50th Anniversary of the Global Carbon Dioxide Record
Symposium and Celebration
November 28-30, 2007
Kona, Hawaii

Summary Report

By

James Butler

NOAA Earth System Research Laboratory

325 Broadway
Boulder, CO 80305

303-497-6898

James.H.Butler@noaa.gov

Melinda Marquis

Cooperative Institute for Research in Environmental Sciences, University of Colorado
216 UCB
Boulder, CO 80309-0216

303-497-4487

Melinda.Marquis@noaa.gov

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Executive Summary

In the face of decades of increasing world demand for energy, scientists have made tremendous strides toward understanding and reducing uncertainty in key areas of climate change. They have not, however, made comparable progress in helping the public grasp the implications of these findings.

Those were among the highlights of the 50th anniversary of the Global CO_2 Record symposium and celebration, held from 28 to 30 November in Kona, Hawaii, near the Mauna Loa Observatory, where Charles David Keeling began measuring atmospheric carbon dioxide half a century ago.

In the keynote address, National Academy of Sciences President Ralph Cicerone emphasized the importance of long-term scientific measurements like those made by Dave Keeling. Referring to measurement of emerging systematic trends, Cicerone noted that this year's Arctic sea-ice minimum shattered the previous record, set in 2005, by 23 per cent and was substantially lower than models' projections.

He pointed out that the United Nations Framework Convention on Climate Change (1992) requires stabilization of greenhouse gases at a level below "dangerous" anthropogenic interference with the climate system. But, even as we watch atmospheric carbon dioxide climb and observe its effects, the term "dangerous" has yet to be characterized.

Expounding on the urgency of the potential climate changes and impacts, Richard Somerville, a contributor to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (Working Group 1), showed how IPCC's projections have not exaggerated climate change and may even have underestimated future changes.

Avoiding high risk scenarios would require limiting the increase in global average temperature to 2 ºC over that of pre-industrial time – doing this would require reducing global greenhouse gas emissions by at least 50 per cent below their 1990 levels by the year 2050, Somerville said.

Bruce Braine, vice president for strategic policy analysis at American Electric Power (the largest US supplier of energy), pointed out that achieving targets like zero-carbon-emissions is aggressive, but potentially feasible.

Rising to meet the challenges of increasing energy demands in a changing climate, Rob Socolow illustrated that we can fulfill the world's energy needs for the next 50 years using only existing technologies and—importantly—avoid a doubling of carbon dioxide levels compared to its pre-industrial level (*Science* ,13 August 2004, Vol. 305).

Chuck Kutscher of the National Renewable Energy Laboratory demonstrated how the USA could cut its carbon emissions by 70 per cent by the year 2030. Julio Friedmann of

Lawrence Livermore National Laboratory described the utility of carbon capture and storage (CCS) technology, noting that the major obstacle is scaling up existing technology.

Michael Walsh, executive vice president of the Chicago Climate Exchange, said society needs to pursue “every possible mitigation” strategy, and said society’s leaders need to get good information “out there.”

As Cicerone argued, climate change is “not just for scientists” anymore. The implications of climate change are broader than the natural environment. They are projected to affect multiple levels of society, the world’s economies, the status of the world’s poorest people, and the struggle for control of finite resources.

Throughout the event, the role of scientists— not only as researchers but also as communicators of current scholarship on and understanding of climate science—resurfaced. Tony Haymet, director of Scripps Institution of Oceanography, closed the conference and challenged participants to redouble their efforts to inform the public. To spread the word about the urgent need to confront climate change, he urged participants to talk to two groups with whom they would normally not talk, to emphasize how serious the projected climate changes are, and explain the clearly attainable options for adaptation and mitigation.

Full report
Presentations, transcripts, and posters are available on the Conference Website.

Jim Butler[1] and Melinda Marquis[2]

[1]NOAA Earth System Research Laboratory
[2]Cooperative Institute for Research in Environmental Sciences, University of Colorado

Meeting Agenda

Nov. 28 – Wednesday [MC=Spinrad]
7:30-8:30 Coffee
8:30-9:30 **Welcoming Remarks** ***Dr. Richard W. Spinrad,* Asst. Admin., NOAA, Oceanic and Atmospheric Research** ***The Hon. Daniel K. Inouye*, Senator, Hawaii** ***Dr. Ken Melville*, Deputy Director for Research, Scripps Institution of Oceanography** ***Mr. Timothy R.E. Keeney*, Deputy Assistant Secretary for Oceans and Atmosphere, NOAA** ***Dr. Len Barrie*, Director, WMO Atmospheric Research and Environment Programme**
9:30-10:15 **Keynote Speaker** *Speaker:* ***Dr. Ralph J. Cicerone*** *President, National Academy of Sciences*
10:15-10:45 Posters-Break
10:45-12:00 **What We've Learned from the CO_2 Measurement Record** *Session Co-Chairs:* ***Prof. Ralph F. Keeling,*** *Scripps Institution of Oceanography* ***Dr. Pieter P. Tans,*** *Senior Scientist, NOAA Earth System Research Laboratory* *Speaker: Martin Heimann, Director, Max Planck Institute for Biogeochemistry* **Mini-Panel [Moderated by Spinrad; 15 mins]**
12:00-1:15 Lunch
1:15-2:30 **Assessing Impacts and Urgency** *Session Introduction by:* ***Dr. Alexander E. MacDonald, Director,*** *NOAA Earth System Research Laboratory* **[** *Speakers:* ***Dr. Richard Somerville*** *Distinguished Professor Emeritus, Scripps Institution of Oceanography* ***VADM Paul Gaffney,*** *Military Advisory Board, National Security and the Threat of Climate Change* **Mini-Panel [Moderated by MacDonald; ~15 minutes]**
2:30-3:15 Posters – Break
3:15-4:45 **Business Challenges, Opportunities & Risks** *Session Introduction by:* ***Mr. Fredrick D. Palmer****, Sr. Vice President for Governmental Relations, Peabody Energy* *Speakers:* ***Ms. Helen Howes,*** *Vice-President, Environmental Health & Safety, Exelon Corp.* ***Mr. Bruce Braine,*** *Vice-President, Strategic Policy Analysis, American Electric Power* ***Mini-Panel [Moderated by Palmer; 20 min.]***
4:45-5:30 **Climate Change Mitigation under Strong Carbon Constraints** *Speaker:* ***Prof. Robert H. Socolow,*** *Co-Director, Carbon Mitigation Initiative, Princeton Environmental Institute, Princeton University*

7:00 Dinner ***Prof. Ralph F. Keeling*** ***Forrest Mims***

7:00 a.m. – 8:15 a.m. Congressional Staff – NOAA Meeting *7:30-8:30 Coffee*
8:30-10:00 **Terrestrial Impacts, Feedbacks & Human Adaptation** **[20 min ea.]** *Session Chair:* ***Prof. Christopher B. Field,*** *Director, Dept. Global Ecology, Carnegie Institution, Stanford University* *Overview Speaker: Paul Kirshen, Tufts University* *Topic Speaker 1: Ted Schuur ,University of Florida* *Topic Speaker 2: David Lobell, Lawrence Livermore National Laboratory*
10:00-10:45 Posters – Break **[45min]**
10:45-12:15 **Ocean Impacts, Feedbacks & Human Adaptation** **[25 min ea.]** *Session Chair:* ***Dr. Richard A. Feely,*** *Supervisory Oceanographer, NOAA Pacific Marine Environment Laboratory* *Speaker: Dr. Scott Doney, Woods Hole Oceanographic Institution* *Speaker : Dr. Victoria Fabry, California State University, San Marcos* **Mini-Panel [15 mins]** *Session speakers and Dr. Rik Wanninkhof,* *Atlantic Oceanographic and Meteorological Laboratory (AOML)*
12:15-1:30 Lunch
1:30-2:15 **The Paleocene-Eocene Thermal Maximum: An Analog for the Future?** **[45 min]** Speaker: ***Prof. James E. Zachos***, *University of California, Santa Cruz*
2:15-3:30 **Panel Discussion: Ecosystem Impacts, Feedbacks & Human Adaptation** **[75 min]** *Moderator:* ***Prof. Edward L. Miles,*** *University of Washington* *Panelists:* *Dr. Richard A. Feely,* *Supervisory Oceanographer, NOAA Pacific Marine Environment Laboratory* *Dr. Scott Doney,* *Woods Hole Oceanographic Institution* *Dr. Victoria Fabry,* *California State University, San Marcos* *Dr. Christopher B. Field,* *Director, Dept. Global Ecology, Carnegie Institution, Stanford University* *Dr. Paul Kirshen, Tufts University* *Dr. Ted Schuur ,University of Florida* *Dr. David Lobell, Lawrence Livermore National Laboratory*
3:30-4:30 Posters – Break **[60 min]**
4:30-5:30 **A Climate Success Story –Reversing Ozone Depletion** **[60 min]** *Speaker:* ***Dr. Susan Solomon,*** *NOAA Earth System Research Laboratory & Co-Chair, IPCC Working Group I*
7:00 LUAU with Sam Choy

Nov. 30 - Friday [MC=Walsh]

7:30-8:30 Coffee

8:30-10:00 **Mitigation Options: Part I**

Intro by:
Prof. Robert H. Socolow, [10 min]
Co-Director, Carbon Mitigation Initiative, Princeton Environmental Institute, Princeton University

*Speaker: Chuck Kutscher, National Renewable Energy Laboratory **[30 min]***

Speaker: Julio Friedmann, Carbon Management Program Leader
Energy & Environmental Directorate
Lawrence Livermore National Laboratory

10:00-10:30 Posters – Break

10:30-11:30 **Mitigation Options: Part 2 Environmental Impacts of Mitigation Solutions**

Intro by:
Prof. Robert H. Socolow

Speaker: Dr. David Keith, Director, ISEEE Energy and Environmental Systems Group, University of Calgary
Speaker : Dave Karl, University of Hawaii

11:30-12:30 **Panel Discussion: Regional Efforts**

Panel Moderator/Session Chair:
Hon. Fran Pavley,
Co-Author of CA's A.B. 32

Speaker : Joanne Morin, Manager, Climate and Energy Programs for the Air Division of the New Hampshire Department of Environmental Services; representing the Regional Greenhouse Gas Initiative
Speaker : David Van't Hof, Sustainability Advisor to Oregon Gov. Kulongoski; representing the Western Governors' Association
Speaker: Hon. Fran Pavley

12:30-1:45 Lunch

1:45-2:30 **Economic Tools & Financial Incentives**

Introduction by:
***Dr. James Butler**, Deputy Director, Global Monitoring Division, NOAA Earth System Research Laboratory*
Speaker:
Dr. Michael J. Walsh,
Executive Vice President, Chicago Climate Exchange

2:30-3:00 Posters – Break

3:00-3:45 **Future Measurements & Research**
Speaker:
Asst.Prof. Wouter Peters,
Wageningen Research University, Netherlands

3:45-5:00 **Panel Discussion: New Research for a Committed World**
Moderator:
***Prof. Ray F. Weiss**, Associate Dean, Scripps Institution of Oceanography*
Panelists:
Dr. Ralph J. Cicerone
President, National Academy of Sciences
Dr. Susan Solomon,
NOAA Earth System Research Laboratory & Co-Chair, IPCC Working Group I
Dr. Pieter P. Tans,
Senior Scientist, NOAA Earth System Research Laboratory
Ms. Joanne Morin
Regional Greenhouse Gas Initiative
Dr. Inez Fung,
Co-Director, Berkeley Institute of the Environment, University of California
Mr. Bruce Braine,
Vice-President, Strategic Policy Analysis, American Electric Power

5:00-5:30 **Concluding Remarks**
***Dr. Alexander E. MacDonald, Director**, NOAA Earth System Research Laboratory*

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Dr. Michael J. Walsh,
Executive Vice President, Chicago Climate Exchange
***Dr. A.D.J. (Tony) Haymet**, Director, Scripps Institution of Oceanography*

Summary Report

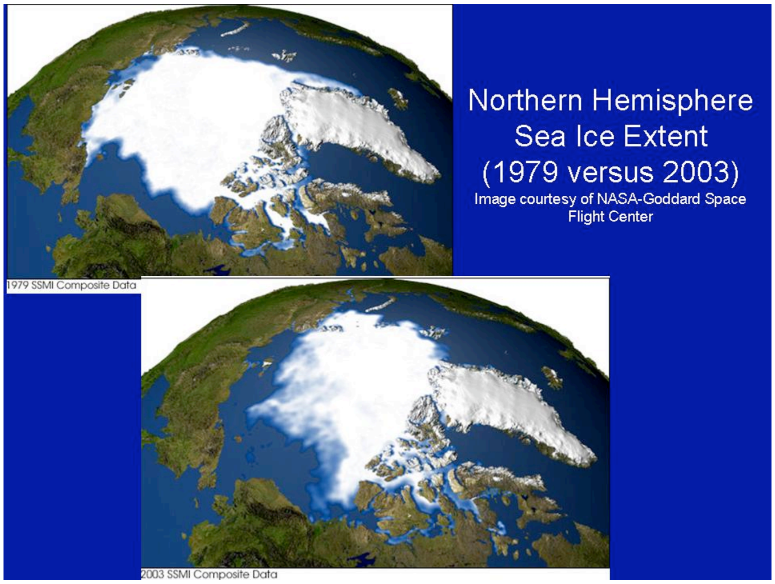
Fiftieth Anniversary of the Global CO_2 Record -- A Symposium Looks to the Future

In the face of decades of increasing world demand for energy, scientists have made tremendous strides toward understanding and reducing uncertainty in key areas of climate change. They have not, however, made comparable progress in helping the public grasp the implications of these findings. Earth's inhabitants face a global environmental crisis that is projected to include increased land and water temperatures, rising sea levels, changing precipitation patterns, increased extreme weather events such heat waves, acidification of oceans, and resultant loss of species. Any one of these could be ruinous; in combination, they could be calamitous, disrupting ecosystems, economies and even, as the Nobel Committee just recognized, world peace. Key strategies and technologies to curtail anthropogenic climate change are available, but must be widely implemented now if dramatic climate change is to be avoided.

Those were among the highlights of the 50th Anniversary of the Global CO_2 Record Symposium and Celebration, held Nov. 28-30 in Kona, Hawaii, near the Mauna Loa Observatory, where Charles David Keeling began measuring atmospheric CO_2 a half-century ago. Attended by leading climate scientists, business executives from major energy-related industries, federal and state agency representatives, and congressional staff, the conference focused on several themes – the evidence before us, the sense of urgency surrounding the issues, and challenges and opportunities ahead. Although the conference was also a celebration and recognition of this critical long-term record and its continuing value to society, the discussions moved quickly to what it meant, what its consequences were, and what it held for society facing an uncertain future.

Leaders of the National Oceanic and Atmospheric Administration, Scripps Institution of Oceanography, and the World Meteorological Organization opened the conference with reference to the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) statements that warming of the climate is unequivocal, that most of the observed increase in global average temperatures since the mid-20th century is very likely due to human emission of greenhouse gases (GHGs), and that CO_2 is the most important among them.

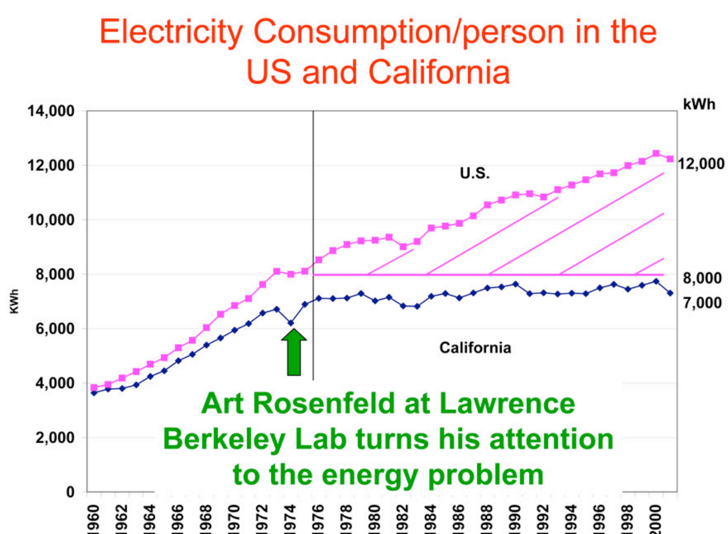
In the opening keynote, National Academy of Sciences President Ralph Cicerone emphasized the importance of long-term scientific measurements like those made by Dave Keeling. Referring to measurement of emerging systematic trends, Cicerone noted that this year's Arctic sea-ice minimum shattered the previous record, set in 2005, by 23% and was substantially lower than models' projections.



Slide from Ralph Cicerone's presentation.

He similarly explained the robust nature of measurements necessary to capture the steady erosion of ice in Greenland. Cicerone, however, spoke to more than just records, noting that lessons learned from records can require subsequent actions.

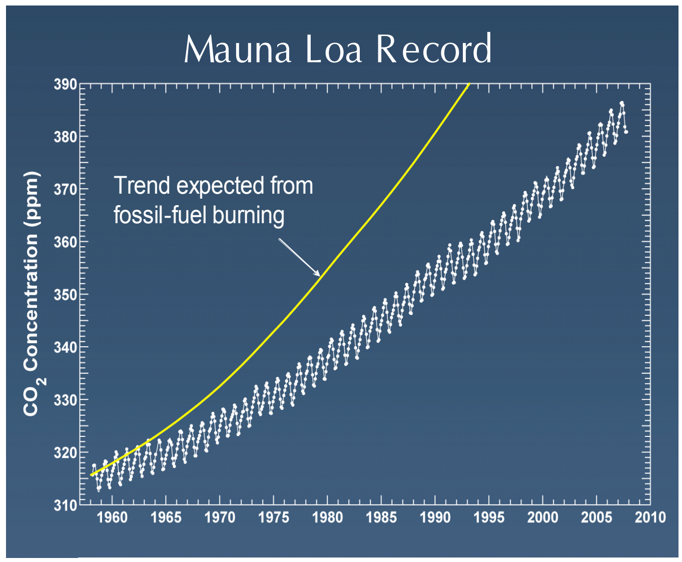
Cicerone cited the electricity usage per capita in California compared to that of the rest of the U.S. In California, per capita usage hasn't grown in the last 30 years, whereas it has grown substantially in the rest of the country. One reason for this difference and the successful stabilization of per capita electricity usage in California is that California introduced a an electricity pricing structure that charges people more for electricity at the hours of peak usage, and so people have adapted to use some of their electricity during non-peak hours. Further, in the 1970s, the biggest usage of electricity in most households came from the refrigerator. So California required better insulation in refrigerators. Even though customers have demanded larger refrigerators, which require more electricity to run, this effect has been counteracted by increased insulation. Now, the largest usage of electricity in most households is "vampire" usage – loss of electricity in appliances and lights in stand-by mode.



Slide from Ralph Cicerone's presentation.

He pointed out that the United Nations Framework Convention on Climate Change (1992) requires stabilization of GHGs at a level below which "dangerous" anthropogenic interference with the climate system is avoided. But even as we watch atmospheric CO_2 climb and observe its effects, the term "dangerous" has yet to be characterized. Cicerone closed by asking how and by whom "dangerous" should be defined.

The value of long-term continuous records was underscored in later presentations from Ralph Keeling of Scripps, Pieter Tans of NOAA Earth System Research Laboratory (ESRL), and Martin Heimann of Max Planck Institute for Biogeochemistry. Keeling noted that the high quality of the CO_2 record has depended on the intimate involvement of scientists and on the redundancy of measurements taken.



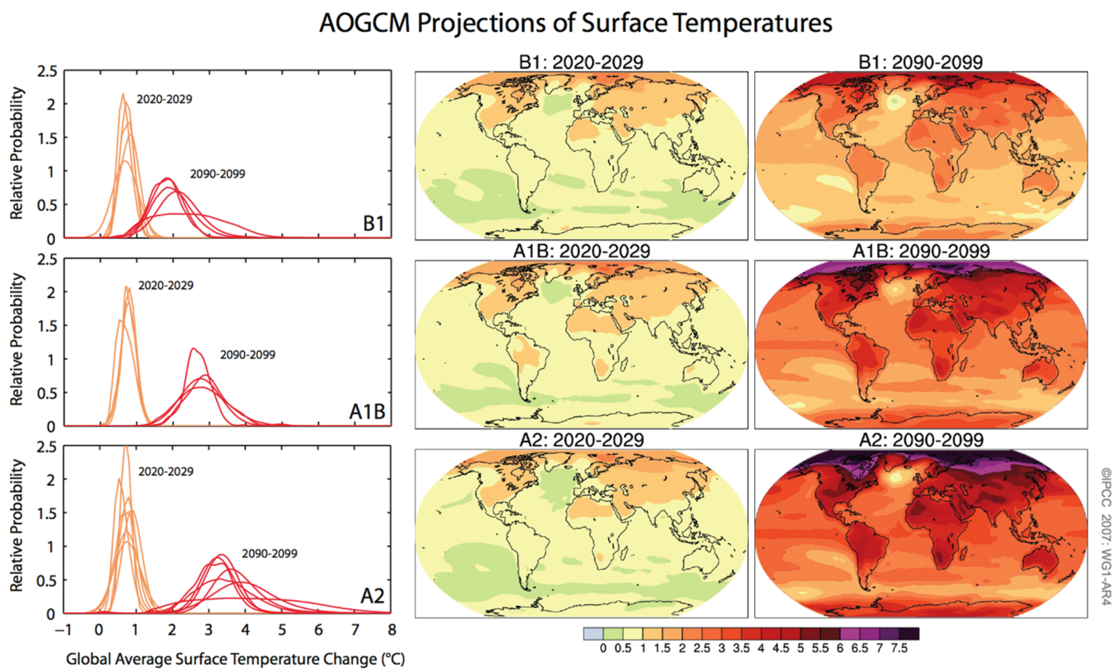
Slide from Ralph Keeling's presentation.

Tans discussed the use of carbon isotopic ratios to determine sources of carbon, and concluded that the "observed increase in atmospheric CO_2 since pre-industrial times is *entirely* due to human activities – not mostly – but entirely." Heimann the climate feedbacks on the global carbon cycle. Heimann explained that, unfortunately, present records do not provide enough information for quantification or validation of non-linear dynamics, and that because current models still yield quite different results, we know that our understanding of climate processes is inadequate. However, based on a range of C^4MIP models, on a 100-year time scale, he estimates carbon cycle feedbacks to be positive, and yielding an increase on the order of a 20%.

A Sense of Urgency

Introducing a session addressing impacts and urgency of this issue, Alexander MacDonald, director of the NOAA ESRL, explained that evidence suggests that Earth's climate system has the potential for large increases in global temperature for CO_2 doubling, and that by reducing uncertainties in climate feedbacks, we can determine the likelihood of very large temperature increases. These feedbacks include those caused by ice-albedo, water vapor, carbon release from permafrost thawing at high latitudes, and clouds.

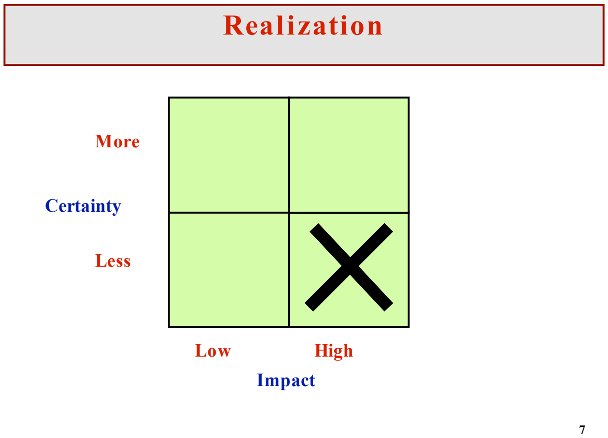
Expounding on the urgency of the potential climate changes and impacts, Richard Somerville, an author of the IPCC AR4 Working Group 1 (WG1), showed how IPCC's projections have not exaggerated climate change and may even have underestimated future changes.



Slide from Richard Somerville's presentation. Figure SPM-6 from the IPCC Working Group 1 Summary for Policy Makers (2007). Projected temperature changes for the early and late 21st century relative to the period 1980-1999. The central and right panels show the AOGCM multi-model average projections for the B1 (top), A1B (middle), and A2 (bottom) SRES scenarios averaged over the decades 2020-2029 (center) and 2090-2099 9right). The left panels show corresponding uncertainties as the relative probabilities of estimated global average warming from several different AOGCM and Earth System Model of Intermediate Complexity studies for the same periods. Some studies present results only for a subset of the SRES scenarios, or for various model versions. There the difference in the number of curves shown in the left-hand panels is due only to differences in the availability of results.

Avoiding high risk scenarios would require limiting the increase in global average temperature to 2 ºC over that of pre-industrial time – doing this would require reducing global GHG emissions by at least 50% below their 1990 levels by the year 2050. Somerville felt that GHG concentrations must be stabilized well below 450 ppm quickly on a large scale because the current value of 383 ppm is increasing at ~ 2 ppm per year, a rate that, unmitigated, could skyrocket as developing countries industrialize. To stay below a 2 ºC increase, global GHG emissions must peak and decline in the next 10 to 15 years. Somerville was one of 200 climate scientists from around the world who issued a declaration to this effect on Dec. 6, urging politicians at the United Nations Climate Change Conference in Bali to agree to meaningful emissions reductions targets (Nature, 6 December 2007, doi:10.1038/news.2007.361).

Taking a different tack to the pressing need to slow climate change was retired Vice Admiral Paul Gaffney, coauthor of the recently published report "National Security and the Threat of Climate Change." The report written, with the CAN Corporation, by 11 retired staff generals and admirals, concluded that projected climate changes pose a serious threat, but that while certainty of particular changes may be low, the potential impacts are high.

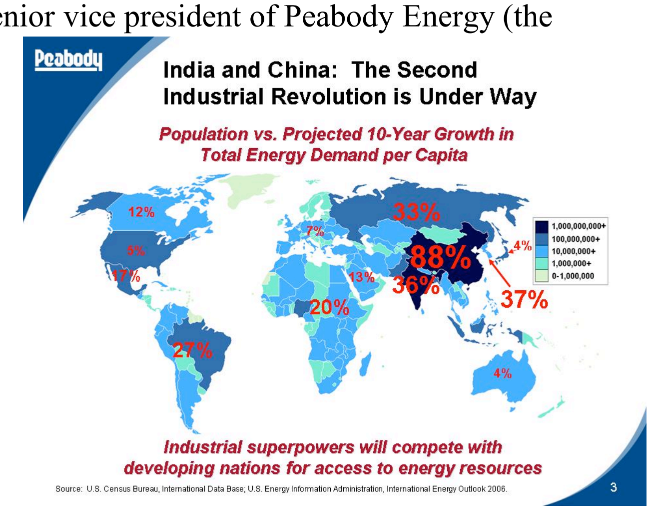


Slide from Paul Gaffney's presentation. Impacts of climate change involve some uncertainty but serious consequences.

Reminding the audience that risk can be thought of as the product of probability and consequences, Gaffney pointed out that a commander in the field who waits for 100% certainty before taking action is doomed to fail. The threat of climate change to global security, he noted, is exacerbated by political volatility in many potentially impacted regions. Mentioning that climate change, security, and energy dependence are inter-related, Gaffney underscored the report's findings that climate-change trends must become part of national-security planning. He strongly advocated harnessing the talent and capabilities of the national security communities as we strive to understand, monitor and predict climate change.

Challenges, Opportunities, and Investment Risks

Representatives of three of the largest businesses from the U.S. energy sector spoke of a huge and rapidly increasing world-wide demand for energy that is unlikely to slow down in the foreseeable future. Fred Palmer, a senior vice president of Peabody Energy (the world's largest private-sector coal company), while alerting us to size of this challenge, noted that any plan put forward must be workable and must consider this demand – that ignoring key energy sectors or current trends in energy use could doom CO_2 reductions to failure.

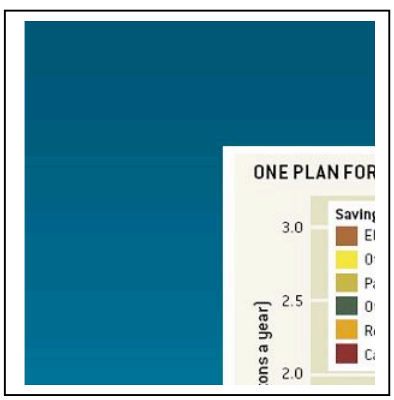


Slide from Fred Palmer's presentation.

Bruce Braine, vice president for strategic policy analysis at American Electric Power (the largest US supplier of energy), pointed out that achieving targets like zero-carbon-emissions is aggressive, but potentially feasible. He suggested that reasonable carbon controls should be comprehensive, cost-effective, realistic, verifiable, and open to new technology. He also cautioned that adjustments to any policy will likely be made as time passes and progress is evaluated.

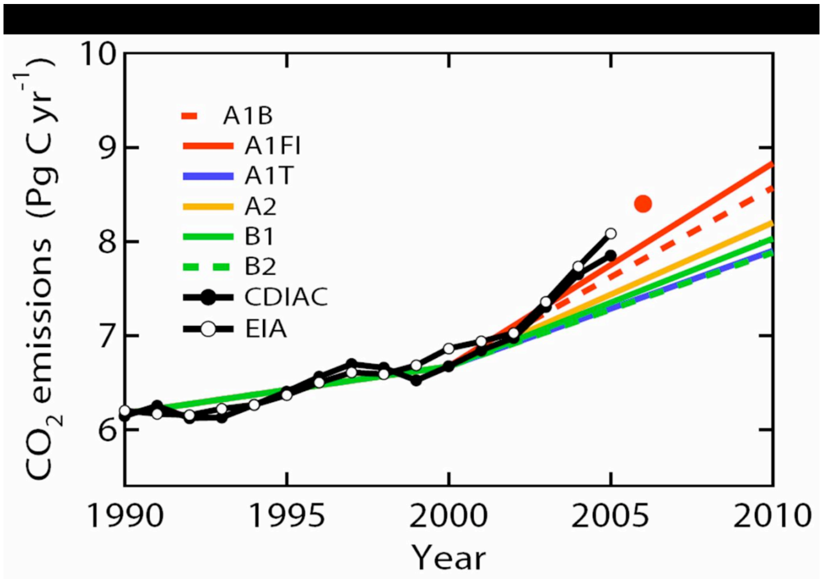
Helen Howes, vice president of environmental health and safety for Exelon Corp., one of the largest U.S. utility providers, illustrated that it takes ~ 14 years to go through the complex, multi-step process of deciding (~ 8 yrs) and then building (~ 6 yrs) a nuclear power plant. Exelon obtains 92% of its electricity from nuclear power – a mitigation option that is looking increasingly desirable in the list of GHG-reduction strategies. Exelon's CO_2 generation emissions were the lowest of the nation's top 10 electric generation companies. The cost of building a nuclear power plant is comparable to building a coal plant equipped with IGCC-CCS technology.

Rising to meet the challenges of increasing energy demands in a changing climate, Rob Socolow illustrated that we can fulfill the world's energy needs for the next 50 years using only existing technologies and — importantly — avoid a doubling of CO_2 levels compared to its pre-industrial level (13 August 2004 Vol. 305 Science). Socolow's metaphor of stabilization "wedges" helps non-experts follow the math of mitigation. A "wedge" is a strategy to reduce carbon emissions in 50 years by 4 $GtCO_2$/yr. One wedge could come from increasing fuel efficiency of cars. For example, because one car driven 10,000 miles at 30 mpg emits 4 tons of CO_2, if two billion cars were driven 10,000 miles per year at 60 m.p.g. instead of 30 m.p.g., one wedge would be achieved. Other wedges can be obtained from carbon capture and storage techniques, and wind, solar, nuclear and other renewable energy applications. We all have our favored approaches, he said, but, to make this work, all "must be prepared to negotiate with others who have different favorites."



Environmental Impacts and Consequences

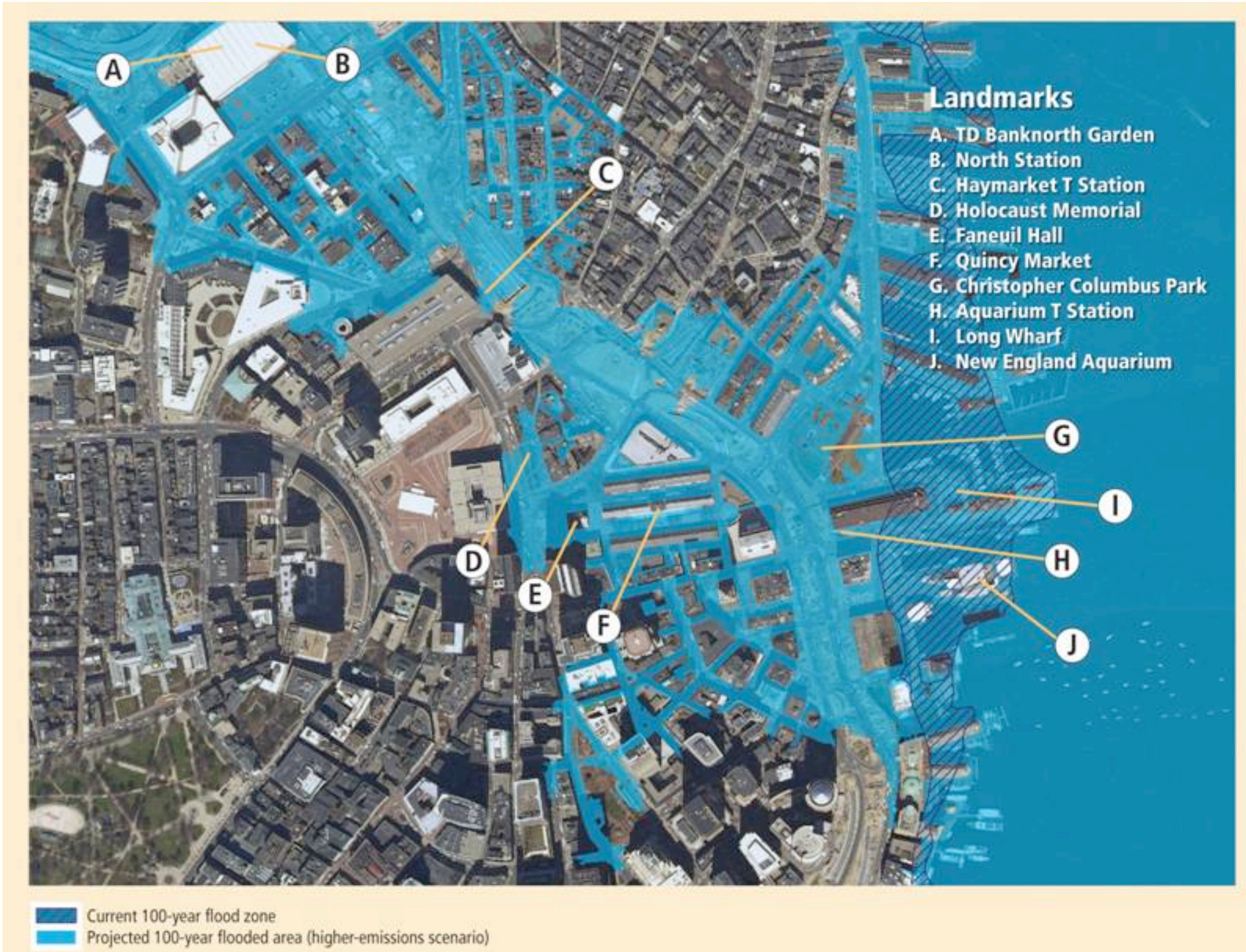
Opening the day of discussions on impacts, Chris Field of the Carnegie Institution at Stanford University, and an author of the chapter on North America of the IPCC AR4 WG2 report, made it clear that the wide-ranging effects of climate change are now clearly documented, with risks from future impacts associated with extreme events. Noting that CO_2 emissions of the last few years already exceed all six of the IPCC emission scenarios, he expressed concern about the lag time between now and when policy development and implementation and technology development and distribution can be achieved.



Slide from Chris Field's presentation. Concentration of atmospheric CO2 according to projections of six SRES scenarios, the observed values from the Carbon Dioxide Information Analysis Center (of the U.S. Department of Energy) and from the Energy Information Administration (official energy statistics of the U.S. Government), and the observed value for 2006 (red dot). Recent observations values exceed projected values from all six SRES scenarios.

If society doesn't accelerate what's expected to take several decades, he said, "human system inertia," coupled with "land and ocean system inertia" could drag on so long that climate feedbacks quicken the changes.

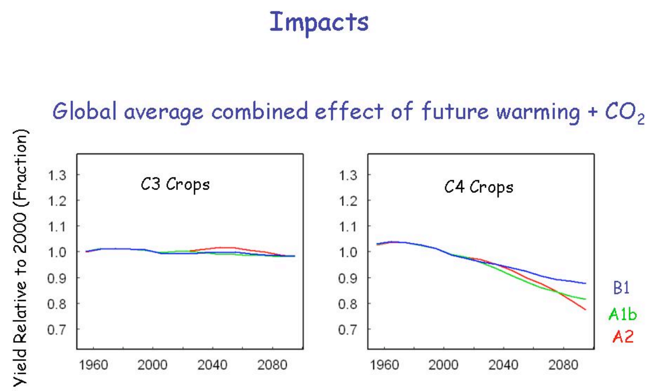
Sea-level rise and coastal flooding were made tangible by Paul Kirshen of Tufts University, who, citing a recent analysis (Rahmsdorf, S. et al. 2007) that projects much greater end-of-century sea-level rise than stated in the IPCC assessments, showed areas of Boston and New York City vulnerable to flooding. In 2050, the maximum elevation of NYC's 100-year flood could easily reach almost 10 feet. He added that building sea walls may be expensive, but doing nothing was far more so.



Slide from Paul Kirshen's presentation. This image shows the current Federal Emergency Management Agency (FEMA) 100-year flood zone (hatched darker blue) as well as the extent of the projected 100-year flood zone in 2100 (lighter blue) under the higher-emissions scenario for the waterfront/Government Center area of Boston. Important Boston landmarks (such as Faneuil Hall) and transportation infrastructure currently not at great risk of flooding could witness repeated flooding in the future unless protected from such events. Flood elevations under the lower-emissions scenario are roughly half a foot lower than the flooding depicted here (but still 1.5 feet higher than the current 100-year flood).

The sobering impacts of climate change on the world's food supply were described by David Lobell of Lawrence Livermore National Laboratory. Lobell delivered the message that, although there could be some near-term benefit to some crops from increasing CO_2 fertilization, these would quickly be wiped out as other climate-change effects took over. Two opposing factors will affect agricultural crops: While (increased) CO_2 availability leads to increased growth and yield in C3 crops like soybeans and wheat and in C4 crops like maize, sorghum and sugarcane (Long et al. 2006, *Science*), warming reduces C4 crops in most regions (Lobell and Field, 2007, *ERL*). The combined effects of increased CO_2 and temperature appear to cancel each other in C3 crops, but substantially reduce growth and yield of C4 crops. Rising CO_2 provides some benefits for agriculture, but the global negative effects of climate changes are likely to outweigh these after ~550 ppm (~2 °C increase, which should occur mid-century).

Reflecting some of the security concerns mentioned by Gaffney on the first day, he pointed out specific, highly probable, regional impacts on already stressed parts of the world, most notably Africa. Further, he noted, crop expansion in response to increased demand for bio-fuels could exacerbate climate change through land-use modification, not to mention added stresses to soils and water supplies.

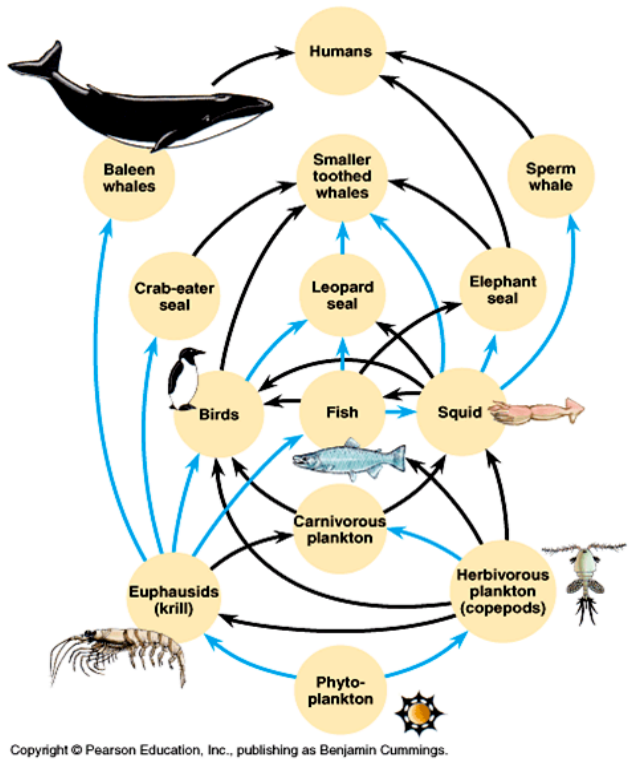


Slide from David Lobell's presentation. The combined effects of increased atmospheric CO2 and temperature increases of > 2 °C.

Ted Schuur of the University of Florida explained that the amount of CO_2 that could be released from thawing permafrost is large (3,483 Pg CO_2 in permafrost, compared to 2,383 Pg CO_2 sequestered in vegetation or 800 Pg CO_2 already added to the atmosphere through human activities). Because permafrost is sensitive to changes in temperature, rapid (decadal scale) destabilization of these pools is possible given threshold dynamics. If large quantities of CO_2 were released rapidly from melting permafrost, the effects could swamp further human emissions. The dangers of this kind of an event leading ultimately to catastrophic warming were outlined by James Zachos, who discussed the cascading runaway preceding the Paleocene-Eocene thermal maximum (~55 Ma).

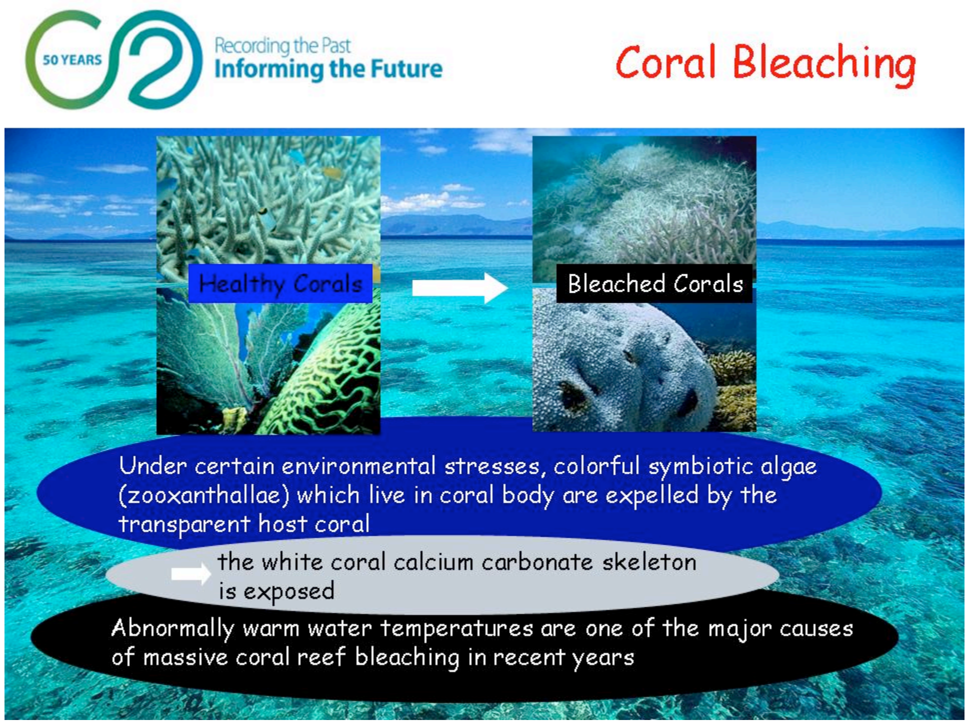
Current and anticipated oceanic impacts were particularly alarming, as those associated with acidification cannot be mitigated without halting the emission of CO_2 into the atmosphere. Warming and sea-level rise only exacerbate these stresses. Richard Feely of NOAA's Pacific Marine National Laboratory pointed out that eighty percent of excess heat caused by anthropogenic GHGs is in the oceans, and reminded the audience that, while ~ 25% of the annual anthropogenic CO_2 emissions are stored in the ocean, its efficiency as a carbon sink has decreased ~16% in the last 50 years. Now, the oceans are 30% more acidic than they were two centuries ago, which has led to a 16% decrease in carbonate ion needed for the growth of corals and calcareous plankton. Following on this point, Scott Doney, of Woods Hole Oceanographic Institution, reported many believe that, to prevent undesirable or high-risk changes to the marine food web due to aragonite undersaturation, the pH value of near-surface waters should not drop more than 0.2 pH units below the pre-industrial value of 8.18 in any larger ocean region (nor in the global mean)" (WBGU Special Report; Caldeira et al. Geophys. Res. Lett., 2007). The U.S. EPA Quality Criteria for Water also calls for a smaller than 0.2 pH change and less than 500 ppm atm. It's already dropped 0.1 pH units. CO_2. Dr. Doney said that he is not certain if this goal to limit on the pH change in the ocean of 0.2 units is appropriate.

What was perhaps the most disconcerting evidence of these effects was presented by Victoria Fabry of California State University in San Marcos. Beginning with a discussion of the observed decrease in populations of krill in the Southern Ocean, driven apparently by decreased winter sea ice and its associated ice-algae near the Antarctic Western Peninsula, she described the potential cascading ecosystem impacts associated with the already observed burgeoning salp populations. Because of this shift in ecosystem composition (salp are very poor in nutritive value), the many animals that depend on krill as their food source, including whales, could suffer substantially.



Slide from Victoria Fabry's presentation. Krill are an important found source for many species, and their populations in the Southern Ocean are declining.

Fabry followed this discussion with examples of other observed stresses, including coral bleaching, which occurs whenever the waters reach 1°C above the maximum monthly mean for four or more weeks, loss of calcarious plankton, and reductions in recruitment of calcareous larvae.



Slide from Victoria Fabry's presentation.

A panel discussion among these speakers, chaired by Dr. Ed Miles of the University of Washington, about the implications of setting emissions reduction targets, particularly in light of the greater-than-predicted growth in emissions in the last several years, led to questions about managing risk, reducing emissions quickly, providing financial incentives for cutting emissions, and revising building codes and designing infrastructures for future climate instead of current and past climate. When Dr. Miles asked how societies could manage adaptation for both terrestrial and oceanic ecosystems and human social systems to reverse or halt movement toward thresholds of change, Dr. Kirshen said that although "adaptation" has been considered a last resort and that societies should choose to implement mitigation efforts strongly enough to halt climate change, we must now admit that adaptation is necessary. Dr. Field and Dr. Lobell agreed that societies will have to prioritize their adaptation options. Dr. Lobell reminded the audience that safeguarding the world's food supply requires a sustained, large capital investment, and that the rewards (e.g., heat-tolerant plant species) will take years to develop. Dr. Doney said that ocean acidification should be considered by fisheries when they draft plans, and Dr. Feely suggested looking toward new technologies, e.g., electrolysis of sea water, as means to reduce impacts of GHG emissions. When asked to comment on how much time do we have to act and what is to be done, Dr. Feely stated that while a clearer understanding of the processes affecting ocean pH is needed, "we need to work in the next ten years to stabilize atmospheric CO_2 below about 500 ppm. If we exceed this threshold, it could be a serious problem." Dr. Doney said, "We know we're committed to increased temperatures, acidification and increased sea levels. If you combine this with a time lag, I'm worried about waiting for then years before we take action. What's the cost of not acting now? We should decide now. What's the lowhanging fruit? We need to have done this five years ago." Dr. Fabry spoke of thresholds. Besides a few coccolithophore species, other studied species are harmed by increased CO_2 levels. Limiting the increase of pH in the ocean to 0.2 units may give a false sense of security. There could be other impacts we've not detected yet. We probably need to stabilize emissions at or below 500 ppm. We should have started to work on this already.

Dr. Lobell said that we're committed to climate for the next 50 years. Regarding agriculture, he said that we must ask ourselves how much we care about other regions, for instance southern Africa. If we care a lot, we much implement adaptation and mitigation strategies quickly because developing new agricultural technologies takes a lot of time. Dr. Field said that we can't identify what is dangerous and what isn't. We don't want the public to despair if we set a certain emissions target and fail to meet it. It would be better to stabilize at 500 ppm than at 550 ppm, and better at 550 ppm than at 600 ppm, etc. Dr. Kirshen said that we must get the public involved. We must inform the public. Dr. Schuur said that people respond to dollar amounts associated with matters. We should explain the dollar amounts associated with sea-level rise and with ocean acidification. Dr. Miles asked what additional and/or revised approaches to carbon cycle measurement are implied in the questions posed earlier. Dr. Feely said that we've focused CO_2 in the oceans. We need to measure two components of the carbon system in the ocean: one should be CO_2 and the other should be either alkalinity or dissolved inorganic carbon. Dr. Doney suggested that applied science should be funded. Dr. Fabry said that a global, international network of observations, obtained via standardized protocols, is needed. Such standard protocols exist for some measurements, like CO_2 in ocean water, but not others, like biological calcification studies. We must invest in long-term monitoring and new technologies, too. Work with the business communities and provide them information they need. Dr. Lobell said that multi-factor analysis of agricultural crops is needed. Dr. Kirshen said that applied research should be funded now; should not just wait.

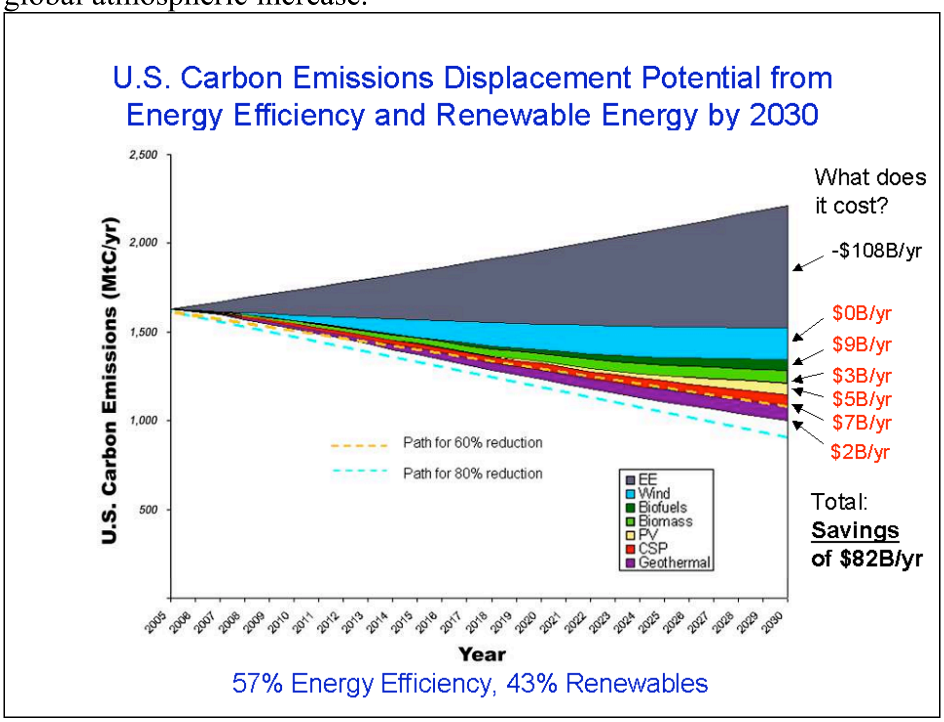
The panel then heard from the floor. Mr. Peter Williams of IBM said that future conferences about climate change should include psychologists and other social scientists because this isn't a physical science problem. This is a human behavior problem. Bernard Mendonza, a retired climate scientist, said that because scientists qualify their statements and acknowledge uncertainties about some things, the public distrusts the information provided by them. Dr. Field reminded the audience of the process by which IPCC assessment reports (the summaries for policymakers) are approved line by line and word by word, by even the most "skeptical" countries, and hence this demonstrates the veracity of the information in the IPCC reports. In a panel discussion of the combined terrestrial and marine impacts, Kirshen said that although "adaptation" has been considered a "dirty word," a last resort because societies should choose to implement mitigation efforts sufficient to halt climate change, humans must now admit that adaptation is necessary. Field and Lobell agreed. Emphasizing the urgency of the situation, Feely stated that while a clearer understanding of the processes affecting ocean pH is needed, "we need to work in the next ten years to stabilize atmospheric CO_2 below about 500 ppm. If we exceed this threshold, it could be a serious problem."

Defining a path forward and supporting an informed future

But it is not necessary to abandon all hope, many speakers said.

Susan Solomon of NOAA ESRL and Co-chair of IPCC AR4 WG1 ended the second day with a recent, global, environmental success story. The research documenting the catalytic destruction of stratospheric ozone by chlorinated fluorocarbons, she said, led to the successful global agreement that halted use and resultant release of these compounds to the atmosphere. Though the issue involved far fewer players than climate change currently does, it nevertheless describes a path that has roles for governments, businesses, and scientists – all of which were necessary to ensure success. The Montreal Protocol, initially an imperfect document, was amended several times after further research indicated that ozone-depleting substances needed to be limited more quickly than scientists and policy-makers had originally thought. Such global support illustrates the scale of cooperation needed to reduce GHG emissions.

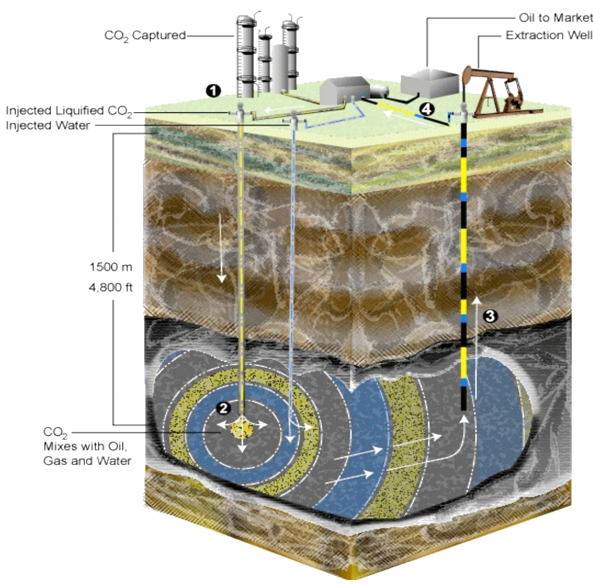
On the last day of the conference, Chuck Kutscher of the National Renewable Energy Laboratory demonstrated how the United States could cut its carbon emissions by 70% by the year 2030. The largest fraction of the emissions, over half of the 70% cut, would come from energy efficiency in buildings, transportation, and industry, which has the added benefit of yielding a savings of $108 billion per year. The remaining reduction would come from wind, biofuels, biomass, concentrated solar power, photovoltaics, and geothermal energy. A 70% reduction equals ~4,400 $MtCO_2$/yr, or 1/3 of the annual global atmospheric increase.



Slide from Chuck Kutscher's presentation. Energy efficiency (EE), along with various forms of renewable energy resources, provide multiple options for mitigations CO_2 emissions in the U.S.

Adding to Kutscher's message and resonating with some of the strategies posed by the industry participants, Julio Friedmann of Lawrence Livermore National Laboratory described the utility of CCS technology, noting, "CO_2 Capture & Sequestration (CCS) can provide 15-50% of global GHG reductions. We know enough to site a project, operate it, monitor it, and close it safely and effectively. We do not yet know enough for a full national or worldwide deployment." Friedmann cited the IPCC Special Report on Carbon Capture and Sequestration (2005), which describes several methods of purifying and capturing the CO_2 stream (post-combustion, pre-combustion, and modified-combustion [oxy-coal]) before storing it underground.

Friedmann noted that several CCS plants are operating already, including the Sleipner site that Statoil has been operating effectively off the coast of Norway since 1996. He also explained that Earth's crust is well configured to trap large CO_2 volumes indefinitely. Because of multiple storage mechanisms working at multiple

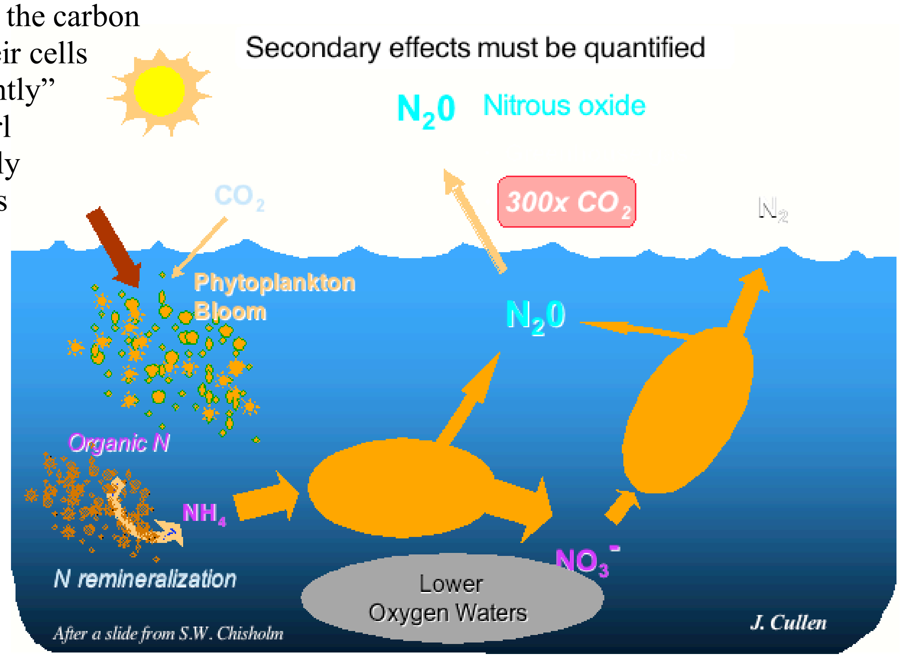


Slide from Julio Friedmann's presentation. This schematic illustrates a method for storing CO_2 under ground.

Time scales, the shallow crust should attenuate mobile free-phase CO_2 plumes, trap them residually, and ultimately dissolve them and form solid minerals. This means that over time, risk of leaks decreases.

After warning the audience that the usual reaction to the next idea was negative and emotional, David Keith of the University of Calgary brought up perhaps the most contentious alternatives of the day – those associated with geoengineering. Keith discussed modifying Earth's albedo, which would not be expected to change the concentration of CO_2 in the atmosphere, hence not helping the ocean acidification issue, but would be expected to decrease global mean temperatures. He discussed the strategy of adding sulfur to the stratosphere, because sulfuric aerosols provide a cooling effect due to their scattering of incoming solar radiation. Why would anyone ever be so cavalier as to entertain the possibility of interfering with the Earth's climate in a large-scale way with no idea of its widespread, unknown, unintended effects? Perhaps, Keith offered, because people have known of the danger of anthropogenic GHG emissions for decades, and yet have continued to emit GHGs as if they posed no danger. Keith argued that humans need a significant international research program to explore geoengineering, its impacts, methods and implications. Geoengineering should be treated as a means of managing the worst impacts of climate change, not as a substitute for emissions controls.

Dave Karl of the University of Hawaii discussed another geoengineering technique – enhancing the ocean's natural carbon pump, which comprises biological processes that transfer organic matter and associated elements to the deep ocean. This natural pump removes CO_2 from the atmosphere and ocean surface. One approach is to add iron to the oceans, to speed up removal of CO_2 from the surface of the ocean by algae that consume CO_2. Eventually the algae and the carbon they have incorporated into their cells are expected to sink "permanently" to the bottom of the ocean. Karl presented evidence that virtually all experiments showed blooms (increased growth) of algae, but that the exact stoichiometry of iron to carbon, as well as undesirable consequences (e.g., production of N_2O which is a powerful GHG), and the uncertainty of the impacts of iron fertilization lead him to be ambivalent about this approach.



Slide from David Karl's presentation. This slide illustrates the undesired production of N_2O upon iron fertilization of the ocean, as a way to store CO_2 under water.

Regional Efforts to Reduce GHG Emissions

The state of California has been leading the nation in efforts to mitigate climate change by reducing emissions of GHGs. Ms. Fran Pavley, who has served three terms in the California State Assembly, discussed a bill she authored: California's A.B. 1493 ("Fran's Clean Car Regulations" and the "Pavley Bill"), which instructs the California Air Resources Board (CARB) to adopt regulations that achieve the maximum feasible, cost-effective, and technologically achievable reductions of greenhouse-gas pollution emitted by new passenger vehicles. The CARB consulted with automobile engineers and determined that emissions from passenger vehicles could reasonably be reduced 30% by 2016. Several states, including Massachusetts and California, filed a lawsuit (Massachusetts et al. v. EPA, Case No. 05-1120), claiming that the U.S. Clean Air Act authorizes the E.P.A. to regulate CO_2 or other GHGs and so allows the E.P.A.'s to grant a waiver to California to set more stringent standards than those required by the federal government. The Supreme Court ruled that GHGs are "air pollutants" under the federal Clean Air Act and that the E.P.A. has the authority to set federal emissions standards. Pavley announced that during this conference, New Mexico just became the twelfth state to adopt the same standards as those of A.B. 1493. (*After the conference, on Dec. 19, the Bush administration announced that it would deny California's bid to set stricter vehicle emissions standards than federal law required. Administrator of the Environmental Protection Agency, Stephen Johnson, said he would deny the state's application for a waiver from federal law that California had been seeking for more than two years.)*

Pavley also discussed California's A.B. 32, the Global Warming Solutions Act of 2006, which requires that the state's GHG emissions be reduced to 1990 levels by 2020. Pavley said that she understands that such reductions will "not solve the problem; that we need to eventually accomplish an 80% reduction by 2050. But we thought that this was doable."

Ms. Joanne Morin, manager of Climate and Energy Programs for the Air Division of the New Hampshire Department of Environmental Services, emphasized the differences between her libertarian state and California. "When we propose legislation to the legislature, the biggest thing we are not supposed to do is use the "C" word, and that is proposing anything "California." Morin stressed the modest goals of the Regional Greenhouse Gas Initiative (RGGI). RGGI consists of a proposed "cap and trade" program for limiting carbon dioxide emissions from major electric power plants in 10 eastern states. A cap-and-trade program establishes an overall limit (or "cap") on CO_2 emissions, allocates some level of emissions to the emitting sources ("allowances," each of which represents the right to emit one ton of CO_2), and then lets the sources determine how to avoid exceeding the limit through reductions, trading and possibly offsets. A cap and trade program provides economic incentives for achieving emissions reductions. The total amount of allowances and credits cannot exceed the cap, limiting total emissions to that level. In order not to exceed the cap, a utility company could purchase credits from those who pollute less. An "offset" is an allowance that originates from outside the regulated area, e.g., outside the utility sector in the case of RGGI. This market-based solution was successful in cutting emissions of sulfur- and nitrogen-compounds that lead to production of acid rain.

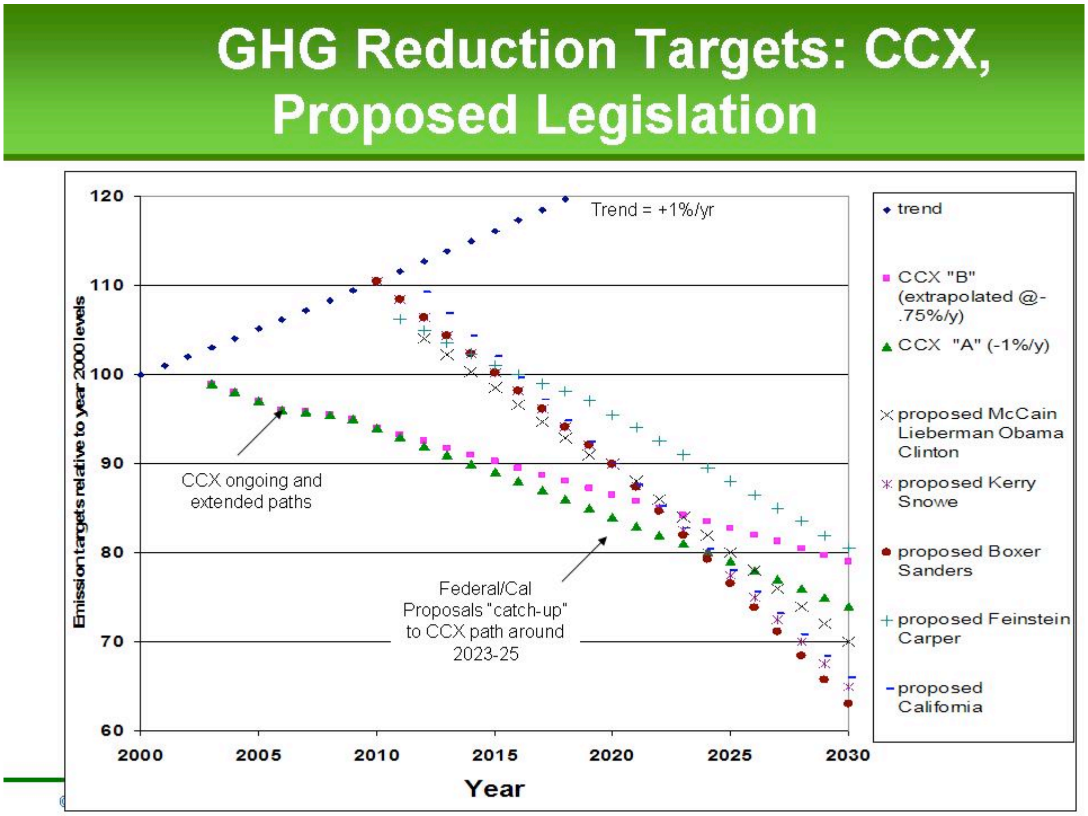
The RGGI participating states of Maine, New Hampshire, Vermont, Connecticut, New York, New Jersey, Delaware, Massachusetts, Maryland and Rhode Island aim to reduce emissions from utility companies in two phases: During 2009 to 2014, stabilization is the goal; during 2015 to 2018, a 10% reduction at a rate of 2.5% per year for four years. In 2012, a significant review will be held.

The Western Climate Initiative (WCI) is another cap and trade collaboration, which was launched in February 2007 by the governors of Arizona, California, New Mexico, Oregon and Washington to develop regional strategies to address climate change. The WCI is identifying, evaluating and implementing collective and cooperative ways to reduce GHG emissions. In the spring of 2007, the Governor of Utah and the Premiers of British Columbia and Manitoba joined the Initiative. Alaska, Colorado, Kansas, Wyoming, Nevada, Idaho, Quebec, Ontario, Saskatchewan, and Sonora have joined as observers. Mr. David Van't Hof, sustainability and renewable energy policy advisor to Oregon Governor Kulongoski, explained that the WCI partners have agreed to reduce GHG emissions in the WCI region to 15% below 2005 levels by 2020. They also have agreed to report their emissions via the Climate Registry. The WCI partners also acknowledged the need to do significantly more over the long run to reduce emissions. Van't Hof said that the WCI will focus its efforts in 2008 on developing its cap and trade program, and addressing issues such as whether "banking" or "borrowing" of allowances will be allowed; whether there will be a "safety valve" or "off ramp," which sets a ceiling on the price of allowances; a mechanism for tracking trade of allowances; standardization of emission measurement, reporting, and data collection; audits to ensure market confidence; and a method to identify leakage from sources outside the boundaries of the trading program.

Market-driven approaches to reduce GHG emissions by businesses are becoming more prevalent and appear to offer great potential – both for reducing emissions and for pecuniary benefits. Dr. Mike Walsh, executive vice-president of the Chicago Climate Exchange (CCX) described his company's approach and the benefits provided by other carbon-trading companies throughout the world. Begun in 2003, the CCX is the world's first and North America's only active voluntary, legally binding integrated trading system to reduce emissions of GHGs, with offset projects worldwide. Members of CCX are leaders in greenhouse gas (GHG) management and represent all sectors of the global economy, as well as public sector innovators. Reductions achieved through CCX are subject to verification by a third party.

CCX members are companies that make a voluntary but legally binding commitment to meet annual GHG emission reduction targets. Those who reduce below the targets have surplus allowances to sell or bank; those who emit above the targets comply by purchasing a CCX Carbon Financial Instrument® (CFI™) contracts. Each CFI contract represents 100 metric tons of CO_2 equivalent. CFI contracts are composed of Exchange Allowances and Exchange Offsets. Exchange Allowances are issued to emitting CCX members in accordance with their emission baseline and the CCS emission reduction schedule. In Phase I, CCX members committed to reduce emissions a minimum of 1% per year, for a total reduction of 4% below baseline (emissions in 2000). In Phase II, CCX members commit to a reduction schedule that requires year 2010 emission reductions of 6% below baseline at minimum.

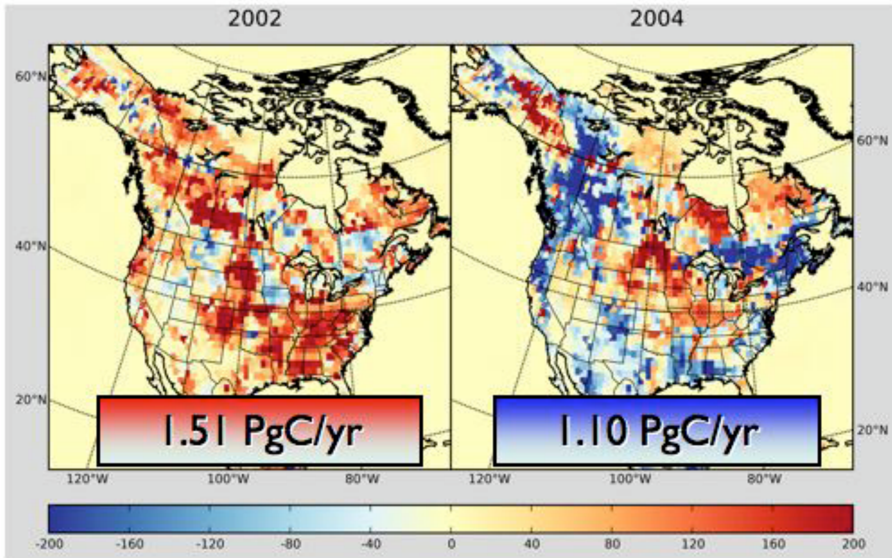
Walsh compared reduction targets of CCX members against targets of current proposed congressional legislation, showing that CCX targets provide for lower levels of emissions until ~2023, when some of the bills eventually catch up with and then surpass the CCX targets.



Slide from Mike Walsh's presentation.

In addition to lowering their GHG emissions, companies participating in such trading develop skills, institutions, and intellectual framework needed to manage GHG emissions cost-effectively, and contribute to the public discourse on managing the risks of climate change impacts.

Given that so many businesses, states and regions are committing to cutting their GHG emissions, a system to help determine the efficacy of such efforts is valuable. Wouter Peters, of Wageningen University and Research Center in The Netherlands and of NOAA ESRL, described "CarbonTracker," a system that calculates carbon dioxide uptake and release at the Earth's surface over time. CarbonTracker produces model predictions of atmospheric CO_2 mole fractions, to be compared with the observed atmospheric CO_2 mole fractions. The difference between them is attributed to differences in the sources and sinks used to make the prediction (the so-called 'first-guess') and the sources and sinks affecting the true atmospheric CO_2. Using numerical techniques, these differences are used to solve for a set of sources and sinks that most closely matches the observed CO_2 in the atmosphere. CarbonTracker has a representation of atmospheric transport based on weather forecasts, and modules representing air-sea exchange of CO_2, photosynthesis and respiration by the terrestrial biosphere, and release of CO_2 to the atmosphere by fires and combustion of fossil fuels.



Slide from Wouter Peters' presentation. The pattern of CO_2 exchange calculated in CarbonTracker. Negative fluxes (blue regions) indicate places where uptake of CO_2 occurs. Positive fluxes (red colors) indicate places where emissions of CO_2 occurs.

Optimism, Caution and a Challenge to the Audience

Near the end of the conference, Ray Weiss of the Scripps Institution of Oceanography, moderated a panel discussion about the proper role of science and scientists in a world that has accepted the challenge of climate change. Maintaining the quality and continuity of long-term Earth observations, reducing uncertainties in impacts of climate change, verifying GHG emissions, informing the public about climate change and its possible impacts, and facilitating effective legislation were among the responsibilities embraced. Michael Walsh, executive vice president of the Chicago Climate Exchange, noted that some people view the scientific consensus selectively. He said society needs to pursue "every possible mitigation" strategy, and said society's leaders need to get good information "out there." The work will require, he said, a cooperative effort by the whole of society. That view was echoed by the late David Keeling in his autobiography (*Annual Review of Energy and the Environment*, 1998):

> "A safe approach is just to remain an interested observer of the unfolding scientific evidence of man-made global climate change and its possible significance to human welfare. Without risk one can comment dispassionately…I believe, however, that a more prudent attitude would be to heed the rise in atmospheric CO_2 concentration as serious unless proven to be benign."

As Ralph Cicerone argued, climate change is "not just for scientists" anymore. The implications of climate change are broader than the natural environment. They are projected to affect multiple levels of society, the world's economies, the status of the world's poorest people, and the struggle for control of finite resources.

Throughout the event, the substantial role of scientists, not only in conducting research as society begins mitigation and adaptation efforts, but most importantly in communicating to the public in understandable terms the science of this issue and the consequences of action or inaction, resurfaced. Tony Haymet, director of Scripps Institution of Oceanography, closed the conference and challenged its participants to redouble their efforts to inform the public. To spread the word about the urgent need to confront climate change, he urged participants to talk to two groups with whom they would normally not talk, to emphasize how serious the projected climate changes are, and explain the clearly attainable options for adaptation and mitigation.

Presentations, transcripts, and posters are available on the conference Website.

Posters

Programs

Ameriflux And The North American Carbon Program: Terrestrial Impacts and Feedbacks To The Atmosphere
[B.E. Law]

The United States Carbon Cycle Science Program: An Interagency Partnership
[E.T. Cloyd, R.C. Dahlman, P.A. Jellison, and R.B. Hanson]

Cooperative China-U.S. Greenhouse Gases Measurement Program
[L.X. Zhou, X.C. Zhang, L.X. Liu, B. Yao, F. Zhang, M. Wen, Y.P. Wen, S.X. Fang, X.J. Zhou, P.P. Tans, R.C. Schnell, E. Dlugokencky, J.W.C. White, T. Conway, A. Crotwell, S.A. Montzka, C.L. Zhao, K. Masarie, A. Andrews, and C. Sweeney]

High Precision Atmospheric CO_2 Concentration Measurement Over India: Plans For Future Research
[Y. K. Tiwari, B.N. Goswami, A. Shivaji, S. Fadnavis, S.Ghude, and G.Beig]

The Scripps Carbon Dioxide and Oxygen Programs
[R. F. Keeling]

Present Day Observations

Atmospheric Carbon Dioxide Measurements in Italy
[R. Santaguida, F. de Nile, L. Lauria, A. Proietti, N. Santobuono, L. Troiano, S. Piacentino, D. M. Sferlazzo, F. Artuso, A. di Sarra, F. Monteleone, F. Apadula, and A. Longhetto]

A Comparison of the Baring Head and Mauna Loa Atmospheric CO_2 Records
[A.J. Gomez, G.W. Brailsford, K. Riedel, and D.C. Lowe]

Two Decades of Quasi-Continuous Methane Measurements at Mauna Loa Observatory
[M.J. Heller, E.J. Dlugokencky, K.A. Masarie, and P.M. Lang]

Improvement in Climate Forcing from Montreal Protocol Gases
[J.W. Elkins, G.S. Dutton, S.A. Montzka, J.H. Butler, D. J. Mondeel, B.D. Hall, A.M. Yoshinaga, and D.W. Fahey]

Vertical Profiles of CO_2 and the Latitudinal Partitioning of Carbon Fluxes
[B. B. Stephens, K. R. Gurney, P. P. Tans, C. Sweeney, W. Peters, L. Bruhwiler, P. Ciais, M. Ramonet, P. Bousquet, T. Nakazawa, S. Aoki, T. Machida, G. Inoue, N. Vinnichenko, J. Lloyd, A. Jordan, M. Heimann, O. Shibistova, R. L. Langenfelds, L. P. Steele, R. J. Francey, and A. S. Denning]

Historical Observations

The Measurement of CO_2 in the Mid-Seventies At Mauna Loa: A Historical Prospective
[J. M. Miller]

New Observations and Observation Systems

Can Carbonyl Sulfide Provide Constraints to Gross Terrestrial Photosynthesis?
[S.A. Montzka, P.P. Tans, C. Sweeney, L. Miller, and J.W. Elkins]

Towards an Autonomous Global Ocean Carbon Observatory
[J.K.B. Bishop and T.J. Wood]

The Orbiting Carbon Observatory (OCO) Mission
[C.E. Miller, D. Crisp and the OCO Science Team]

Constraining the North American Carbon Sink with CO_2 Measurements from the NOAA/ESRL Aircraft Program
[C. Sweeney, C. Crevoisier, P. Tans, A. Karion, S. Peterson, and S. Wolter]

The Expanding NOAA Tall Tower Network for Monitoring CO_2 and Related Gases
[A. Andrews, P. Tans, J. Kofler, J. Williams, C. Zhao, E. Dlugokencky, P. Lang, S. Peterson, M. Heller, D. Guenther, S. Wolter, A. Hirsch, S. Montzka, L. Miller, B. Vaughn, S. Englund, S. Oltmans, B. Vasel, M. Trudeau, K. Masarie, W. Peters, and D. Neff]

Using Atmospheric $^{14}CO_2$ Measurements for Quantification of Fossil Fuel Emissions and Evaluation of Simulated Atmospheric Transport
[J. Miller]

On the Use of the Boulder Atmospheric Observatory as a CO_2 Tall Tower Site
[W. Neff, A. Andrews, D. Wolfe, J. Kofler, J. Williams, B. Bartram, and D. Welsh]

High-Precision Measurements of Carbon Dioxide, Methane and Water Vapor for Atmospheric Inversion and Eddy Covariance Flux Based on Cavity Ringdown Spectroscopy
[K.A. Hartnett]

CO_2 Measurements from Space: Present and Future
[S.W. Boland and C.E. Miller]

Models and Interpretation

The Changing Carbon Cycle at Mauna Loa Observatory

[I. Fung, W. Buermann, B. Lintner, C. Koven, A. Angert, J. Pinzon and C. Tucker]

Routine Checks of Model Consistency on Terrestrial Carbon Sink Components
[G.A. Alexandrov and T. Matsunaga]

The NOAA Annual Greenhouse Gas Index (AGGI)
[D.J. Hofmann, J.H. Butler, T.J. Conway, E.J. Dlugokencky, J.W. Elkins, K. Masarie, S.A.. Montzka, R.C. Schnell, and P.P. Tans]

Quantifying Regional GHG Emissions from Atmospheric Measurements: HFC-134a at Trinidad Head
[A. Manning and R. F. Weiss]

The Contemporary European Carbon Balance: Competing Roles of Rising CO_2 and Climate Change
[R. Harrison, C. D. Jones, and J. Hughes]

The Atmospheric CO_2 Airborne Fraction and Carbon Cycle Feedbacks
[C. D. Jones, P. M. Cox, and C. Huntingford]

Large Scale Temporal and Spatial Gradients of CO_2 as Derived from the NOAA/ESRL Aircraft Profiles
[S.E. Peterson, C. Sweeney, D.W.Guenther, E.J. Dlugokencky, K.A. Masarie, P.M. Lang, and M.J. Heller]

CarbonTracker, a Tool to Quantify Human and Natural Emissions of Greenhouse Gases Based on Atmospheric Observations
[P. P. Tans, W. Peters, A. R. Jacobson, A. Andrews, L. M. P. Bruhwiler, T. J. Conway, E. J. Dlugokencky, K. A. Masarie, J. B. Miller, G. Pétron, and C. Sweeney]

Reports

The State of Greenhouse Gases in the Atmosphere Using Global Observations through 2006
[L.A. Barrie, G.O. Braathen, J.H. Butler, E.Dlugokencky, D.J. Hofmann, P. Tans, Y. Tsutsumi]

U.S. Climate Change Science Program Synthesis and Assessment Report 2.2, The First State of the Carbon Cycle Report (SOCCR): North American Carbon Budget and Implications for the Global Carbon Cycle
[SOCCR Scientific Coordination Team, presented by E.T. Cloyd]

WMO Greenhouse Gas Bulletin
[World Meteorological Organization]

Greenhouse Gas Observations: Key to Detecting Climate Change
[World Meteorological Organization]

Committees

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Dr. Mack McFarland	Global Environmental Manager	DuPont Fluoroproducts
Fred Palmer	Senior Vice President Government Relations	Peabody Energy
Kathleen Ritzman	Assistant Director	Scripps Institution of Oceanography
Dr. Michael Walsh	Executive Vice-President	Chicago Climate Exchange

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Dr. Michael Walsh, Co-Chair	Executive Vice-President	Chicago Climate Exchange
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Dr. Alexander E. MacDonald	Director	NOAA Earth System Research Laboratory
Dr. Mack McFarland	Global Environmental Manager	DuPont Fluoroproducts
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Prof. Robert Socolow	Co-Director, The Carbon Mitigation Initiative	Princeton University
Dr. Pieter Tans	Senior Scientist	NOAA Earth System Research Laboratory

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Dr. Melinda Marquis	Program Specialist	NOAA Earth System Research Laboratory
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