mollusk harvests of $1.7 to $10 billion through 2060. He noted that Dr. Cooley's work, while providing a useful initial estimate, is based on lost revenue rather than more appropriate measures of welfare such as consumer surplus.

Next, Dr. Finnoff discussed the economic consequences of ocean acidification, noting that disruptions in ecosystem services are material damages that imply welfare changes. He highlighted the reciprocity of the relationship where ocean acidification is caused by human activity and, in turn, affects human activity. Dr. Finnoff explained that assessment of material damage requires characterizing the changes in production and consumption, determining the responses of prices, and identifying adaptation options. He noted that changes in ocean acidification do have the potential to affect production possibilities, as well as direct and indirect costs.

Dr. Finnoff explained that both reduced-form/partial equilibrium and structural/general equilibrium representations have pros and cons. He emphasized the importance of identifying the appropriate balance and utilizing both approaches. He explained that non-convexities and species interaction require more detailed and comprehensive models. Through a series of simplified graphs, he demonstrated that with problems characterized by non-convexity, it is necessary to understand the entire surface of possibilities to be able to locate the global optimum.

Using an illustrative example of the Bering Sea Food Web, he discussed a simplified model that might be used in an IAM. He demonstrated the non-linear, non-systematic results from shocks, and identified non-convexities, non-monotonic changes, and problems with reduced-form aggregation. He concluded that bio-economic harvests of fish and crab are likely affected to varying degrees and magnitudes depending on their location in the food web; non-harvested stocks may or may not have cascading effects depending on their location in the food web; and to assess tradeoffs, it is necessary to assess changes in flows and stocks simultaneously.

Dr. Finnoff concluded that welfare measurement of materials damages has some well-known characteristics, but that for ocean acidification, a lot of issues remain unresolved. He suggested that a clear understanding is needed of how ocean acidification affects production and consumption possibilities in a consistent setting. He noted that using dose-response relationships of environmental change from the natural sciences is crucial, but that it is not yet resolved how much detail is necessary for a good understanding. Finally, Dr. Finnoff concluded that if problems are convex or well-behaved, aggregate representations of the natural science may be sufficient for good economic assessments. However, if problems have pervasive non-convexities, he noted that policy makers must expand the scope of their analysis for good economic assessments. It may be necessary for the assessor to know the entire possibilities surface.

Nonmarket Valuation of Climate and Acidification Impacts on Marine Resources

Dr. John Whitehead of Appalachian State University delivered the final presentation in the marine ecosystems and resources impact category. He described nonmarket valuation of climate change and ocean acidification impacts to marine resources.

Using the example of coral reefs, Dr. Whitehead described the different methods available to estimate nonmarket values. He explained that use values may be estimated by the willingness to avoid climate change due to use of affected resources. Direct uses of coral reefs include diving, snorkeling, and viewing; indirect uses include fishing. He then explained that non-use, or passive use, values may be estimated by the willingness to avoid climate change without the intent to use the affected resources. Willingness to pay for nonuse values can be motivated by altruism, ecological ethic, or bequests.

Dr. Whitehead explained that use values can be estimated using revealed preference or stated preference valuation methods, while non-use values can only be estimated using stated preference methods. Dr. Whitehead further explained that revealed preference methods include hedonic price, averting behavior, and travel cost methods, as well as producer surplus values. He noted that the travel cost method is most appropriate when considering marine resources. Dr. Whitehead then described stated preference methods, which include contingent valuation, choice experiments, and contingent behavior. He explained that there are problems with both revealed preference and stated preference methods, which can be mitigated by joint estimation of revealed preference and stated preference data.

Dr. Whitehead cited several examples in the climate change literature of revealed preference and stated preference studies. He explained that no study to date explicitly addresses nonmarket valuation of climate change and marine resources. Instead, Dr. Whitehead discussed a very simple nonmarket valuation based on data from national recreation surveys, where he regressed saltwater fishing participation and fishing days on temperature and precipitation. He suggested a more complex estimation would be possible using the recreational fisheries demand study.

Dr. Whitehead concluded that there is very little existing research with which to develop the SCC for marine resources. He suggested that meta-analyses could be used in a benefit transfer study, using values for coral reef recreation, outdoor recreation, and recreational catch. However, he noted that the behavioral response to climate change is missing. Dr. Whitehead suggested that a wide variety of studies is needed, using both revealed and stated preferences, to estimate total economic value, use value, and non-use value. He suggested the most promising avenue is using existing revealed preference data. New studies using stated preference data could differentiate between marine and other values and estimate the behavioral response to climate change. Revealed preference and stated preference joint estimation could differentiate between use and non-use value.

Discussion: Marine Ecosystems and Resources

During the question and answer session, one participant asked how changes in keystone species can be incorporated in food web models. Dr. McElhany suggested that if food web models are built properly, keystone species should be included. He noted that model results become more tenuous as conditions change further away from the case in which the model was parameterized.

A second participant questioned the incorporation of thresholds and discontinuities into economic models. He noted that economic models indicate small marginal changes, but that natural scientists tend not to consider marginal changes, as they are more concerned with thresholds. Dr. Finnoff agreed about the importance of thresholds and discontinuities, emphasizing the aspects of his presentation that dealt with non-linearities. Dr. Finnoff explained that the economics literature knows how to handle thresholds, in principle. He suggested the need for an approach to evaluate the proximity of thresholds. He suggested using a recursive view and developing a model that can handle changes in states. Dr. Whitehead added that there is a need for non-use values in a world very different from today. He suggested the possibility that entire classes of opportunities could disappear. He noted the need for modeling to address individuals' recreational choices. Dr. McElhany cited large scale ecological changes in the North Pacific as a historical example of state changes that resulted in big community changes.

A third participant asked if the rate of ocean carbon uptake is constant or changing. Dr. Cooley noted recent efforts to evaluate the ocean's ability to take up CO_2 in the long run. She cited evidence that ocean uptake is slowing and will continue to slow due to chemical reasons and changes in ocean circulation. She noted that the slow-down will not reverse or even significantly alleviate ocean acidification.

Several participants asked about the interactions between different stressors. One participant asked about climate change impacts other than ocean acidification, such as loss of phytoplankton biomass. Dr. McElhany explained that the results he presented were based on a model generation previous to newer data on changes in primary productivity. He emphasized there is ongoing and continued learning, as well as remaining unknowns including changes in primary productivity, in ocean circulation, in temperature regimes, in stratification, and in availability of nutrients. He noted that each unknown could have significant effects.

Another participant asked if productive areas of the ocean would be squeezed as warming-induced range shifts move commercially valuable species pole-ward and ocean acidification pushes some species toward the equator since ocean acidification happens more rapidly in colder water. Dr. McElhany agreed that might happen, noting a lack of study on the interacting trends. Dr. Cooley agreed with the participant's summary, noting the need to do lab experiments to better understand the interacting effects.

A different participant asked whether coral reefs would be able to adapt to sea level rise by growing towards the sun and whether ocean acidification would affect their ability to adapt. Dr. Cooley noted that coral reefs can grow annually by millimeters or centimeters. However, she noted several interacting factors that might impede the ability of corals to adapt, including the change in deep ocean chemical conditions and the vertical and latitudinal shrinking of optimal waters. She explained that these interactions are not well understood. She further noted that coral growth rates do not necessarily correlate with vertical growth, due to the somewhat horizontal structure of corals.

A final participant asked about incorporating coral bleaching into IAMs. He noted that coral bleaching is tied to warming and is an example of a non-linear, non-marginal impact. Dr. Cooley agreed with the need to incorporate coral bleaching, disease, and destruction. She suggested that research on ocean acidification is a necessary first step, since it is necessary to understand acidification before it is possible to understand synergistic interactions. She further noted that ecosystem-scale studies are time- and manpower-intensive, and expensive, resulting in a small number of existing studies. Dr. Whitehead added that revealed preference studies would not address coral bleaching well, but that stated preference studies could. Dr. Finnoff noted economic studies on previous large scale disasters might be informative to this issue.

Terrestrial Ecosystems and Forestry

The seventh session covered the impacts and damages to terrestrial ecosystems and forestry. The session was moderated by Dr. Steve Newbold of EPA and included presentations by Dr. Karen Carney, Stratus Consulting; Dr. Brent Sohngen, Ohio State University; and Dr. Alan Krupnick, Resources for the Future.

Biological Responses of Terrestrial Ecosystems to Climate Change

Dr. Karen Carney of Stratus Consulting started the terrestrial ecosystems and forestry discussion by presenting the impact of climate change on terrestrial ecosystems. She noted that her presentation was not meant to be comprehensive, instead aimed at highlighting some key impacts and related tools.

Dr. Carney described how terrestrial ecosystems provide numerous economically important services: the provisioning of food, water, and raw materials (e.g., timber, non-timber forest products); regulation of air quality, storm protection, and waste assimilation; and cultural services such as recreation and passive use value. She noted that climate change will fundamentally and potentially dramatically affect the location and character of today's ecosystems. She noted key changes including changes in species locations, ecosystem productivity, rates of ecosystem processes, and disturbance regimes (e.g., drought, fire, pest outbreaks).

Next, Dr. Carney discussed three major ecosystem impacts—changes in vegetation distribution and dynamics, wildfire dynamics, and species extinction risks—that have the potential to be included in IAMs. She selected these impacts as they best met the following criteria: ecological importance, economic importance, and being well understood. For each of the three impacts, Dr. Carney discussed why the impact is likely to occur, the tools available to estimate the impact, what research has shown, key uncertainties or other shortcomings with projecting future impacts, and what key services are likely to be affected.

Dr. Carney noted that changes in vegetation distribution and dynamics, which will be affected across the globe, are most commonly examined using dynamic global vegetation models (DGVMs). She noted that there are many DGVMs available that can examine multiple scales (e.g., countries, regions, globe). Most DGVMs consist of interacting biogeography, biogeochemistry, and fire modules. She highlighted a couple of studies using DGVMs, one which examined vegetation changes in the United States and a second which examined changes in global tree cover. She emphasized that both studies predict fundamental and large-scale changes. Dr. Carney explained the limitations of DGVMs, including that there is a significant amount of variability across models for the same region and climate scenario, with results highly dependent on the GCM used. She noted additional limitations, including an absence of most other anthropogenic factors, the assumption of no barriers to plant dispersal, and an absence of pest and pathogenic influence. She noted that there are some general areas of agreement between models and that scientists should look for these areas, perhaps averaging DGVM results, when possible.

Next, Dr. Carney explained that climate change will affect wildfire dynamics through direct (e.g., higher temperatures, dryer fuels) and indirect (e.g., changes in vegetation type) mechanisms. She noted that wildfire dynamics can be modeled using statistical models based on historic fire behavior, as well as using the fire module of DGVMs. Dr. Carney presented the results of one study that predicts decreased fire in northern Canada and Russia, and increased fire in the United States, central South America, southern Africa, western China, and Australia. She explained that wildfire models can only roughly approximate both historic and future wildfire dynamics, and that they are unable to predict the timing and location of specific fires.

Finally, Dr. Carney discussed species extinctions, which are most commonly modeled using climate envelope models. These models use current distributions of a species to construct climatic requirements and then determine where species could live under future climate conditions. She noted that extinctions are likely to occur, but that the results of these studies vary widely, with predicted extinctions ranging from relatively low levels up to 60% of species. She noted several key uncertainties in climate envelope models, including: that species may be flexible and able to survive in a wider range of climate conditions than is predicted by their current range, that biotic interactions may be more important than climate in determining species range, that dispersal is likely limited by habitat fragmentation, and that land use change may amplify climate change impacts. She further noted that is difficult to value global biodiversity and that economic value is often tied to specific species or locations rather than global extinctions.

Dr. Carney concluded with recommendations for future research needs. She suggested that methods need to be developed to integrate results across studies and tools (e.g., meta-analyses, ensemble means). She suggested a major need to develop large-scale, long term projections for changes in pest outbreaks and interior wetland change and loss. She also noted the importance of understanding changes in snow pack, particularly as related to ecosystems and recreation.

Estimating the Economic Impact of Climate Change on Forestry

After Dr. Carney's presentation, Dr. Brent Sohngen of the Department of Agricultural, Environmental, and Development Economics at Ohio State University and a University Fellow for Resources for the Future, presented on estimating the economic impact of climate change on forestry.

First Dr. Sohngen described the general process of measuring damages, which starts with future climate scenarios and concludes with economic impacts. He noted that feedbacks and interactions between different steps of the analysis are important and require additional research. Dr. Sohngen then explained that both models and observations indicate increases in productivity due to: CO_2 fertilization, warming in colder climates, and precipitation gains where water is limited. He noted that DGVMs indicate limits to productivity gains and suggest ecosystems will change from a carbon sink to a carbon source within the next several decades.

Dr. Sohngen presented results in the literature that predict a reduction in total U.S. ecosystem carbon, with losses greatest in the eastern United States and under more recent climate scenarios. Without accounting for adaptation, these ecosystem effects could result in emissions of up to 500 million t C per year and a total loss over the century of 10-20 billion t C. He then presented regional estimates from the literature on timber market results. He showed that timber output and consumer surplus is expected to increase in almost all regions, but that producer returns only increase in about half of the regions.

Dr. Sohngen then presented preliminary results from an analysis that is currently underway. That study incorporates several key factors into the economic analysis, including yield change, stock losses, and area suitable for trees. It also incorporates adaptation options, including existing stock management by changing rotations and salvage; replanting of new species if growing and economic conditions warrant it; and future stock management by changing rotations, management, and investments. He showed that that global output is expected to increase by 5-15% while global prices are expected to decrease by 5-15%.

He explained that regional results suggest that there will be winners and losers, but that the allocation of benefits and losses depend on the climate scenarios. He noted that Brazil, Canada, Russia, and Oceania are likely to experience net benefits. Finally, he emphasized that the management of forest stocks will be complicated by disturbance. He noted that large-scale disturbances are already influencing outputs in many regions (e.g., mountain pine beetle outbreaks in Canada, forest fires in Russia) and that disturbance patterns are expected to change with climate change. He noted that increases in productivity are not expected to be able to counter falling global prices.

Dr. Sohngen concluded by describing some of the study's limitations. He noted that timber markets may not be most important demand on forestland in the future, that models are deterministic, and that ecosystem models are calibrated without human influences. After the conclusion of his presentation, Dr. Carney asked if crop shifting is incorporated into his model. She noted that if timber prices drop too low, people may decide to use the land in other ways. Dr. Sohngen explained that this type of crop shifting is partially incorporated.

Valuing Climate-associated Changes in Terrestrial Ecosystems and Ecosystem Services

Dr. Alan Krupnick provided the third and last presentation for the terrestrial ecosystems and forestry impact category, on valuing the impacts of climate change on terrestrial ecosystem services. Dr. Krupnick focused his comments on non-use values and stated preference studies. He noted that even a low WTP per person can amount to significant totals.

Dr. Krupnick discussed the transition from natural science assessment to economic assessment, where biophysical endpoints estimated by natural scientists are used as the starting points in valuation studies. He explained a need for natural scientists to provide biophysical impacts assessment endpoints that correspond to the items assessed in valuation exercises (valuation starting points), that people value and care about, and that have functional relationships with climate drivers. He explained a parallel need for economists to develop a consensus approach to classify endpoints to be used as valuation starting points. He noted that natural scientists have identified large numbers of climate change impacts, from which endpoints need to be identified. He further noted that economists have not been able to easily define the things that matter from an economic perspective.

Dr. Krupnick explained that, when conducting stated preference studies, it is crucial to ask the right questions. He noted that survey respondents should be asked to value biophysical outputs (e.g., number of eagles), rather than biophysical inputs (e.g., number of acres of eagle habitat). He explained that natural scientists should identify the production function that defines the relationship between inputs and outputs. He also noted that it may be better to not mention climate change, particularly in U.S. studies, as climate skeptics might provide biased answers. He questioned how best to admit uncertainties in surveys without inducing protest bids.

Dr. Krupnick presented several examples of stated preference surveys where survey respondents are given a set of options to choose from with a suite of associated conditions. He noted one study that suggests the household monthly mean WTP for a 30% greenhouse gas reduction is $22 in Sweden, $17 in the United States, and $5 in China.

Dr. Krupnick classified starting points for climate change into four categories: use values; "standard" non-use values; combinations associated with events or broad scale changes; and novel changes. He then classified valuation studies into four categories: studies valuing relevant commodities in a non-climate context; studies transferring non-climate values to a climate change context; studies directly valuing relevant commodities in a climate change context; and stated preference top-down studies.

Dr. Krupnick went on to summarize and classify the literature using his set of starting points and survey types. Dr. Krupnick noted that there is a broad range of existing studies falling into almost every combination of startpoint and survey type. He suggested these studies provide a lot of material for meta-analyses and benefit-transfer. Dr. Krupnick noted the studies range widely in their spatial scale, but that spatial specificity enhances credibility. He highlighted that scope sensitivity tests ensure WTP is greater for avoiding larger damages or gaining larger benefits and that marginal returns decrease. He noted that existing studies suggest timing of benefits is not significant, implying low or zero discount rates. He explained that most studies assume certainty and very few vary uncertainty.

Dr. Krupnick noted that existing "non-climate" studies are useful but limited, that benefits transfers studies are artificial and assumption-based, and that climate-driven studies are useful and growing in number, but that they will always be location-specific and thus patchy. He noted that top-down studies are tempting as they provide a broad coverage of endpoints and locations, but that they involve highly imprecise commodity definitions and scenarios. He highlighted a need for holistic valuation estimates.

Discussion: Terrestrial Ecosystems and Forestry

After Dr. Krupnick's presentation, the terrestrial ecosystems and forestry discussion session commenced. One participant noted the finding highlighted by Dr. Sohngen that forest productivity would increase due to climate change. Since forests provide an important low-cost mitigation option, she asked how this trend could be incorporated into mitigation costs in the SCC. Dr. Sohngen noted that initial unpublished models suggest lower costs of carbon sequestration, but that it is a broad, uncertain result.

Several participants and speakers discussed the usefulness of the concept of ecosystem services. Dr. Krupnick expressed satisfaction that the concept had gained traction, as it does provide a bridge into the economic sphere by using the term 'service'. However, he suggested it was only a starting point that only partially overlaps with important endpoints lying underneath the services. Another participant suggested that the literature does not provide good information on how climate change will impact ecosystem services. He agreed with Dr. Krupnick that the concept has potential and begins to provide a useful bridge. However, he suggested the concept had not gotten a lot of traction in policy making. He suggested that the concept should continue to be pursued in a sensible way. Dr. Sohngen agreed with the previous assessments. He added that the economic drivers for management and adaptation of timber markers seem to be decreasing, suggesting it is more compelling to consider their ecosystem services. Dr. Carney suggested that the concept of ecosystem services, while perhaps imperfect, is still useful. She explained that ecosystem services provide a way to translate ecological effects into changes that are important to individuals in a policy context.

Another series of comments focused on the language of stated preference surveys. Dr. Krupnick explained that a tax is frequently used as a vehicle in surveys but that the standard practice is to try to present a hypothetical real choice that has real costs. He emphasized that stated preference studies are not attitude surveys, and that responses should be limited by income and choices should be binding. He noted that surveys are aimed at estimating the individual willingness to pay. He added that studies are constructed to eliminate the possibility of "free riding" and to incorporate the effect that one individual paying in the absence of other contributions would have no effect.

In response to a final question, Dr. Sohngen explained that models do, at least partially, incorporate country variables (e.g., poverty) as timber production shifts across political borders. He explained that models incorporate different production costs (e.g., labor costs), management structures, species uses, and prices. He suggested the extent of incorporation may not be sufficient or perfect.

Energy Production and Consumption

The eighth session covered the impacts and damages to energy production and consumption. The session was moderated by Dr. Stephanie Waldhoff of EPA and included presentations by Dr. Howard Gruenspecht, U.S. Energy Information Administration; and Dr. Jayant Sathaye, Lawrence Berkeley National Laboratory (LBNL).

U.S. Energy Production and Consumption Impacts of Climate Change

As the first speaker for the Energy Production and Consumption Impact Category, Dr. Howard Gruenspecht of the U.S. Energy Information Administration discussed the energy system impacts of climate change. He noted that climate change impacts on energy systems have received considerable attention, despite high-profile reports finding that the impacts will be modest.

First, Dr. Gruenspecht presented climate change impacts on energy demand for space heating and cooling. He noted that the United States is a relatively cold country, where the amount of energy used for heating is three to four times as great as the amount used for cooling. He noted that this gap is even greater in other industrialized countries. He further noted that energy use for space conditioning is highly tied to development. Dr. Gruenspecht explained that the details of warming are very important in considering energy impacts. This includes the latitudinal, diurnal, and seasonal gradients. He explained that space conditioning is subject to thresholds and that measures of comfort produce very different impact estimates than measures of energy expenditures. Finally, Dr. Gruenspecht noted the importance of incorporating technology changes over relevant time horizons. Historic increases in cooling efficiency had significant impacts, and new technologies such as smart grid will likely have similar impacts.

Dr. Gruenspecht noted that the literature has focused on energy demands for space conditioning but that other areas of energy demand merit additional attention. He highlighted the energy-water nexus, since climate change stresses traditional water sources. He showed that non-traditional sources such as desalinized water require significant amounts of energy.

Next, Dr. Gruenspecht presented climate change impacts on energy supply. He noted impacts on access to traditional resources, including hydroelectricity's sensitivity to melting glaciers and arctic oil infrastructure's sensitivity to melting permafrost. He further noted the need for cool water and air to maintain power plant operation. However, Dr. Gruenspecht emphasized his feeling that too much attention has been placed on energy issues, which may not be quantitatively important in overall effects, particularly after mitigation and adaptation are considered.

Finally, Dr. Gruenspecht discussed the impacts of climate change on non-traditional energy sources. He noted the very significant effects of cloud cover and aerosols on solar power, the unclear changes in wind patterns that will affect wind power, and the agricultural effects on biomass.

Dr. Gruenspecht concluded that energy impacts may be beneficial for small to modest climate change, but dominated by negative impacts in the long-run. He emphasized that details are crucial in modeling impacts and that changes must be considered in the context of adaptation and technology change. He suggested the importance of distinguishing between energy system impacts, which are important to energy planners, and energy-system-related welfare impacts, which are important for cost-benefit analysis of climate change policies.

Impacts of Climate Change on Global Energy Production and Consumption

Following Dr. Gruenspecht, Dr. Jayant Sathaye of LBNL presented the impacts of climate change on global energy production and consumption. He started by presenting a list of over a dozen hydro-meteorological and climate parameters that each have numerous effects on energy demand and supply.

Dr. Sathaye then presented a selected review of international impact analyses in the literature. He noted that most of the literature focuses on energy demand, as opposed to energy supply. The literature indicates that global reductions in energy demand for heating will be greater than global increases in energy demand for cooling. For example, the POLES model estimates 200-300 million tons of oil equivalent (Mtoe)reductions in heating demand compared to 60-130 Mtoe increases in cooling demand. The literature indicates that global nuclear generation will decline, while hydroelectricity generation may increase or decrease depending on the scenario (more likely increase). Dr. Sathaye also presented examples of international studies at the national and regional scale.

Next, Dr. Sathaye presented an example of a study conducted in California to demonstrate the data and information needed to conduct an energy impact analysis. He explained that the study, funded by the California Energy Commission, focuses primarily on three impacts: increased temperature impacts on electricity capacity and demand; sea level rise impacts on energy infrastructure; and wildfire impacts on energy infrastructure. He presented the intricate flow chart of analysis stages, commencing with AOGCM emission scenarios and culminating in a summary of damages.

Dr. Sathaye then presented results from the study. He explained that warming temperatures may lead to both losses of up to 4,000 megawatts (4%) of available natural gas-fired power plant capacity, as well as increases in peak load cooling demand of 20%. He noted that the combined effect of changes in demand and supply result in a 24% gap between energy supply and demand that needs to be addressed.

Dr. Sathaye presented the maps of the wildfire analysis, which involved identifying the climate factors affecting wildfires, overlaying transmission lines on near-term and long-term spatial models of wildfire probability, and quantifying the length of transmission lines exposed to wildfires under modeled future climate scenarios. Dr. Sathaye explained a similar analysis for sea level rise, which concluded that a 1.4 meter projected rise in sea levels would affect 25 power plants and approximately 90 substations.

Dr. Sathaye concluded that there is a general lack of quantitatively-based impacts information for the energy sector, but that the base of international literature is growing. He reiterated global projections of larger decreases in heating demand compared to increases in cooling demand. He noted that the temperature impact on demand is much higher than on supply infrastructure and that the impact of wildfires could potentially be significantly high. Finally, he suggested that more data and research are needed to evaluate wildfire and sea level rise impacts on power sector infrastructure and temperature impacts on electricity transmission and distribution.

Discussion: Energy Production and Consumption

During the question and answer session, one participant again raised the need to incorporate interactions and double-counting across sectors, highlighting the intersection of health impacts driven by temperature with impacts on cooling demand. Another participant noted that an impact in one sector might be an adaptation in another. Dr. Gruenspecht added that there are significant impacts from adaptation, technology, and efficiency that must be considered. Dr. Sathaye agreed, noting the need to develop a long-term scenario of future infrastructure possibilities and combine that scenario with climate data.

Another participant asked how cooling penetrates lower socio-economic classes, noting that middle class and poor country adoption of cooling greatly determines international impact. Dr. Sathaye agreed with the importance of these effects. He noted that the air conditioning load in India has been increasing annually by 25%. He suggested that similar changes are occurring elsewhere in developing countries.

A third participant asked about distinguishing between costs of damages and costs of reducing risks, noting that the costs of reducing risks are often significantly lower than costs of damages. Dr. Sathaye agreed that this distinction is critical and should be reflected in the cost analysis. Dr. Gruenspecht also agreed, emphasizing that the future must be considered in the context of technology change. He acknowledged the extreme difficulty in attempting to predict the 100 year future, but emphasized its necessity.

During the discussion session, both speakers emphasized a need for more and better climate data, noting the need for information on things like cloud cover. One participant suggested that economists need to move forward with the data available now, since some aspects of physical climate change are going to be difficult to estimate more accurately anytime soon. Dr. Gruenspecht acknowledged the validity of her point but suggested that there is a middle ground where climate scientists might be able to provide more than what is provided now, but not everything desired by economists. For example, he suggested it would be helpful to have information on cloud cover on a global average scale. Dr. Sathaye agreed, noting that global average numbers provide a sense of the underlying information. Another participant argued that global average numbers are enormously insufficient and could do more harm than good when considering spatially specific investments and activities related to cloud cover and wind patterns. Yet another participant challenged the community to do better. The first participant suggested that economists need to lower their expectations. She explained that global average cloud cover is the greatest uncertainty in models. She suggested a need to make decisions under uncertainty. Another participant suggested it would be helpful to put bounds on the uncertainty with factors such as this.

Finally, one participant asked if heat waves and blackouts are incorporated in models. One of Dr. Sathaye's colleagues explained that the California study did incorporate the effect of heat waves, but did not include the costs of blackouts. The participant suggested that this would affect the overall conclusion related to heating and cooling demand. Dr. Gruenspecht reemphasized the distinction between energy impacts and welfare impacts.

Socio-economic and Geopolitical Impacts

The ninth session covered the socio-economic and geopolitical impacts and damages. The session was moderated by Dr. Alex Marten of EPA and included presentations by Dr. Nils Petter Gleditsch, Peace Research Institute Oslo; and Dr. Robert McLeman, University of Ottawa.

Regional Conflict and Climate Change

Dr. Nils Petter Gleditsch of the Centre for the Study of Civil War, the Peace Research Institute Oslo, and the Department of Sociology and Political Science at the Norwegian University of Science and Technology commenced the last impact session with his presentation on regional conflict and climate change. Dr. Gleditsch is an expert on conflict. During his presentation and through his abstract, Dr. Gleditsch indicated that the policy debate is running well ahead of its academic foundation, and sometimes even contrary to the best evidence.

First, Dr. Gleditsch presented current trends in armed conflicts and number of deaths. He explained that the world is moving towards a liberal peace – as democracy and trade increase worldwide, conflict becomes less likely. This movement includes increases in the number of international governmental organizations (IGOs), in democracy, in wealth, and in trade. He noted four possible threats to the liberal peace: shifting patterns of power, the financial crisis, fundamentalist religion, and climate change. He noted that climate change is arguably the most serious threat, highlighting numerous statements from non-governmental organizations, politicians, and some academics indicating climate change is a major issue that will greatly impact conflict. Despite the rhetoric, however, there is little systematic evidence to date that long-term climate change or short-term climate variability has had any observable effects on the pattern of conflict at any level. Dr. Gleditsch then presented a flowchart from the World Bank that presents numerous possible pathways that lead from climate change to conflict. He showed that natural disasters, migration caused by sea level rise or other climate factors, and increasing resource scarcity may all promote conflict.

Next, Dr. Gleditsch presented numerous, sometimes contradictory, findings from the literature regarding the influence of climate factors on conflict. To date there is little published systematic research on the security implications of climate change. The few studies that do exist are inconclusive, most often finding no effect or only a low effect of climate variability and climate change. The scenarios summarized by the Inter-Governmental Panel on Climate Change (IPCC) are much less certain in terms of the social implications than the conclusions about the physical implications of climate change, and the few statements on the security implications found in the IPCC reports are largely based on outdated or irrelevant sources.

Dr. Gleditsch presented evidence regarding the effects of precipitation, temperature, sea level change, and natural disasters. He noted that millions of people may become refugees due to sea level rise. He also noted that natural disasters may reduce conflict as people tend to unite in the face of adversity. Dr. Gleditsch discussed the economic effects of climate change, noting that economic factors are important in conflict. He explained that economic interdependence and economic development limit inter- and intra-state conflict, respectively; but that economic decline could reverse this.

Dr. Gleditsch presented arguments and counterarguments for several climate change impacts on interstate conflict. He suggested increased scarcity may or may not lead to interstate conflict. He also explained that climate change will open up new trade routes and new ocean territories. He noted that uncertainty about ownership and competition for exploiting these resources may or may not promote conflict. He suggested that climate change may affect where nations fight, rather than whether or when.

Dr. Gleditsch described methods analyzing the scarcity theorem, highlighting several criticisms of past studies. He highlighted the interactions of climate change with other factors, such as poverty, poor governance, and ethnic dominance, suggesting that climate change may act as a threat multiplier and destabilize conflict-prone regions. He suggested that, from a policy perspective, it is useful to examine whether it is easier to reduce climate change or other factors in the interaction. Dr. Gleditsch presented a map of the distribution of armed conflict, highlighting Africa, East Asia, and Central and South Asia as particularly vulnerable regions.

Finally, Dr. Gleditsch presented a list of research priorities. He suggested that future research needs to look at interactions between climate change and political and economic factors, to focus on countries with low adaptive capacity, to examine a broader set of conflicts, to conduct disaggregated studies of geo-referenced data, to balance negative and positive effects of climate change, and possibly to couple models of climate change to models of conflict. Dr. Gleditsch suggested that if climate change has negligible impacts on conflict, it matters significantly for the credibility of climate change research, very little for mitigation, and possible a lot for adaptation.

After the conclusion of his presentation, Dr. Gleditsch agreed with one participant's concern that studies of historic conflict may not inform the effects of unprecedented changes in climate. Another participant asked if there was evidence for conflict in small islands, which are particularly vulnerable to sea level rise. Dr. Gleditsch explained that there is not a lot of conflict in those areas, and that migration and security concerns will more likely result from climate change, than conflict.

Migration Impacts of Climate Change

Following Dr. Gleditsch, Dr. Robert McLeman of the University of Ottawa's Department of Geography presented the migration impacts of climate change. Dr. McLeman began with an overview of climate change-caused migration. He noted that the media has already identified the first climate change refugees, including those from Shishmaref, Alaska; the Cataret Islands, and the Lake Chad region.

Dr. McLeman provided a range of estimates for the number of future environmental refugees, ranging from 50 million refugees by 2100 to 1 billion refugees by 2050. He noted that predictions are based on identifying areas and populations exposed to negative climate change impacts. However, he noted that exposure does not equate to migration, climate-migration does not result from a simple stimulus-response, and there are numerous intervening socio-economic, cultural, and institutional factors. All of these caveats affect the accuracy of the estimates.

Dr. McLeman explained that migration may be caused by sudden onset events (e.g., hurricanes), persistent conditions (e.g., drought), or other stimuli. He noted that one of the earliest groups of climate change migrants will be oil workers migrating to the arctic. Dr. McLeman explained that climate change will generate migration stimuli nearly everywhere people live, including the arctic, high latitudes, wet tropics, mid- to low-latitudes, dry tropics, coastal plains, deltas, and small islands.

Dr. McLeman explained that climate events and conditions do not always stimulate migration and that multiple migration outcomes can be generated by a single climate event (e.g., brief evacuation, extended leave, permanent migration, new arrivals). He presented data from Hurricanes Katrina and Mitch that inform ensuing migration patterns. He noted one study that shows a 10% decrease in agricultural production in Mexico due to drought is associated with a 2% rise in Mexican-U.S. migration. Dr. McLeman explained that migration is one of a range of potential adaptive responses to environmental stress. Migration is used in many parts of world, is typically initiated by households, is not available to everyone, is not always used, and, in the worst case, could be the only adaptation option.

Dr. McLeman explained that vulnerability is a function of exposure, sensitivity, and adaptive capacity. He noted that migration changes the composition of the population left behind, which in turn changes the area's adaptive capacity. He further noted that migration is motivated by numerous non-climate factors (e.g., opportunity-seeking, cultural norms, lifestyle, love, persecution), with which climate interacts. He explained that most observed climate-related migration is not conflict-related, is internal or intra-regional, and generally follows established routes or transnational communities when international.

Dr. McLeman described numerous climate-migration models, including examples of each. Models include: historical climate-migration models, spatial vulnerability models, multi-level hazard analysis models, multi-stage regression models, and agent-based models. As part of one of the examples, he explained that migrants tend to be young, healthy, skilled, educated members of the middle class with uncertain land tenure and family ties elsewhere. Meanwhile, those less likely to migrate include wealthier classes, landowners, owners of fixed assets, those with strong local social networks, the poor and destitute, the elderly, the infirm, or those with broken families.

Dr. McLeman concluded with a list of challenges and opportunities. He noted many challenges related to a lack of data availability and reliability, including the lack of a single global database, fragmented data, and data missing reasons for migration. He noted other challenges including understanding system linkages and the role of intervening variables, as well as uncertainty about future climatic stimuli. Dr. McLeman listed three opportunities: to develop monitoring and data collection protocols, to enhance empirical research into environment and migration linkages, and to develop and improve migration models as climate change models improve.

Discussion: Socio-economic and Geopolitical Impacts

During the question and answer session, one participant highlighted the work of Robert Bates, which uses a different approach than described by Dr. Gleditsch to examine conflict. Dr. Gleditsch commented that he thought adding climate variables to Dr. Bates work would produce similar results to those he discussed.

Another participant asked whether climate change detection and attribution would affect the result that people unite in the face of natural disasters. He asked whether the existence of human cause or blame would affect the potential for conflict. Dr. Gleditsch clarified that the observation that people unite in the face of adversity does not only apply to natural disasters, but includes human-induced disasters such as bombings. He suggested that results may be different if a population's own government was responsible for the climate change. Dr. McLeman added that climate change adaptation planning was actually a fairly effective way to get otherwise quarreling parties to collaborate.

Dr. Gleditsch agreed with a third participant that climate conflict models should be focused on multiple stressors rather than climate as a solitary force. He noted that there has been some work in this area and reemphasized the notion of analyzing whether it is easier to address the issue by changing the climate variable or the other variables.

In response to another participant, Dr. McLeman acknowledged that he overlooked the effects of climate change on amenity migrants during his presentation. He agreed that climate change would affect the places to which affluent and retired people migrate.

A final participant asked whether the literature has examined the interaction between climate change, energy markets, and conflict and migration. Dr. Gleditsch reiterated the importance of resource scarcity in climate change. He suggested that there could be a benefit from a reduction in oil dependence and oil prices. Dr. McLeman noted that there may be an effect on energy markets from predicted rural-to-urban migration. He explained that rural residents tend to have a smaller energy footprint than urban residents, so that increased urbanization will lead to increased energy demand.

Panel Discussion: Incorporating Research on Climate Change Impacts into Integrated Assessment Modeling

Following the impact-specific sessions, a five-member panel discussed the incorporation of research on climate change impacts into integrated assessment modeling. The panel discussion was moderated by Dr. Elizabeth Kopits of EPA and included Dr. David Anthoff, University of California, Berkeley; Dr. Tony Janetos, Joint Global Change Research Institute, Pacific Northwest National Laboratory (PNNL); Dr. Robert Mendelsohn, Yale University; Dr. Cynthia Rosenzweig, NASA Goddard Institute for Space Studies; and Dr. Gary Yohe, Wesleyan University. The panel discussion started with comments from each of the panelist members and concluded with questions from the audience. Dr. Kopits framed the discussion by asking the panelists whether there was any hope in improving IAMs or whether it was only possible to outline a long-term research agenda.

David Anthoff, University of California, Berkeley

Dr. David Anthoff of the University of California at Berkeley, who works on the FUND model with Richard Tol, commenced the discussion. Dr. Anthoff reflected on each of the nine impact categories as presented by the workshop speakers and reflected on how well the state of the literature is incorporated into IAMs (specifically FUND). He noted that his comments would merely reflect how well the literature is reflected in FUND, without assessing the state of the primary research itself. He further qualified his comments by noting that they simply reflect his impressions from listening to the two days of presentations.

Dr. Anthoff suggested that FUND does a decent job incorporating the research for storms, water, sea level rise, forestry, and energy demand. He noted that Dr. Cropper's suggestion regarding the income elasticity for health impacts could be investigated fairly simply in the short-term. He suggested that the primary literature for agriculture seemed contradictory and does not provide the aggregated numbers necessary for IAM incorporation. He noted the difficulties associated with translating research on individual crops into the models. Dr. Anthoff noted that ocean acidification is not incorporated in any of the three models. He suggested that progress could be made to incorporate ocean acidification in the mid-term. Dr. Anthoff noted that FUND incorporates biodiversity loss, but that the primary research is rough. He noted that while energy demand is incorporated in IAMs, energy supply is not. He suggested the possibility of incorporating conflict is very far off. He noted that FUND incorporates a very simple migration model for sea level rise, but that other causes of migration are not incorporated.

Dr. Anthoff then suggested that primary researchers need to evaluate the IAMs to assess how well the data sources, damage functions, and outputs reflect the primary literature for each of the impact categories. He noted that uncertainty and extreme impacts are critical in IAMs, but were not discussed much during the workshop sessions. Lastly, Dr. Anthoff remarked that IAMs are severely understaffed and underfunded, particularly as compared to GCMs.

Tony Janetos, Joint Global Change Research Institute, Pacific Northwest National Laboratory

Next, Dr. Anthony C. Janetos of the Joint Global Change Research Institute suggested that there are many possibilities for improving IAMs based on the workshop presentations, noting that the physical impacts research seems to have advanced more than the valuation research. However, he suggested that very few of the advancements are readily incorporated into IAMs. He noted a need for additional understanding of thresholds, non-linear behavior, and process-level understanding. He further indicated a need to model interactions between sectors with an explicit representation of the sectors themselves, as well as the economic and physical factors (e.g. competition for water and land) that connect them.

Dr. Janetos identified several reasons that limit the generation of good central estimates of physical and economic parameters, which he noted are necessary for SCC development. First he cited the non-linearity and thresholds that pervade physical systems. He noted that some thresholds are not necessarily attributable to anthropogenic changes (e.g., climate changes driving pine beetle infestations). Dr. Janetos suggested a need to improve knowledge of the reference case, noting that the major drivers of big changes over the past half-century are human-driven (e.g., land-cover changes).

Dr. Janetos emphasized the importance of interactions among sectors, which he emphasized is a first-order problem. He explained that competition for water among various human uses and ecosystem uses is just the tip of the iceberg and not particularly well understood. He noted that aggregation and disaggregation issues are extremely important, which is a challenge for the response-surface approach.

Dr. Janetos then enumerated well-known deficiencies in the ecological models. For example, in the Vegetation/Ecosystem Modeling and Analysis Program (VEMAP), when all major ecosystem models were driven by same factors, they diverged. He noted that there has not been a subsequent reconciliation of that divergence. Dr. Janetos noted other deficiencies: ecological models typical do not include threshold responses; they underplay or omit biotic interactions like pests and pathogens; and DGVMs are largely unverified and potentially unverifiable.

Dr. Janetos suggested that it is useful and important, while difficult, to infer or develop statistically- or model-based response functions for use in reduced form IAMs. He noted that current damage functions are not robust beyond the ranges for which they were originally designed, and suggested that a process-based approach might be useful. He emphasized that uncertainty and error bars must be well characterized, noting that IAMs are better at doing this than the impacts community.

Robert Mendelsohn, Yale University

Dr. Robert Mendelsohn of Yale University shared brief remarks following Dr. Janetos. He noted that IAMs are not able to capture the level of detail available from climate modeling, ecological impact assessment, and damage assessment. He suggested some concern regarding the lack of connection between detailed impact studies and IAMs, however, he noted this lack of connection does not necessarily mean the IAMs are biased.

Dr. Mendelsohn emphasized the absolute necessity for studies to include adaptation. He highlighted that IAMs are interested in the actual damages of climate change, not the potential damages. He explained that significant adaptation will be implemented and models must acknowledge it. Next, Dr. Mendelsohn noted that the workshop seemed to be missing any discussion of catastrophic events and tipping points.

Next, Dr. Mendelsohn emphasized that the community should not be disheartened about IAMs or damage estimates. He emphasized that IAMs do a good job, in general, and that a lot of progress has been made over the last 20 years. He noted that natural science, ecosystem models, and economic models are all improving steadily, especially for short-term predictions. He acknowledged that long-term predictions are more difficult. He suggested a need for a third generation IAM to address spatial detail.

Finally, Dr. Mendelsohn suggested that the near-term agenda should be focused on capturing damage assessment work within impact models, so that IAMs can incorporate all current knowledge.

Cynthia Rosenzweig, National Aeronautics and Space Administration

Next, Dr. Cynthia Rosenzweig of NASA discussed three points and proposed a way forward.

First, Dr. Rosenzweig discussed the impacts, adaptation, and vulnerability (IAV) component of impacts assessment and valuation. She noted that adaptation has been severely underfunded but has been getting increased attention recently. She acknowledged a need to improve the biological, physical, and social science of impacts, as impacts research is much less advanced than climate science and has real effects on society. She highlighted an eagerness to work with and improve IAMs, but noted the great difficulty in doing so.

Second, Dr. Rosenzweig discussed the economic components of impacts assessment and valuation. She suggested that current work (e.g., SCC) is focused on justifying mitigation action. She suggested the need for an adaptation lens in economics work, and even analysis of the balance of resource allocation between adaptation and mitigation. She questioned whether IAMs are capable of addressing all three questions. She suggested a need to understand the economic underpinnings of adaptation, to better understand state changes arising from incremental and marginal changes, and to better address equity and environmental justice issues.

Third, Dr. Rosenzweig discussed integration of scales, of mitigation and adaptation, and of sectors. She noted that urban areas are where all sectors are integrated. She suggested climate change assessment in cities be conducted.

Finally, Dr. Rosenzweig suggested a need for on-going trans-disciplinary groups to work to improve basic research and translation. She highlighted EMF-24, OCMIP, and VEMAP as examples of trans-disciplinary efforts aimed at creating processes and structures for progress. She suggested collaboration with the National Climate Assessment and with international impacts efforts. She highlighted a movement to coordinate IAV scientists behind research questions. She noted the United Nations Environment Programme (UNEP) Programme of Research on Climate Change Vulnerability, Impacts and Adaptation (PRO-VIA), a new organization aimed at setting research questions and directions.

Gary Yohe, Wesleyan University

Finally, Dr. Gary Yohe of Wesleyan University shared his comments. He noted that his comments serve as an outline of the more complete paper he wrote to address the charge questions.

First, Dr. Yohe suggested a need for humility regarding our confidence estimates of the research. He emphasized a need to identify uncertainty issues.

Second, Dr. Yohe suggested a possible Type 3 Error in assessing economic impacts from climate change to build the SCC, cautioning scientists and economists not to spend time addressing the wrong issues, with little value added. He discussed his use of PAGE with Chris Hope to do a Monte Carlo analysis of probabilities with a range of different parameter assumptions. The analysis concluded that, in PAGE, differences in damage estimates were not as important as other variables such as time preference, risk aversion, etc.

Third, Dr. Yohe instead suggested an alternative approach for estimating benefits of marginal reductions in emissions, with higher value added. He suggested that an iterative process be built to set a target and work towards a shadow price. First, he suggested using an assessment of climate risk to determine the long-term objective and medium-term climate budget. Second, he suggested the U.S. contribution to this budget could be determined, working within the political process. Third, the results from this analysis could be used to price carbon for non-climate policy needs. Within this process, IAMs would be used to check the reasonableness of the assessment, to design cost-minimizing approaches (including net economic damages), and to highlight areas where adaptation in economic sectors will be most productive.

Panel Discussion

Following remarks from the five panelists, the panel discussed questions from the audience. One participant asked what detail is needed, what uncertainty is important to characterize, and what factors most influence the results in IAMs. She noted the orders of magnitude difference resulting from carefully conducted impact analyses. Dr. Janetos agreed that modelers must identify which complexity is important to include. He noted structures arising to address this question, including validation studies and a process-level understanding of the individual sectors. Dr. Anthoff noted that exploring relative importance is a key strength of IAMs. He noted that IAMs can use ranges and limits from the impact community as inputs, to determine how much the SCC reacts to a full range of inputs from a single sector.

Another participant questioned the interaction of high non-use and non-market values with the imposed limit that damages cannot be more than GDP. A third participant underscored a couple of Dr. Anthoff's comments. He emphasized the importance of the tails of impacts (as opposed to means, medians) to policy makers. He highlighted the need for impact studies beyond 2100. He emphasized the small size of the IA community. He noted that a lot of the community's time is spent on discussing their work at meetings like this workshop, which limits time available to do the work. Dr. Rosenzweig expressed her hope that by expanding the community that is working on rigorously comparing models, they will be able to work with and help integrated assessment modelers by providing more rigorous estimates.

Closing Remarks

The workshop concluded with closing remarks from Dr. Rick Duke, Deputy Assistant Secretary for Climate Policy at DOE and Dr. Al McGartland, Director of the National Center for Environmental Economics at EPA.

Summary Comments by U.S. Department of Energy

First, Dr. Rick Duke, the DOE Deputy Assistant Secretary for Climate Policy, thanked the participants for attending, particularly those that braved the weather on Day 1. He expressed his appreciation of the great conversation between natural scientists and economists, noting that he was struck by Dr. Anthoff's desire to engage natural scientists to review economists' work on impacts.

Dr. Duke again noted that the workshop grew out of the interagency SCC work, which has since been used in rulemaking. He acknowledged that the SCC values have numerous limitations that need to be addressed, some beyond the scope of these workshops. He outlined a challenge to the community on two timescales: to help to make better regulatory decisions in the near-term and to promote research to improve assessment and valuation in the long-term.

Dr. Duke highlighted the need to evaluate the impacts of higher temperature outcomes, as well as median outcomes. He noted that climate policy is much like insurance policy -- a primary goal is to reduce the consequences of particularly unfavorable states of the world (e.g., high climate sensitivities) as well as to reduce expected losses. He emphasized the importance of evaluating the more significant outcomes given the major challenges in achieving planned mitigation.

He closed by thanking the presenters, the broader research community, and DOE's partner, EPA.

Summary Comments by U.S. Environmental Protection Agency

Finally, Dr. Al McGartland, Office Director for EPA's NCEE, extended both personal and EPA thanks to the participants for attending despite the inclement weather. He said that he intended to finish the conference with a ray of hope.

First, he noted that due to the field's interdisciplinary nature, everyone in the community must stretch to accommodate other groups. He emphasized that policy institutions have to stretch as well. Dr. McGartland noted that the SCC process was aimed at developing a set of numbers and asked if the right questions are being asked. He noted that the process is not aimed at legislation or the next Kyoto Protocol. Rather, the process seeks a shadow price so that EPA and DOE can incorporate the benefits of carbon reduction in any rule affecting carbon emissions.

Next, Dr. McGartland highlighted the significant progress that has been made in risk assessment since the work on particulate matter, lead, and pesticides in the 1980s. He suggested that simply duplicating the historic rate of progress in this area would be great. He noted that EPA's long-term strategy is dominated by regulatory work in areas where there are large net benefits.

Looking forward, Dr. McGartland highlighted a number of good points from the workshop. He emphasized the need to address interactions among sectors. Finally, he highlighted his commitment to move forward with the SCC using a transparent process.