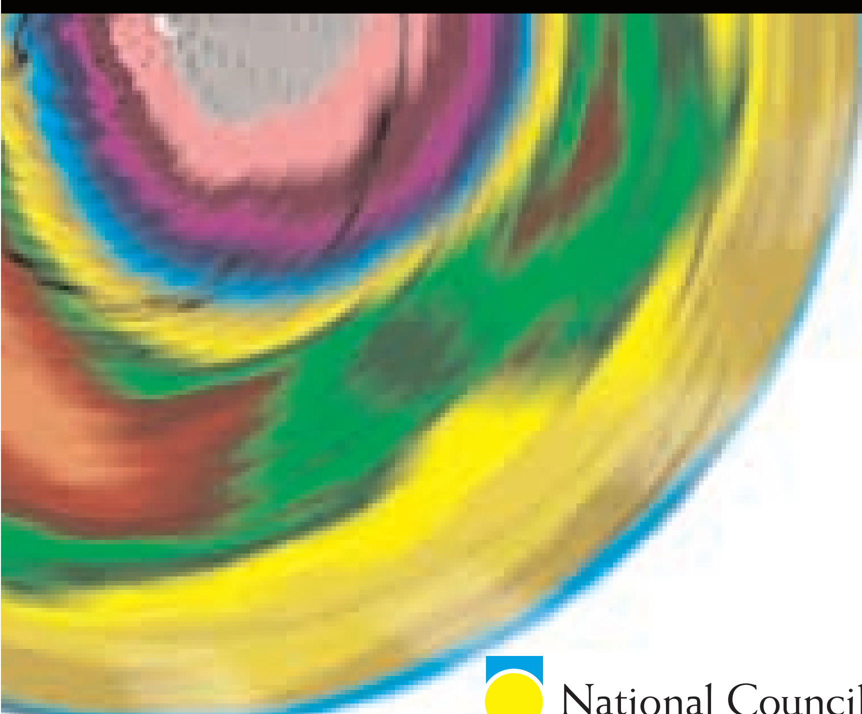
If not us, who?
If not now, when?

THE CFC-OZONE PUZZLE:
Environmental Science in the Global Arena

The JOHN H. CHAFEE Memorial Lecture
on Science and the Environment



Dr. F. Sherwood Rowland *and*
Dr. Mario J. Molina

National Council for Science and the Environment
Improving the scientific basis for environmental decisionmaking

National Council for Science and the Environment: *Improving the Scientific Basis for Environmental Decisionmaking*

The National Council for Science and the Environment (NCSE) has been working since 1990 to improve the scientific basis for environmental decisionmaking, and has earned an impressive reputation for achievement. The Council helped stimulate the National Science Foundation's new long-term environmental science and engineering initiative, which over the next five years will seek to attain an additional $1 billion-per-year for environmental research, assessment, and education grants.

The Council envisions a society where environmental decisions are based on an accurate understanding of the underlying science, its meaning, and its limitations. In such a society, citizens and environmental decisionmakers receive accurate, understandable, and integrated science-based information, and they understand the risks, uncertainties, and potential consequences of environmental decisions.

The Council promotes a new crosscutting approach to environmental science that integrates interdisciplinary research, scientific assessment, environmental education, and communication of science-based information to decisionmakers and the public. Supported by nearly 500 academic, scientific, environmental, government, and business organizations, the Council works closely with representatives of the many communities that play key roles in creating and using environmental knowledge, affecting science, and shaping environmental decisions.

Council Programs Focus on Four Areas

Bringing Communities Together

NCSE brings diverse communities together to advance science for more informed environmental decisionmaking. Three Council programs bring together these communities to work and learn in the same room:

- developing and implementing science agendas,
- annual National Conference on Science, Policy, and the Environment, and
- annual John H. Chafee Memorial Lecture.

Information Dissemination—
National Library for the Environment (NLE)

Continuously expanded and updated, this widely-acclaimed online Library includes directories of academic environmental programs, journals, foundations, meetings, job opportunities, news sources, laws and treaties, reports, reference materials, and much more. NLE includes: Congressional Research Service Reports, PopPlanet.org, PopEnvironment.org, and USenvironment.org.

Education and Outreach

NCSE carries out a wide range of education and outreach programs promoting interdisciplinary science that integrate crosscutting research with scientific assessment, information dissemination, and education, meeting the needs of decisionmakers. These include creation and support of the Council of Environmental Deans and Directors.

Publications

Through regular analysis and reporting, the Council documents and encourages efforts to improve the scientific basis for environmental decisionmaking at the National Science Foundation and other federal agencies. A monthly Science, Environment, and Policy Report is available exclusively to members of the NCSE University Affiliate Program. NCSE Updates (e-mail and fax) are available to anyone requesting the service.

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Dr. F. Sherwood Rowland
1995 Nobel Laureate in Chemistry
University of California Irvine

and

Dr. Mario J. Molina
1995 Nobel Laureate in Chemistry
Massachusetts Institute of Technology

JOHN H. CHAFEE Memorial Lecture on Science and the Environment
1st National Conference on Science, Policy and the Environment

PRESENTED AT
National Academy of Sciences
Washington, DC

December 7, 2000

This volume documents the inaugural John H. Chafee Memorial Lecture on Science and the Environment, organized by the National Council for Science and the Environment. It is the first in a series of books documenting the annual Chafee Lecture series.

ACKNOWLEDGEMENTS

John H. Chafee Memorial Lecture on Science and the Environment

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The National Council for Science and the Environment is grateful to the following sponsors for making possible the inaugural John H. Chafee Memorial Lecture on Science and the Environment:

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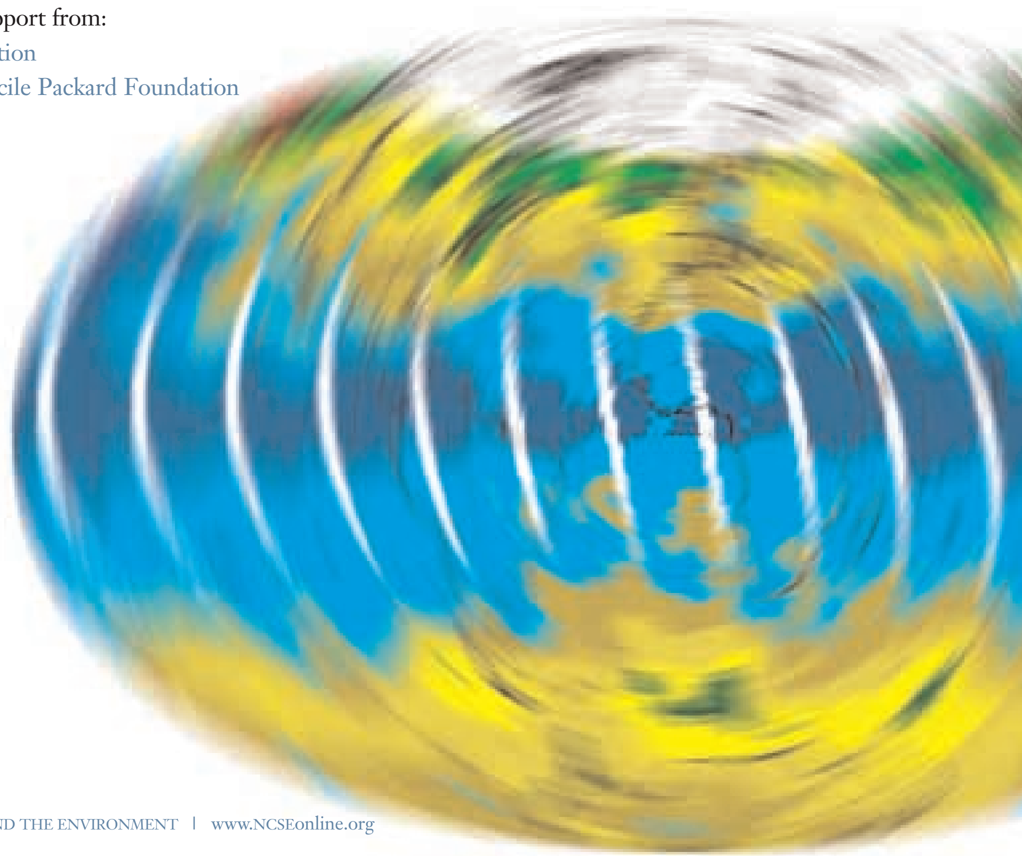

DEDICATION

This book is dedicated to the memory of Senator John H. Chafee who, in his 23 years representing Rhode Island in the U.S. Senate, was a leader in promoting a bipartisan, science-based approach to environmental issues.

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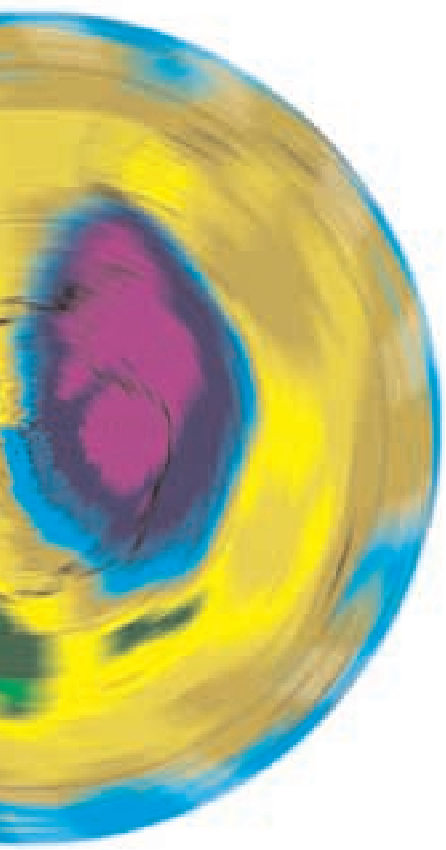

PROGRAM

Inaugural John H. Chafee Memorial Lecture on Science and the Environment

December 7, 2000

COLOR GUARD
Young Marines

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Dr. A. Karim Ahmed, National Council for Science and the Environment

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Ambassador Charles S. Whitehouse

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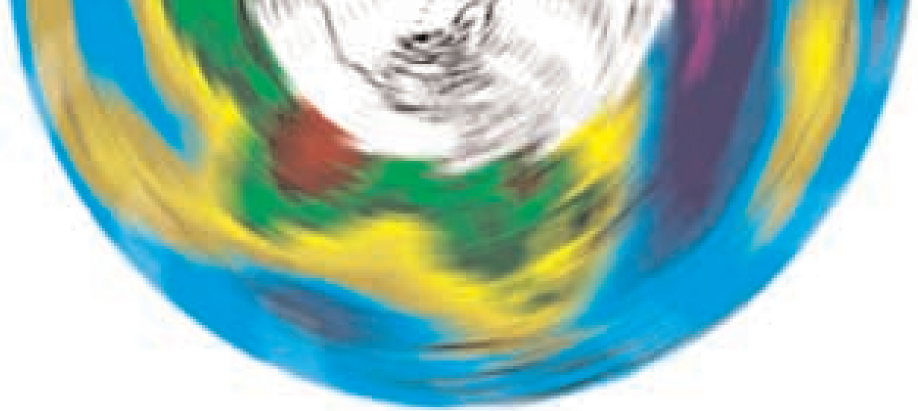

PREFACE

Science, Policy and Stratospheric Ozone: An Environmental Success Story

A. KARIM AHMED Ph.D., Secretary-Treasurer and Director, International Programs, National Council for Science and the Environment

While it is relatively easy to speak about global degradation and the loss of natural resources, such as tropical forests, fisheries and coastal areas in many regions of the world today, it is instructive for us to examine an environmental success story, which is the subject of the inaugural *John H. Chafee Memorial Lecture on Science and the Environment*. It will show quite dramatically how, by using sound scientific and technical knowledge combined with a commitment to reach consensus in enacting an international treaty, we can achieve sound public policy to ensure a more environmentally sustainable future.

The subject I am speaking about is the destruction of our protective stratospheric ozone layer by man-made chemicals, known collectively as chlorofluorocarbons or CFCs, which were once considered to be miracle substances. While CFCs were known to have remarkable physical and chemical properties that allowed their extensive use in a variety of consumer products, they also possessed low human toxicity. Thus, they were employed as relatively safe refrigerant fluids in air conditioners and refrigerators and were widely used as propellants in aerosol cans. For instance, in the 1960s and 1970s, over two-thirds of all CFCs manufactured in the world were incorporated in aerosol cans for consumer products, such as underarm deodorants and shaving creams.

In the early 1970s, two physical chemists–Dr. Sherwood Rowland and Dr. Mario Molina, working together at the University of California, Irvine–discovered that the chemically inert CFCs could potentially break down in the stratosphere, which contains earth's protective ozone layer. Under the influence of intense ultraviolet radiation in the stratosphere, they postulated in a path-breaking article in the journal *Nature* that CFCs underwent a series of chemical reactions to form highly reactive chlorine atoms, which destroyed a significant fraction of the protective ozone layer.

While the non-essential uses of CFCs, such as aerosol propellants, were being completely phased out in the United States by the late 1970s, the production of these commercial substances had, by the early 1980s, risen dramatically for use in new air conditioners and refrigerators, both domestically and overseas. It seemed that the worldwide market for CFCs had in fact increased, notwithstanding the initial attempts to reduce the commercial uses of these compounds.

Then a dramatic and far-reaching event took place. A group of scientists, who had been carrying out scientific measurements in Antarctica, noticed that a huge ozone hole developed each spring over the southern polar region, which lasted for many weeks at a time. At this point, even the most skeptical critic of the stratospheric ozone depletion theory, which included scientists in the chemical industry, began to concede that an unprecedented event of major proportion was happening to the global environment.

What is especially heartening about this environmental success story is that within a few years after the discovery of the Antarctic ozone hole, most national governments of the world signed and ratified the Montreal Protocol, calling for an orderly and step-by-step phase out of all CFCs and other similar halogenated compounds.

What did we learn from this turn of events? After the publication of the Rowland-Molina paper, the worldwide scientific community participated in a joint effort to elucidate and verify the original stratospheric ozone depletion theory. This led to the adoption of an international treaty that brought an end to the global use of a potentially harmful class of compounds in a systematic, well thought out and timely manner.

In recognition of their scientific contributions, Dr. Sherwood Rowland and Dr. Mario Molina–the two speakers at the inaugural *John H. Chafee Memorial Lecture on Science and the Environment*—along with their Dutch scientific colleague, Dr Paul Crutzen, shared the Nobel Prize for Chemistry in 1995. Their contributions to both science and public policy is indeed an environmental success story that must not be forgotten as we continue to seek answers to other serious global environmental questions that we face today.

OPENING REMARKS

PRESENTATION OF THE COLORS Young Marines Color Guard.

KARIM AHMED Good evening. On behalf of the National Council for Science and the Environment, I wish to welcome you to the inaugural John H. Chafee Memorial Lecture on Science and the Environment. My name is Karim Ahmed and I will begin by reading a statement from Senator John Warner who is unable to be here with us this evening, and who is the co-chair of the Host Committee of the John H. Chafee Memorial Lecture on Science and the Environment. Senator Warner's statement reads as follows:

> *My dear friend, John Chafee, would have been proud and honored that you are recognizing his lifelong passion to protect and preserve our natural world through this annual lecture series on Science and the Environment.*
>
> *From his earliest days when the Congress focused on our national responsibilities to improve air and water quality, to preserve wildlife habitat, to control ozone depleting chemicals, to his latest commitment to develop an international consensus on global climate change, John was a leader, not just a participant.*
>
> *We know of his many policy accomplishments. Every major environmental statute reflects John's dedication and heartfelt commitment to improving our quality of life. It was not only his political skill that led to this success but his grace and unfailing sense of purpose that won us over.*
>
> *Let us continue in John's footsteps, with his steadfast conviction to tackle the challenges ahead—and to do it, as he would say, "with good cheer."*
>
> *I commend the Council for this living tribute to John Chafee, and wish you every success.*
>
> *With kind regards, I am, sincerely, John Warner.*

I also received a similar letter from Senator Max Baucus, who also, as you know, was a close colleague of John Chafee in the US Congress and is co-chair of the Host Committee. His letter reads as follows:

> *Dear Friends:*
>
> *I had the privilege of serving in the Senate with John Chafee for more than 20 years, including serving with him for a decade in the leadership of the Senate Environment and Public Works Committee. He was a gifted legislator and a dear friend.*
>
> *On environmental issues, he worked tirelessly to protect the environment. But his approach was never strident. Instead, he would listen, educate and seek common ground. In this way, he won many quiet victories that will benefit our nation and world for generations to come.*
>
> *I appreciate this tribute to John and am pleased to be associated with it.*
>
> *Sincerely, Max Baucus*

As you know, Senator Baucus is the co-chair of our Host Committee tonight. In the folder distributed to you this evening, we have included a wonderful article entitled, "John Chafee: The Gentle Warrior." It not only gives you an overview of his leadership and accomplishments in the United States Congress, but also portrays him as a remarkably committed, fair-minded and decent human being. This article, published earlier this year, was written by Steven Shimberg, someone who knew him very well, having served as his legal counsel on the Senate's Committee on Environment and Public Works, and, most recently, as its Staff Director. Also, in this article – in a box – are remarks by one of Senator Chafee's Congressional colleagues from the other side of the aisle, Senator Max Baucus whose statement I just read.

Now, I would like to introduce one of Senator Chafee's former classmates from Yale University. Ambassador Charles Whitehouse, who, along with other members of the Yale class of 1944, is a member of the Host Committee for this evening's event. Ambassador Whitehouse, who was a close personal friend of Senator Chafee, has had a very distinguished career in government service. Like Senator Chafee, he served in the U.S. Marine Corps during World War II, where he earned 21 air medals and seven distinguished flying crosses.

Over the years, he has held high-level appointments in both the Defense and State Departments. Ambassador Whitehouse was deputy ambassador in Vietnam in 1972 and later served as ambassador in Laos and Thailand during the middle seventies. Not only has Ambassador Whitehouse been repeatedly honored by the U.S. State Department for distinguished service to his country, he is a recipient of the French *Legion* of Honor. I now call upon Ambassador Charles Whitehouse to speak on behalf of Senator Chafee's classmates, Yale class of 1944.

Ambassador CHARLES WHITEHOUSE Thank you for that very generous introduction. I feel a bit like a clergyman when they make the announcement in church and everybody in the church has in their pew a list of the announcements that he is making. All of you have a copy of the remarks that I am going to make. But I am not going to ask you to read in unison with me.

Almost all of us here today were friends of Senator John Chafee and some of us, notably Chuck Alling, Bill Goedecke, Tim Hoopes, Junie O'Brien, Eddie Welles and I were in his class at Yale and, therefore, first came to know him 60 years ago in the autumn of 1940. Not all of the persons whom I mentioned are here today, but the Allings are here, the O'Briens are here, and Eddie Welles is here and my wife and I are here.

I will not pretend that any of us foresaw what an extraordinary career in public life John was to have. Who could guess that he would serve twice as Governor of Rhode Island, become Secretary of the Navy, and be a Senator representing his state for 23 years?

What we did notice right away was that John was an extraordinarily decent and nice person and instantly became one of the most popular men in the class. As the years passed we also became aware of the fact that he had an unerring instinct for doing the right thing and for doing it well. All of us served in World War II, but John left Yale right after Pearl Harbor! He saw a lot of combat on Guadalcanal and in the other parts of the Pacific and then later as a Company Commander in Korea.

Becoming a warrior was the right thing to do at the time. Typically, when he came to the Senate he saw that becoming a champion of environmental causes was then the right thing to do.

We, who knew John for so long, salute you for organizing this lecture in memory of our dear friend and classmate. As we all know, he richly deserves a tribute of this kind.

KARIM AHMED Thank you, Ambassador Whitehouse. I'd like to now call upon Mr. Edward Welles, who wishes to say a few words about a program he has been involved with at Yale University to honor Senator Chafee.

EDWARD O. WELLES First, I am pleased to be here in the company of many distinguished scientific individuals. I don't fit into that category, but I do fit into the category of being a great friend and admirer of John Chafee. One thing that sticks with me through the years is that in the summer of our sophomore year at Yale, we drove a rattletrap old Ford to West Texas and worked in the oil fields for 60 cents an hour, but we did get a little overtime.

In any event, having said that, what I want to say about John is that we here tonight, I think, reflect a great character and more than that the great appreciation his classmates have for the work he has done for our country, for his state, for his family and for all of us. I do feel the Yale School of Forestry does have a great opportunity to march ahead with something significant for the environmental world in years to come. I think one of the mainstays of that program will be the scholarship program for graduate students who are pursuing their work at Yale. Thank you.

KARIM AHMED As no one in the audience need be reminded, Lincoln Chafee was appointed by the governor of Rhode Island to fill the unexpired term of his father who passed away, as you all know, in October 1999. In his own right, Senator Lincoln Chafee ran for office in this year's general election as a Republican, which was his father's party. We're happy to report that he won the Senatorial election by an overwhelming majority in a northeastern state where the vast majority of voters are registered Democrats.

Other members of the Chafee family are also present with us this evening. I now ask Senator Chafee to step up to the podium to introduce members of his family and to present his personal reflections on this inaugural *John H. Chafee Memorial Lecture on Science and the Environment.*

Senator **LINCOLN CHAFEE** Thank you very much. And yes, on behalf of the Chafee family, I do want to thank the Council for establishing this wonderful celebration of John Chafee's environmental legacy. I also want to thank Dr. Sherwood Rowland and Dr. Mario Molina for presenting tonight's inaugural lecture. My father relied on your scientific findings and counsel to craft some of our nation's most significant environmental policies. As we all know, my father believed the stewardship of the environment is our sacred duty.

My sister, my wife, my sister's husband and my brother are here tonight as is my mother. My mother was our family's first environmentalist and she says that an early inspiration was *Our Plundered Planet* by Fairfield Osborn. Anybody here read it?

Tonight we'll hear about an area where John Chafee made important strides. In 1986, he was the first in the Senate to sound the alarm about the dangers posed by CFCs and other common chemicals to our atmosphere. As Ambassador Benedick notes in his book on the subject, *Ozone Diplomacy*, John Chafee's mission to alert the public to the hazards of disintegrating ozone helped pave the way for the ratification of the Montreal Protocol and further strengthening of laws to protect the ozone layer.

Now, this task will be shouldered by a new Congress and a new President. Whether Vice President Gore or Governor Bush occupies the White House, all of us in public office ought to make this charge one of our highest priorities. Within this area, the single greatest challenge we must address is the issue of climate change and my father thought that we could accomplish this mission in three ways: First, science must drive policy. I think we all agree that Congress must provide increased funding to support scientific research. Without this research, we on Capitol Hill will have a hard time making the case for climate change policy. Your organization can and will be an invaluable resource to us.

Second, we must walk the tightrope, balancing the need to safeguard our planet with the need to sustain the economy that powers it. Third, we must remain sensitive to the needs of developing countries that fear mandated cuts in emissions would stunt their efforts to attain the same level of prosperity that Americans enjoy.

And what we need most of all is great openness on the part of everyone involved in this debate. Throughout the twentieth century, efforts to preserve the environment have been challenged by people who fear that steps to control pollution would halt our prosperity. In fact, these fears were proven wrong each time. We need to have greater confidence today. By using our imaginations and venturing outside the narrower set of assumptions that constrain us, we can make progress. The divided composition of the House and Senate, and, indeed, the American electorate, demands that any progress on this issue be forged at the center.

And let us not forget the conundrum of climate change stretches far beyond domestic politics. We are all bound together as inhabitants of one fragile planet, and I am confident that together as inhabitants of this one earth, we will find wise solutions to our environmental challenges. And I know that my father would be honored to have this lecture series named for him.

KARIM AHMED Thank you, Senator Chafee. Finally, the last act I will perform tonight is to ask Ambassador Richard Benedick, President of the National Council for Science and the Environment, to replace me at the podium in order to introduce the main speakers for tonight's event. Ambassador Benedick was responsible in the US State Department for population affairs and subsequently for environmental issues. In this capacity, he was the chief US negotiator and principal architect of the historic Montreal Protocol that Senator Chafee just mentioned, which protected the stratospheric ozone layer, that he has described in his classic book, *Ozone Diplomacy*. He is currently a Deputy Director at Battelle Institute in Washington, DC and is a Visiting Fellow at the German Social Science Research Center in Berlin. Ambassador Benedick has served since 1994 as the President of the National Council for Science and the Environment.

RICHARD BENEDICK Thank you very much, Karim, ladies and gentlemen, Senator Lincoln Chafee, distinguished guests.

For me, it is a personal privilege and pleasure to be able to participate this evening in honoring a great statesman, a champion for science and the environment, and, at the same time, to be introducing not just one but two eminent scientists—Nobel Laureates—who will be the first presenters of this annual *John H. Chafee Memorial Lecture*. I must say after hearing Senator Chafee, the current Senator Chafee, I have renewed faith in the power and potential of our Congress. I hope that they can live up to the sincere wishes and the very well founded sentiments that Senator Chafee last mentioned. I also thank him for the plug for my book, *Ozone Diplomacy*. Very kind of you.

The work of our lecturers tonight, in effect, exemplifies the principles that Senator Chafee stood for, namely, the need for innovative and brilliant science to support rational environmental decision making. As the current Senator Chafee said, science must drive public policy. Not just that, policy makers must exemplify the courage that Senator John Chafee showed so often in his career.

In 1974, the now historic landmark article by Dr. Sherwood Rowland and Dr. Mario Marino was published in a British scientific journal, theorizing that CFCs had the potential—and it was only a theory at that time—to destroy the fragile ozone layer thirty miles above where we're sitting today, a layer of unstable molecules that protects all life on earth from the effects of potentially fatal ultraviolet radiation. We may have forgotten how this article shook the scientific and industrial communities to their foundations. And it may be emblematic that while my book is called *Ozone Diplomacy*, the first book on that subject recording those events was called *The Ozone War*.

And Dr. Sherwood Rowland and Dr. Mario Molina were right in the middle of that war. It took the same kind of courage that on so many occasions Senator John Chafee also demonstrated in the Senate, to come through that and eventually, of course, to be recognized for their great achievements by the Nobel Prize committee. I've had the personal good fortune, in the course of my own professional career, to be associated with all three of these remarkable individuals.

When Secretary of State George Schultz asked me to lead our nation's efforts internationally to save the ozone layer, I learned from Dr. Rowland and from Dr. Molina the scientific underpinning for our negotiating position that eventually led to the historic Montreal Protocol in 1987. An outcome, by the way, that was by no means assured given the very strong opposition at that time from most other nations in the world and from most of industry, and even at home. During these tough international negotiations, it was Senator John Chafee whose courage, wisdom and vision mobilized Congressional support that was essential to overcoming very determined domestic political opposition to a strong international treaty.

It is therefore indeed fitting that, at this first national conference of the National Council for Science and the Environment, these two giant figures in the modern history of science policy come together this evening. For their work also exemplifies the underlying vision of the National Council for Science and the Environment, with its unique mission of promoting science for environmental decision making and with its unique consortium of environmental stakeholders: universities, scientific associations, private industry, state and local governments and civil society—all of whom have been represented today and will be tomorrow at this wonderful conference.

So ladies and gentlemen, I have the honor to present to you the inaugural presenters of *The John H. Chafee Memorial Lecture on Science and the Environment*.

Dr. A. Karim Ahmed

Amb. Richard E. Benedick

Senator Lincoln D. Chafee

Mr. Edward Welles

Amb. Charles Whitehouse

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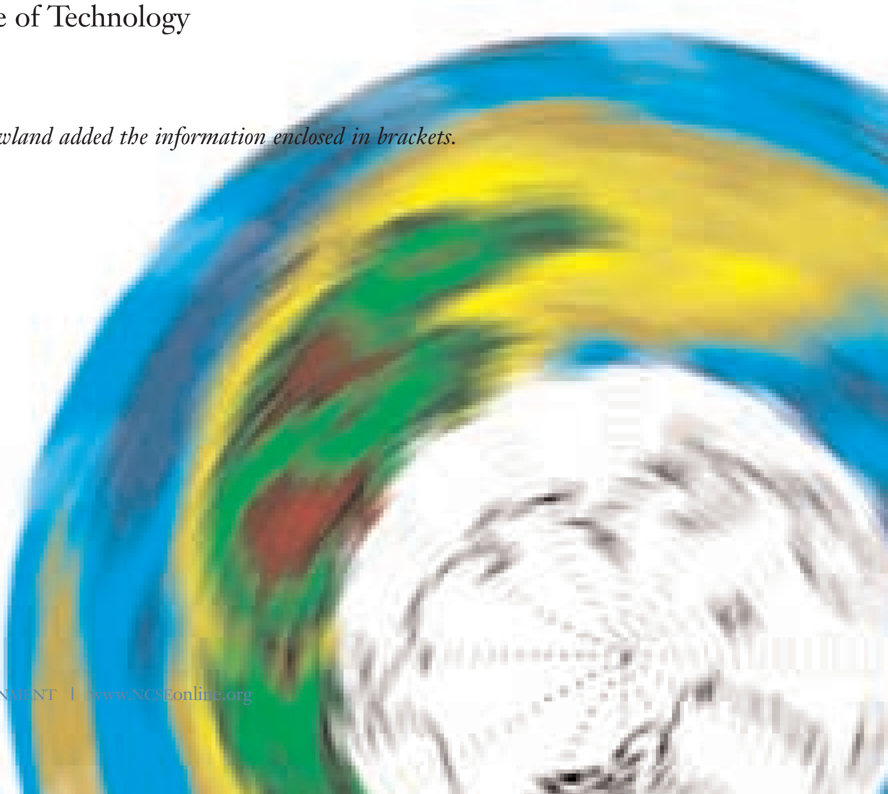
Following the lecture, Dr. Rowland added the information enclosed in brackets.



Dr. F. Sherwood Rowland

Dr. Mario J. Molina

ROWLAND Mrs. Chafee, the new Senator Chafee, Karim Ahmed and Richard Benedick. We are pleased to be here to honor one of the outstanding participants in our government, the kind of participant that makes scientists feel that it is worthwhile to work with them because you are dealing with someone who is trustworthy, honest and a fighter for what needs to be done.

MOLINA Just like Sherry, I'm very honored to be able to present this lecture this evening. I remember when I first met Senator Chafee. I was quite a young scientist at that time. I was very impressed with him and remained impressed over the years, so it is a very big honor for me to be here tonight presenting this inaugural Chafee lecture.

ROWLAND You've seen that there are two of us giving the lecture. So the only thing I want to say about it—what we plan to do is basically to describe alternate slides. So this will be a joint lecture. The only problem we have is the feeling that one has of coming to the national track championships in a relay race without having practiced the handoff. With that as background, we will start.

SLIDE 1: *Ft. Lauderdale, January* 1972

ROWLAND This introductory slide is a copy of the notes that I took at a meeting in Ft. Lauderdale in January of 1972. The lecturer [Dr. Lester Machta] reported the results of some experiments by a man named James Lovelock, who had discovered a new component of the earth's atmosphere that is, trichlorofluoromethane, one of the CFCs [chlorofluorocarbons]. He had measured it and found that it existed in both hemispheres. To a chemist, this raised a challenge. Here was a new compound that had not been in Earth's atmosphere before, and the question was, "What will happen to it?"

Fortunately, I had a research contract with the Atomic Energy Commission that gave me considerable freedom as to what research we would do. So, in 1973, I asked the question. I said we would like to study what would happen to this molecule in the atmosphere. I was delighted when an outstanding graduate student, a new post-doctoral from Berkeley, a Mexican scientist named Mario Molina, applied to my research group to study. I offered to him several possible research projects, one of which was the question of the chlorofluorocarbons.

SLIDE 2: *FSR and MJM, with Dr. Luisa Molina in the foreground, University of California, Irvine laboratory,* 1976

MOLINA So this was many years ago. To me at that time, it was really a fascinating question. I immediately picked that project, of course, the CFCs. What happens to them in the environment? It is an open-ended question. Why is it that we asked it? Well, we had the situation in human society, of industry using some chemicals and actually changing the chemical composition of the atmosphere. And that was happening on a global scale!

So I said to myself, this is the sort of situation that requires an answer. If human society is changing something important in the environment, human society should also find out whether there are any consequences. At the very least, I thought it was very bad manners just to release these chemicals without even knowing what would happen.

In fact, we learned later, Sherry and I, that at that time there were actually other groups of scientists who had asked a similar question because they were aware that these chemicals were in the environment, but they concluded that there was really nothing to worry about. These compounds are extremely stable. You can even breathe them and they were present at that time in the atmosphere at parts-per-trillion levels.

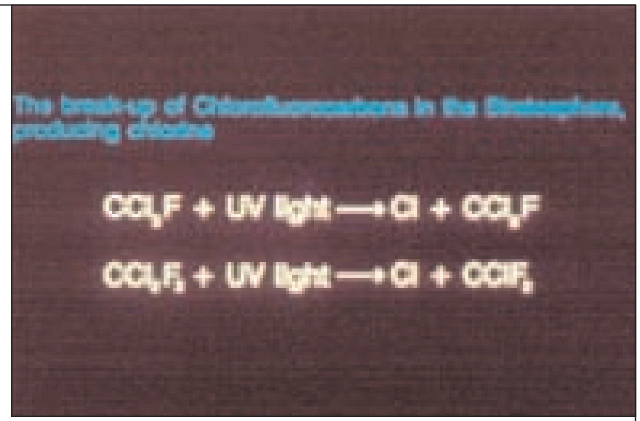
So why worry? Well, we reached a different conclusion.

ROWLAND The search started by asking what would happen to these molecules in the atmosphere. There are three common things that happen to most molecules. One is, if they form a colored gas, then it is decomposed by sunlight. The color tells you that it is intercepting the sunlight. Another thing that happens is for a molecule to dissolve in rainwater. That is the fate of hydrogen chloride, for instance, in the atmosphere. And the third is to be oxidized somewhere in the atmosphere.

But Mario went through this list very quickly and realized that chlorofluorocarbons were not soluble in water. They were transparent, and they didn't react with any of the oxidizing agents in the atmosphere. This left as the only possibility something that we had both known all along—if they got up into the atmosphere far enough, and this would have to be in the middle of the stratosphere, then these compounds would run into ultraviolet light that is energetic enough to break them apart. And this would release the chlorine atom that is shown in the equation.

We had found out the answer to the question that was originally asked—the molecules would break up in the stratosphere. In fact, we calculated that for the upper molecule [CCl_3F] it would take on the average about 50 years and for the bottom one [CCl_2F_2] an average of 100 years. And it would decompose with the release of chlorine atoms.

So, now there was another question. What would happen to the chlorine atoms?

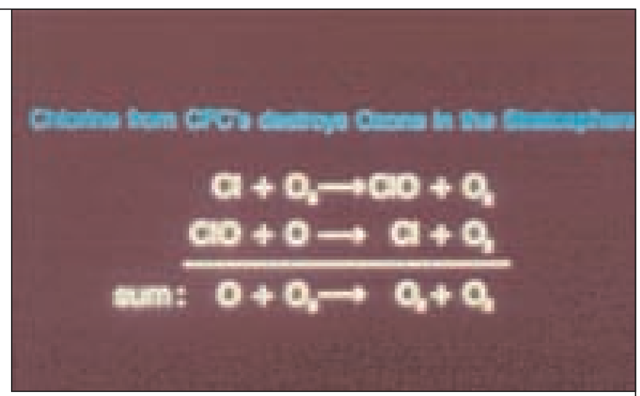


SLIDE 3: *CFC photolysis with high energy UV radiation in the stratosphere*

MOLINA This question had to do with what are the consequences of this chlorine atom release. It was not sufficient just to find out how these molecules were to be decomposed. What we realized at that time is that there is a process that involves very small amounts of certain species—free radicals like these chlorine atoms—the so-called catalytic process that could potentially affect the ozone layer.

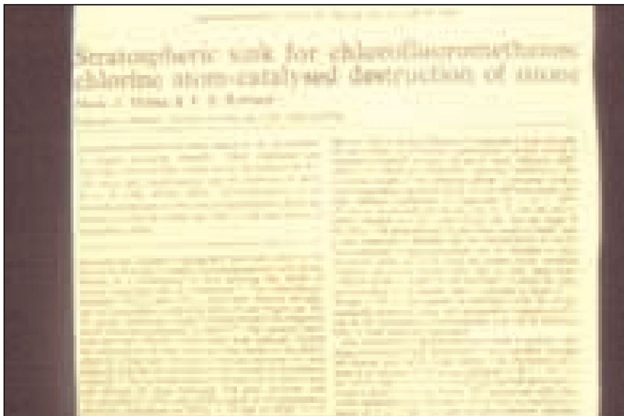
We have learned from earlier work of our colleague Paul Crutzen and from Harold Johnston that we had this situation in the stratosphere. Very small amounts of certain compounds—levels measured in parts per billion or less—these small amounts of these catalysts could actually affect and control the larger amounts of ozone that are vital for our survival here on the earth's surface. Ozone itself is present at the parts per million level.

So, here we had a situation where human activities could actually generate large amounts of these species in the parts per billion levels comparable to those natural levels of catalysts that control ozone. And as you see in these reactions, what happens is that there is a recycling—the chlorine and ClOx radicals are generated and regenerated.



SLIDE 4: ClO_x *catalytic chain*

We were actually not aware, when we first realized that these reactions could happen, that some colleagues of ours, Ralph Cicerone and Richard Stolarski, had several months earlier, in fact, come up with the same idea in terms of the catalytic effects of chlorine. But they had not associated chlorine with the CFCs. They were worried about chlorine from the space shuttle or chlorine from volcanoes.



SLIDE 5: *Original ozone depletion paper by Molina and Rowland, Nature, June 28, 1974*

ROWLAND This started out as an environmental scientific problem—that is, something where we were curious about what the situation was. But there was no thought at the start that this was an environmental problem in the sense that it was something that required people to be worried about it. However, as soon as we found out that there was a long chain reaction, and a global threat involved with it—then we realized that this was not something that you can start talking about in the newspaper and have it come out believable.

What we needed to do was publish first in the recognized scientific journals. The first paper that we had came out in June 1974 in *Nature* called: "The stratospheric sink for chlorofluoromethanes: chlorine atom-catalyzed destruction of ozone." We actually thought that there would be a big reaction to this, but there was initially very little response. It wasn't until a few months later that it began to be widely discussed in public.

SLIDE 6: *New Times, March 7, 1975*

MOLINA In hindsight, it was really not surprising that there was very little reaction initially. We were talking about this invisible gas rising in the atmosphere to affect an invisible layer that was protecting us from invisible rays. And with a title such as this one, it is not a surprise that not much happened.

But eventually the press indeed got interested in this issue and articles began to appear and, of course, it was in connection with spray cans, spray cans in American homes. There were on the average, I think, 30 or 40 spray cans per household at that time. And so it is the connection—just the idea that a lot of people pressing these little buttons inadvertently were actually polluting the planet—that eventually caught the attention of the press.

ROWLAND At the time, the figure we had was 6 billion spray cans produced every year in the world, and in our home we had 15 of them. So my wife went around and threw them all out, and I thought, 15 down and 6 billion to go.

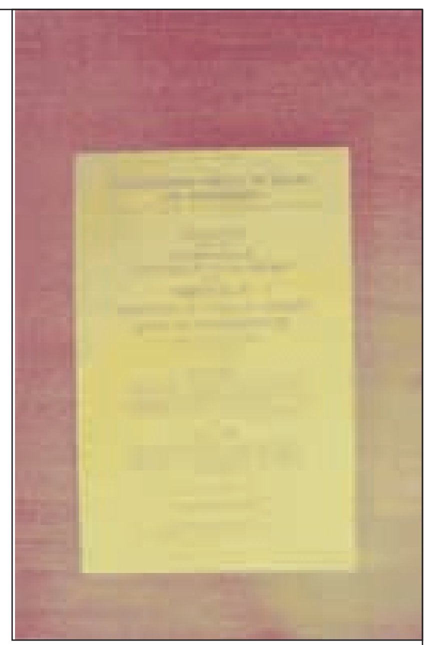
The first time the CFC-ozone story hit the public in a major way was at the American Chemical Society meeting in September of 1974 at which Mario and I presented papers on aspects of the chlorofluorocarbon problem, and then ventured into public policy. Both of us agreed we ought not to be releasing CFCs into the atmosphere. The value of the CFCs produced in 1974 was about 2 billion dollars, and the industrial efforts that depended upon that were estimated at 200 billion dollars by the industry. So they did not exactly leap to follow our suggestion that they quit putting it into the atmosphere.

SLIDE 7: Chemical and Engineering News, FSR, September 23, 1974

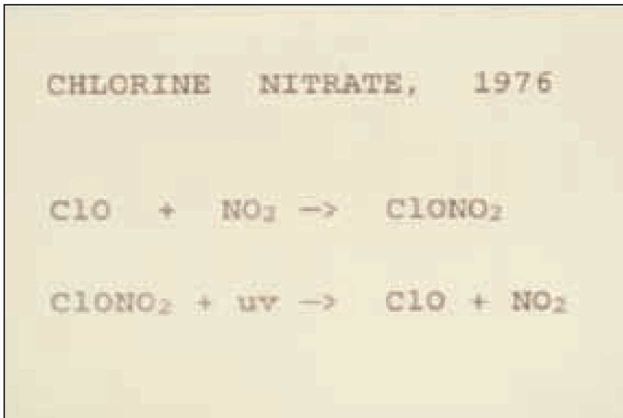
MOLINA Our initial preoccupation with the press was, of course, not just to seek publicity. We knew that was the way to get the attention of government, of the regulators.

So it was early on in the hearings by the Rogers Committee of the House of Representatives, in this case, that the government began to pay attention to this issue. That was indeed what happened. After the press responded, the public began to be concerned. And this initial idea that we had, we really had to be explicit about it. Is it enough for a scientist simply to publish a paper?

Isn't it a responsibility of scientists, if you believe that you have found something that can affect the environment, isn't it your responsibility to actually do something about it, enough so that action actually takes place? There was nobody else at that time that would actually fulfill that role. So that's why Sherry and I, pretty consciously then, decided to take that additional step to make sure the government would actually pay attention.



SLIDE 8: Report of Rogers Subcommittee, House of Representatives: December 11-12, 1974



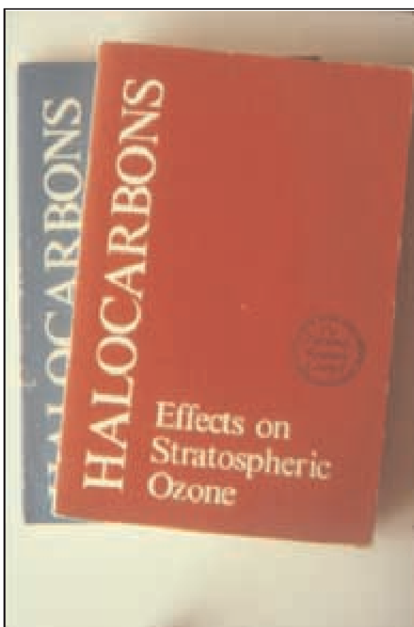
SLIDE 9: *Chlorine nitrate formation from chlorine oxide and nitrogen dioxide radicals*

ROWLAND The government responded in two ways. One of them was to create a committee called the Inadvertent Modification of the Stratosphere [IMOS] Committee, with members from 14 agencies of the government. The second was to fund [jointly by NSF, NASA, NOAA, EPA and FAA] a study to be done by the National Academy of Sciences to see whether there was validity to the questions about ozone depletion that had now come into the public press.

During 1975, the IMOS Committee made a report, which said that it looks as though this is quite a valid argument here, and, unless the National Academy of Sciences finds some reason that is different in the science, regulation will probably be required. The first problem that came up, that raised a question on the science, was raised by Mario and myself.

We had assumed that this molecule, chlorine nitrate, shown in the slide, would be in very low concentration in the atmosphere and wasn't going to be important. Then we realized that this wasn't actually true. We made some chlorine nitrate, which is not hard to make but is difficult to keep because it reacts very easily with water. We found out that its lifetime would be long enough that it could probably exist in the stratosphere.

The National Academy of Sciences had a report about ready to come out in April 1976 when we said that chlorine nitrate might be significant, and the Academy had to pull it back because the stratospheric calculations were thrown into disarray. This led to a delay of about six months in its coming out.



SLIDE 10: *1976 reports from two NAS committees*

MOLINA I remember thinking at that time that it was sort of ironic because chlorine nitrate was a very esoteric molecule. I remember finding it in the old German scientific literature. But that is the way science works. The German scientists at first working with this chemical species really could not foresee at all that something like this, so esoteric, that actually human activities were going to be making many tons of this compound floating in the atmosphere.

So, the National Academy reports began to come out and these were, of course, very influential reports validating the science, or at least the idea that the CFCs would indeed reach the stratosphere and actually affect the ozone layer. And this CFC problem was something that certainly deserved further study, and quite possibly regulations by governments all over the world.

ROWLAND The conclusions for these two volumes I can put in two words. The red volume said "yes," and the blue volume said "but." And most people said, "Can you shorten that?"

This is a picture taken in Utah just after a long-scheduled meeting that occurred just four days after those two volumes came out. Mario and I are shown in Logan, Utah. One of the consequences, one of the things that happened was this: when the National Academy of Sciences said: "yes, there is validity to this science," then that took a certain weight off our backs. Because for the previous two years, it had been Mario, Ralph Cicerone, and I that would appear to do the testimony [to Congress and to state legislatures]. Now somebody else had said that if they are kooks they're hiding it well, and the CFC-ozone problem became something that was very much of scientific interest.

SLIDE 11: FSR and MJM near Logan, Utah, September 1976

MOLINA The expectations we had had earlier eventually began to materialize. There were indeed regulations. You can read here that labels were required on sprays cans. In fact, it was the FDA commissioner, and also the EPA and the Consumer Product Safety Commission, that came up with this regulation.

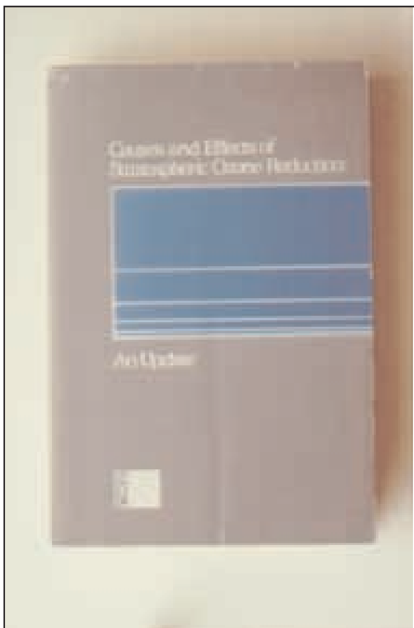
As was to be expected, the first target of the regulation was spray cans. Spray cans, after all, were perceived not to be essential. And certainly less essential was the use of CFCs as propellants for these devices. There are other ways to deliver whatever you need to spray. In some sense, it was a victory because the US government began to take some action.

SLIDE 12: FDA Commissioner Alexander M. Schmidt at press conference, October 1976

SLIDE 13: *Substitutes for CFC aerosol sprays—roll-on, pump valve, hydrocarbon propellant*

ROWLAND For instance, the substitutes that could be put in for CFCs as propellant gases include: having a pump spray where you used your finger to provide the pressure, and a roll-on, (over on the left) and then you have an "environmental formula" that substituted hydrocarbons as the propellant gases. There was a lot of argument about the banning of CFCs saying that they were very safe to use. I remember Mario saying that he had never heard of anyone swallowing a roll-on deodorant.

The overall problem, of course, was that in the United States at the time, about two-thirds of the CFCs were used as the propellant gases in aerosol sprays, and the US used about half of all the CFCs in the world. But the ban on CFCs as spray can propellants left out all the other uses: as refrigerants, in air-conditioning; using them as solvents, etc. The CFC problem was partially solved, but only for use as a propellant gas, and then only in the United States, Scandinavia and Canada, because the other countries didn't follow suit on the aerosol propellant controls.



SLIDE 14: NAS *Report* 1982

MOLINA Here we have additional National Academy reports and updates. By that time the science began to be really validated. There were, of course, many remaining uncertainties. Indeed, the science process was moving ahead and, again, these National Academy reports really were extremely important.

ROWLAND It is worth noting the title, "Causes and Effects of Stratospheric Ozone Reduction." I point out that the word was "reduction." What was happening was that the scientific community was saying, "All of these calculations have been done about the atmosphere but the only change that is included is the steady increase in the amount of chlorofluorocarbons." But, in the real atmosphere, carbon dioxide is increasing too, and methane is increasing, too. They began to make more complex models. As soon as you began to have more complex models, then you get more spread on what was being predicted as eventual outcomes.

There were many scientific conferences, including this one in 1982 in Berlin called the Dahlem [a suburb of Berlin] Conference. This is Mario on the right, I'm sitting next to him, and then we have Paul Crutzen, the Dutch scientist working in Germany, with whom we shared the 1995 Nobel Prize, and on the left is Ralph Cicerone who had found the chlorine chain reaction with his partner, Rich Stolarski. The scientific community continued to work very hard on these problems, but the regulatory situation was not much changed.

SLIDE 15: Dahlem Conference, Berlin 1982—Ralph Cicerone, Paul Crutzen, FSR and MJM (left to right)

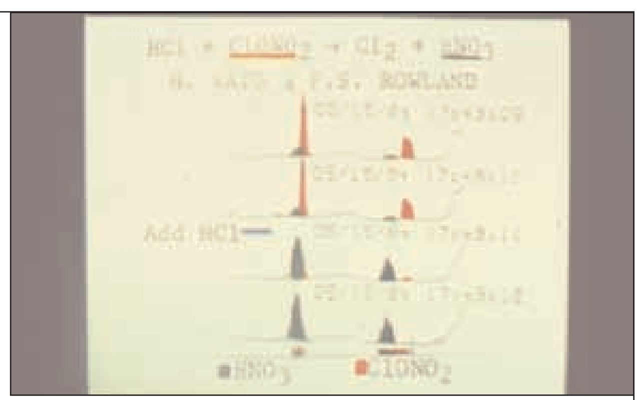
MOLINA We had an additional National Academy of Science report in 1984. Notice the change in wording here. The title doesn't say "reduction" any more, but now uses "changes" here. Because of these complexities that Sherry was alluding to—the use of these more complicated models, incorporating more and more variables—there were calculations for some of these models raising the possibility of ozone levels increasing in the lower atmosphere as a consequence of the release of these compounds. Of course, this possibility only happened in some of these models and for some of the guesses about future inputs of other atmospheric gases.

SLIDE 16: NAS Report 1984

ROWLAND Back in 1975, when the National Academy was doing their initial study, one of the questions that was asked of me at a meeting in Snowmass, was, "Is there anything you can think of that would make ozone depletion worse?" I said, "Yes, if hydrogen chloride were to react with chlorine nitrate, then two chemical forms of chorine, inactive forms that do not attack ozone, would be reacting to create an active form." But there was no evidence for this reaction occurring.

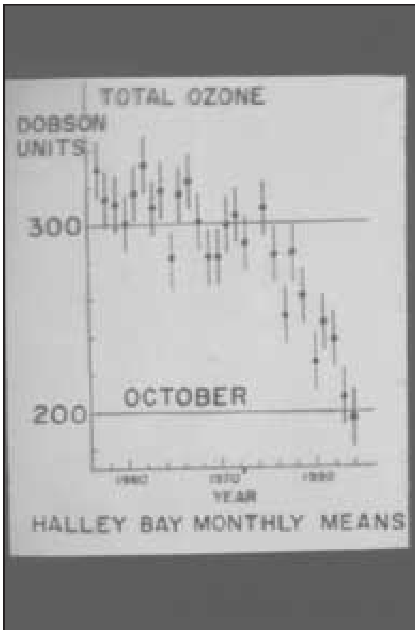
Mario and I had tried an experiment with John Spencer in 1976. We mixed the two gaseous chemicals, hydrogen chloride and chlorine nitrate, and John ran them down to the infrared instrument at the end of the corridor, and found that everything had already reacted. But the experiment had lasted five minutes, and that was too slow. Certainly a reaction had occurred, but if the reaction had required all of five minutes, then it was not fast enough to be significant in the atmosphere. And at the time, we didn't have equipment available to carry out the experiment more rapidly.

But now in 1984, when we started looking back at this possibility again, a Japanese post-doctoral associate, the late Haruo Sato, and I looked at hydrogen chloride and chlorine nitrate with a new piece of equipment [a Fourier-transform infrared spectrometer] which would allow separate measurements in one-second intervals. What Haruo found was that as soon as you added hydrogen chloride, the chlorine nitrate disappeared: gone in one second.



SLIDE 17: Haruo Sato and FSR: HCl + $ClONO_2$ data, as presented at a conference in Feldafing, Germany, June 1984

When we [with Don Wuebbles and Peter Connell of the Livermore Laboratory] put this finding into the model, it created a major loss in stratospheric ozone. If this reaction were happening in the atmosphere, and there was no evidence then that it was, then it would be serious because it could change the magnitude of eventual ozone loss quite substantially from 4 percent to 32 percent in the future.

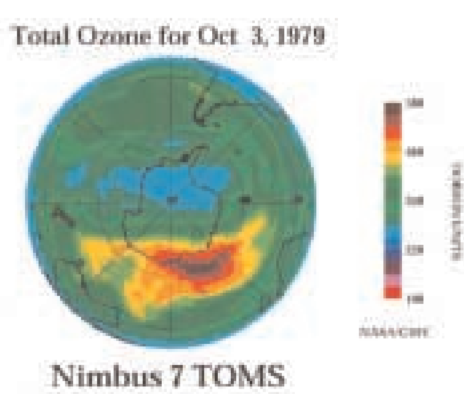


SLIDE 18: *October average ozone over Halley Bay, Antarctica* 1957–1984

MOLINA By that time I was working independently of Sherry, but we had reached quite similar conclusions in our own laboratory experiments.

Something else happened around that time, a very, very important finding, but also very unexpected. Here we have measurements of ozone levels: the levels in Dobson units, the measure of the total amount of ozone that exists over the earth's surface, but in this case, over Halley Bay in Antarctica. A scientist from the British Antarctic survey, Joe Farman, had been doing these measurements with his team since the International Geophysical Year in 1957. They realized early in the 1980s that something strange was happening with ozone. In the springtime, which is when the light begins to appear after the long Polar night, the levels were going down.

At first, his team did not believe these data. They thought that perhaps something was wrong with their instruments. There was another piece of information that made them skeptical. There was a NASA satellite measuring ozone already globally, including Antarctica, and they had heard nothing unusual about the results of those measurements. As you can see, eventually in 1985, Joe Farman and his team published their results, and actually suggested that this very big change in ozone over Antarctica was a consequence, or was connected to, the release of CFCs.



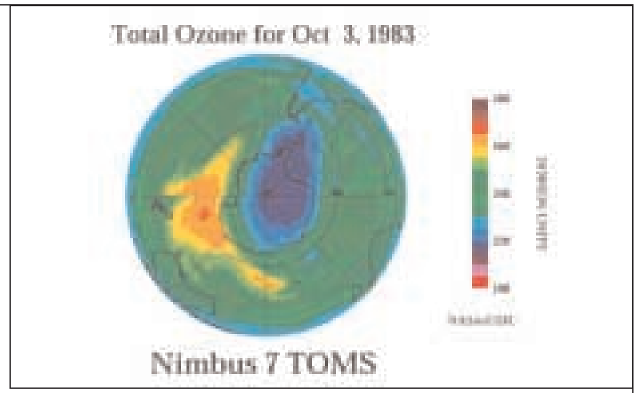
SLIDE 19: *Antarctic ozone, October* 3, 1979 *(All satellite images produced by Dr. Rich McPeters, NASA)*

ROWLAND This observation by the British brought the NASA satellite people back to look at their data. Actually, they've gotten sort of a bad rap about it. What they did was program their data to reject, but notify, that some unusually low ozone values were being recorded. If you are getting unexpected low values when the instrument is working at the very limit of its detection, then you put that aside, saying, maybe there is something happening there that is real, but maybe it is an instrumental problem, and we'll have to go back and look at it carefully.

Then, when Farman published his work, they realized that the other explanation, that the numbers were real, that the ozone levels were very low, was very likely true and they looked again. This is the way their instrument [the Total Ozone

Mapping Spectrometer on the Nimbus 7 satellite] recorded the ozone levels. With hundreds of thousands of ozone measurements, the numbers have been converted to a color code, and all of the data for the southern hemisphere on one single day are shown in the Figure. You can also see the outlines of the continents: South America, Africa, Australia, and Antarctica. The first slide is for October 5, 1979, and the next is for October 5, 1983, four years later.

All you have to do is look at the color change to know that something very striking had happened in the four years in between the two measurements. The amount of ozone had decreased over all of Antarctica, not just Halley Bay. These observations raised a red flag for the whole atmospheric scientific community. Something startling was going on over Antarctica that had been tipped off by Farman's measurements and then confirmed by the NASA satellite that it wasn't just something at Halley Bay, but it was something the size of Antarctica; that is, over an area somewhat larger than the entire geographic area of the United States.

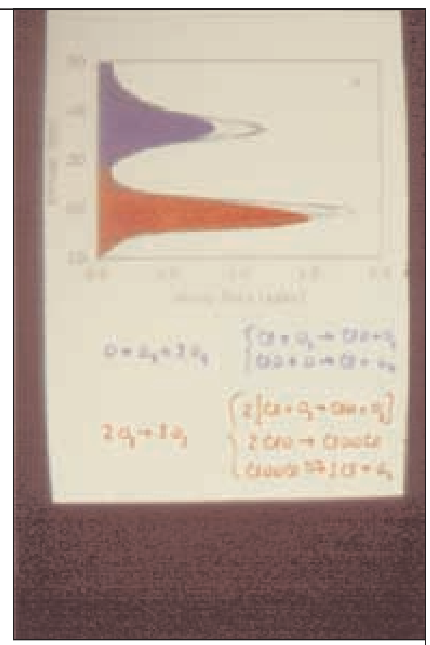


SLIDE 20: Antarctic ozone, October 3, 1983

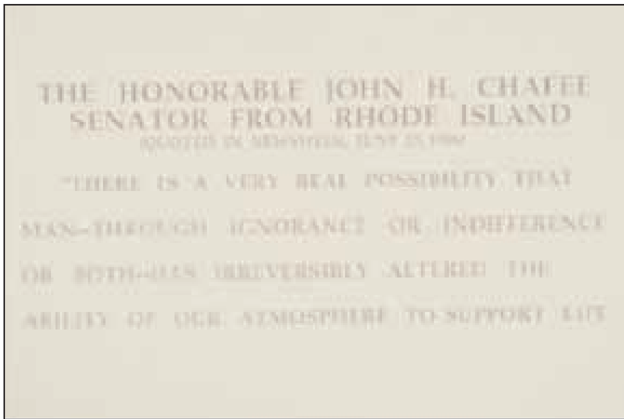
MOLINA Because of these observations, scientific expeditions were organized to go to Antarctica. In the first one, the most important one, a number of scientists went to Antarctica to study what was happening. The team of Bob deZafra and Phil Solomon [unrelated to the NOZE Expedition leader, Susan Solomon] were able to detect emissions at ground level from the key ozone-depleting radical, ClO, with an instrument, which also provides information about the altitude where it occurred.

We have their results you see in this figure. We already knew that some very significant changes in the ozone were happening, but now the changes actually could be attributed to the presence of chlorine catalysts, the very same catalysts we had been worried about initially. Except we had, of course, not specifically suggested that these catalysts would be abundant over Antarctica.

However, at that time, portable computer power was not particularly large, and they had to take their data back to the laboratory in the US and refine the calculations to obtain the altitude distribution shown here. Consequently these data did not receive as much pubic attention as they deserved in hindsight.



SLIDE 21: Two ClO altitude measurements over Antarctic region (Robert deZafra and Philip Solomon)

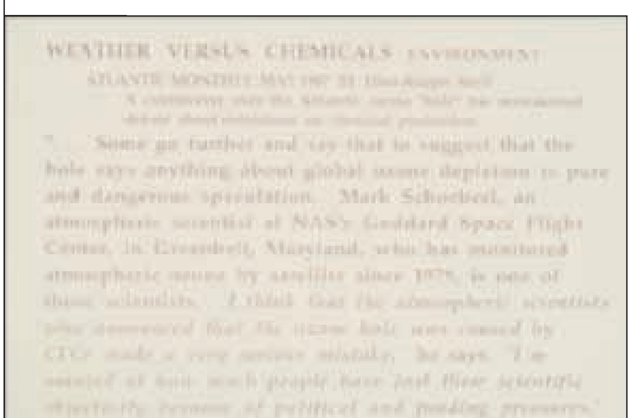


SLIDE 22: *June 10, 1986 statement by Senator John Chafee, as quoted in Newsweek*

ROWLAND In June of 1986, Senator Chafee held hearings on the questions of stratospheric ozone depletion, greenhouse effect and global climate change. This is the statement that he made at those hearings, "There is a very real possibility that man, through ignorance or indifference or both, has irreversibly altered the ability of our atmosphere to support life." That was a very strong statement, a very powerful statement, coming from an influential senator. It was quoted not only in *Newsweek* but also later in *U.S. News and World Report*. The statement indicated that there would be support for regulations because of the concerns that had reached the senatorial level and had made an impression there.

MOLINA When this depletion of ozone over Antarctica first became known, it wasn't really clear at that time what was the cause. I remember we worried about it. We thought it was very likely that the CFCs, the man-made compounds, were involved. Of course, it also could possibly have a natural cause. We also realized later we hadn't really covered all the bases, natural or man-made, we missed something that the press actually uncovered.

SLIDE 23: *Ozone loss from UFO Aliens? (December 16, 1986)*



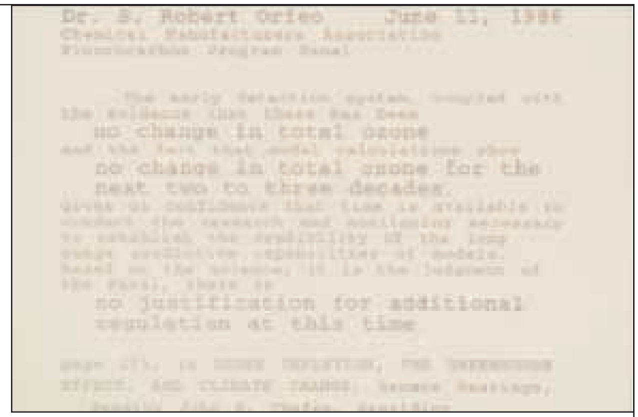
SLIDE 24: *Weather Versus Chemicals—Atlantic Monthly, May 1987*

ROWLAND The scientific objection to this article is that it was not peer reviewed.

On the other hand, there were some genuine arguments, and a number of explanations. The meteorologists leaned toward meteorology, and the chemists leaned toward chemistry, and it became a bit acrimonious. This quotation is taken from the *Atlantic Monthly* in May 1987.

> "I think that the atmospheric scientists who announced that the ozone hole was caused by CFCs made a very serious mistake. I'm amazed at how much people have lost their scientific objectivity because of political and funding pressures."

There was a certain amount of war about everything that was going on at that time and it was necessary to have further expeditions to explore it. After the ground expedition to Antarctica in 1986, led by then 30-year-old Susan Solomon, she subsequently led another very successful one in 1987, and there was an aircraft expedition [based in Punta Arenas, Chile] that went as well in 1987.



Dr. S. Robert Orfeo June 11, 1986

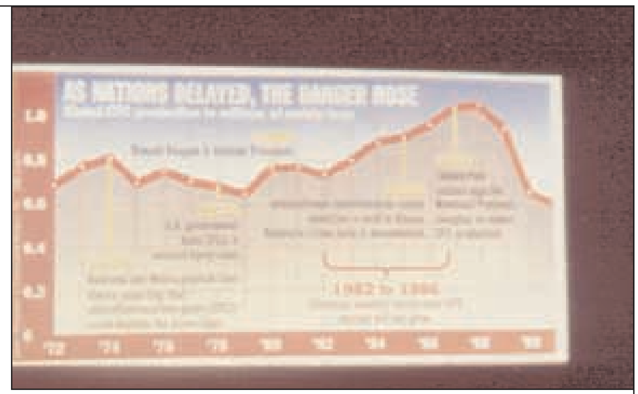
no change in total ozone

no change in total ozone for the next two to three decades.

no justification for additional regulation at this time

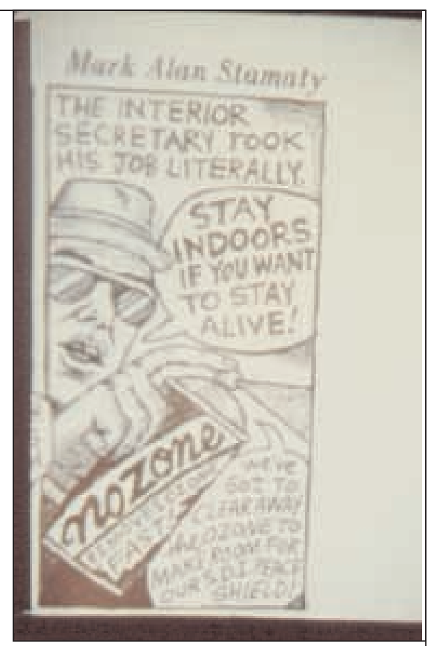
SLIDE 25: *Statement by Robert Orfeo, Chemical Manufacturers Association, at Senator John Chafee hearing, June 11, 1986*

MOLINA The war that Sherry was alluding to also extended to industry. Here we have a statement to Senator Chafee's hearings in 1986, from Bob Orfeo, a representative of the fluorocarbon manufacturers. You can read it, but his conclusion really was that there was no justification for additional regulation at that time. Indeed, at that time, the problem of ozone depletion over Antarctica was already surfacing, but there again, the fact that it was possible that it was an entirely natural phenomenon was certainly a fact that industry emphasized quite a bit.



SLIDE 26: CFC Events: *Time Magazine* 1993

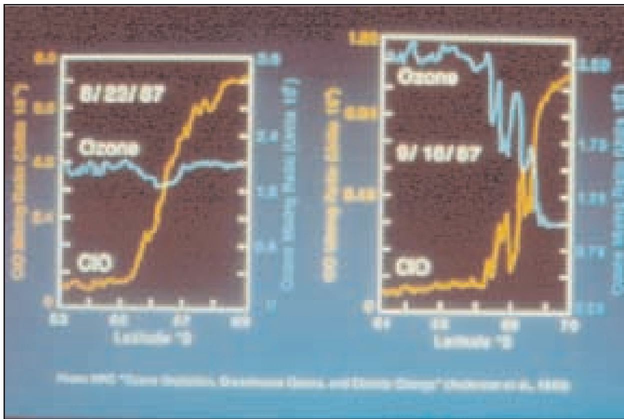
ROWLAND *Time* magazine later published a description of the timeline that was involved in the stratospheric ozone situation. In 1985, the first international action was led by Ambassador Benedick. The Vienna Convention arranged that it would be possible to establish regulations, but it did not call for regulations at that time. But then in 1987, the Montreal Protocol was signed just in advance of the results that were obtained from the two 1987 expeditions carried out flying over Antarctica from South America and on the ground in Antarctica itself.



SLIDE 27: *Mark Alan Stamaty Cartoon, Village Voice*, 1987

MOLINA So, we have this argument among the scientists and this argument with industry, but also this argument with the government.

It turns out the Secretary of Interior Hodel, at that time, had some other ideas, mainly that it was perhaps possible to protect ourselves with sunglasses from the harm of ultraviolet radiation that would penetrate in larger amounts if ozone were depleted in ways that did not require any real changes in the industry. Actually, the press had a field day. They had elephants, lions, and zebras all wearing sunglasses.



SLIDE 28: ER-2 *Flights over Antarctica*, 1987

ROWLAND The key experiment that firmly convinced many people involved the simultaneously measurement of ozone loss and the presence of very high concentrations of chlorine oxide, the smoking gun of chlorine attack on ozone. But I think it is worth describing a little more about the circumstances of this experiment. What it required was sending an airplane with a single pilot flying from Punta Arenas about 3,000 miles down over Antarctica and back. It was an ER-2, a single engine airplane that evolved from the U-2 that Gary Powers was flying over the Soviet Union when he was shot down in 1960. There are no alternate airports. If its engine conks out, then that is pretty much the end of the story.

These experiments were critically dependent on an exceptionally courageous and dedicated group of pilots, who flew for hours toward the polar darkness, knowing that there was no hope for survival in case of engine failure. The experiments are all automatic; the pilot turns on the equipment at the proper time, the instruments record the data, and when the plane comes back the scientists examine what they have found. You don't know until the plane has returned and people have had a chance to look at the data.

On the first flight everything seemed to have worked well. Mike Proffitt's instrument to measure ozone worked throughout and showed less ozone over Antarctica than outside the Polar vortex. The key instrument for measuring chlorine oxide was working very well until the plane got over Antarctica where the temperature in the stratospheric polar vortex is very cold, about minus 85 degrees Centigrade, or minus 120 degrees Fahrenheit. In the intense cold, the instrument quit working. And then as the plane emerged from the Polar vortex, the temperature went up and the instrument came on again. Well, needless to say, the pilots who were risking their lives on every flight were not enthusiastic about further trips if the key chlorine oxide instrument was not going to work.

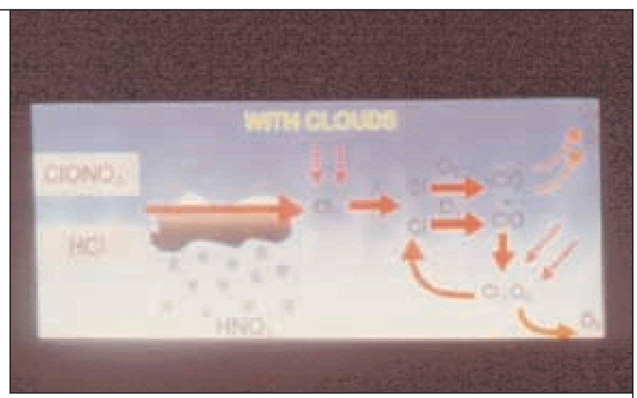
This instrument was newly created by Jim Anderson's group from Harvard especially for these flights. The only in-flight testing that had been possible was on the "ferry" flights that took the ER-2 to South America. [Actually, "newly created" is an understatement. The instrument went from hardware sketches in January to unassembled parts in May, a marginally operating flight system in July, and included software development under the ER-2 wing in driving rain during stops in Panama and Puerto Montt, Chile.] The person who had programmed the instrument flight computer that both controlled the instrument and recorded data in flight was an exceptional undergraduate, Norton Allen, who joined the research group after graduation and had then accompanied the group to the flight base in Punta Arenas, Chile, a base used by the Chilean Air Force as a strategic outpost.

After the first flight, Allen wrote a new watchdog routine overnight for the flight computer that surveyed all communications between the instrument and the computer. The next time they flew, the same thing happened. Everything worked fine until they got into the Polar vortex, and then the chlorine oxide instrument quit again. After the ER-2 returned, and the data had been analyzed, the computer program indicated where the problem lay. [As the temperature dropped through -85 degrees Centigrade, a main status line buried in the spinal column of the instrument opened up, a result of metallic contraction at the site of a microscopic defect in the solder joint in the center pin of a connector. The evidence was unmistakably captured and stored in the instrument's memory.]

Prior to the third flight, the connector was isolated, tested to failure at low temperature with liquid nitrogen and then replaced. On the third flight the instrument then performed flawlessly, and the results shown on the left side of the figure for the 23rd of August came from that flight. What they found was that there was a lot of chlorine oxide over Antarctica, but little or no change in the ozone. However, the change in ozone had always been observed during September and into October. This was late August, the end of the southern winter, and the sun had just barely begun to penetrate to the latitudes over Antarctica.

On September 16, as the flights continued, they again found lots of chlorine oxide, but now two-thirds of the ozone had gone away during the intervening three weeks. This evidence from the whole series of flights persuaded almost everyone in the scientific community that the cause of the loss of ozone over Antarctica could be attributed to chlorine, and that the presence of all this chlorine could be attributed to compounds put into the atmosphere by mankind.

MOLINA By that time, we were also carrying out additional laboratory experiments, and we really understood well why it is specifically over Antarctica that we would have this huge effect on ozone. It was related to the very low temperatures that exist at those latitudes. There is very little water in the stratosphere. It is very dry. But if it gets sufficiently cold, that even that little bit of water actually condenses, and you get clouds, ice clouds. And these ice clouds provide those surfaces that promote the reactions that Sherry alluded to before. You get chlorine activation making this catalysis very efficient. You also remove the nitrogen oxides that interfere with the chlorine chain by reacting with chlorine oxide.

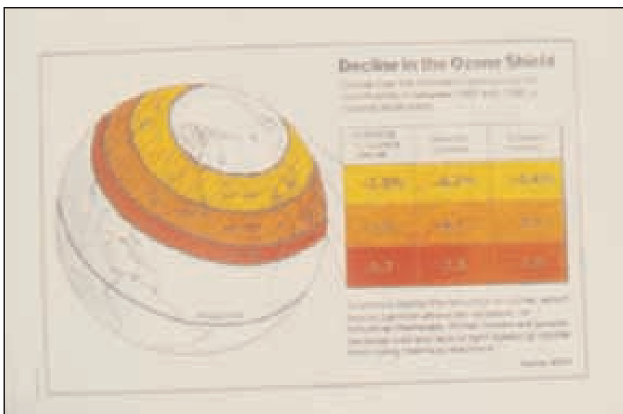


SLIDE 29: *Chlorine chemistry with clouds over Antarctica*

We were able to carry out some experiments in my laboratory in collaboration with my wife, Luisa, in which we demonstrated the presence of another compound that we had not considered before, namely chlorine peroxide, the combination of two ClO radicals to form Cl_2O_2. And we came up then, with additional chemical explanations that were specific to Antarctica, a region where ozone has not been made, but it could be destroyed extremely efficiently by these reactions. In fact, the time scale of a few weeks coincided very, very well with the observations of Jim Anderson.

SLIDE 30: NASA—WMO Ozone Trends Panel, 1988

ROWLAND Starting in 1985 there had begun to be international assessments and measurements to replace the series of National Academy studies. In late 1986, Bob Watson of NASA put together a group called the Ozone Trends Panel, which involved initially about 25 scientists in the main panel, and, perhaps, 125 after sub-panels were formed. In 1988, the Ozone Trends Panel made its report as shown here. This volume did not come out until later, but the initial press conference was held on March 15, 1988 and essentially said that the cause of the loss of ozone over Antarctica was chlorine-containing compounds, especially the chlorofluorocarbons.



SLIDE 31: *Decline in ozone over northern hemisphere, as reported in the New York Times, March 16, 1988*

MOLINA This graph was prepared by the New York Times from the Ozone Trends Panel material, indicating very clearly that observations had shown ozone being depleted and thinned, not just over Antarctica, but actually also in the northern hemisphere winter where it also gets very cold. The depletion doesn't reach the same extent found in Antarctica, but the very important consequence of these observations is the fact that the phenomenon of ozone loss was not really confined to the deep southern latitudes.

SLIDE 32: NASA—WMO 1988 *report of winter-time loss of ozone in northern hemisphere (derived from Ozone Data of the World, ODW)*

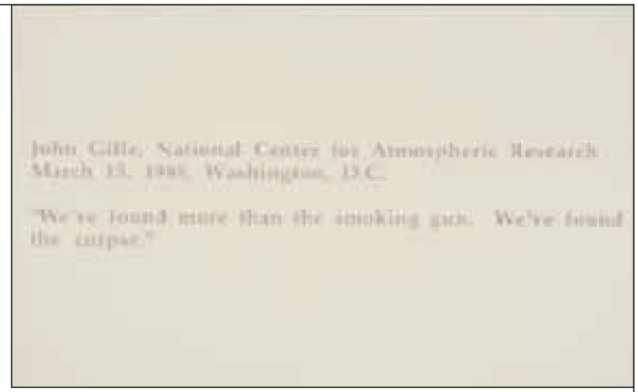
ROWLAND The starting point for this determination was a series of ozone measurements that had been made for many years. In fact, people had been asking since 1974, "Is there any evidence for ozone losses over the United States or Europe?" And, for 11 years, statisticians had been doing very elaborate calculations and had always concluded that no evidence for any ozone loss had been detected. This new effort started with a graduate student of mine named Neil Harris, an Englishman, who now is back in England. He first did some calculations for the long record since 1931 of ozone measurements at the permanent station in Arosa, Switzerland.

He divided the record into 1931-1969 and 1970-1986 and compared the before/after averages for each calendar month, and found that there had been less ozone over Arosa in the winter months after 1970 than before. Then, as part of a subgroup of the Ozone Trends Panel, we extended this to all of the ozone-measuring stations with records for at least 22 years, that is, for the length of two solar sunspot cycles [because it was known that ozone levels varied a little with sunspot activity]. These calculations were simply the average over the winter months for one 11-year period, and then for another period of 11 years, subtracting one from the other. Every station in the northern hemisphere north of 30 degrees N latitude had shown less ozone in the second 11-year period than in the first.

The statisticians had missed this because they had assumed that if there were any ozone loss that it would be uniform all through the year. And it had been known for many years that the summer months had much less natural variation in ozone, so, if the summer had much less natural variation, then obviously, you should look at the times where a change would most easily be detectable. What the Ozone Trends Panel showed was that there was clearly a wintertime loss, and no significant evidence at that time for a loss during the summer. These calculations were the first evidence that ozone had been lost over heavily populated latitudes of the northern hemisphere.

MOLINA The scientific evidence was really accumulating by that time. Here we have a statement from by a colleague of ours at the Ozone Trends Panel press conference on March 15, 1988, "We've found more than the smoking gun. We've found the corpse." So, no surprise, ten days later after all of these findings really became evident, the Dupont Company, the largest manufacturer of CFCs, changed their mind and decided they would no longer manufacture these compounds.

The scientific evidence was extremely clear. I believe that was a very important turning point for the chemical industry. As many of you might know, the chemical industry, the Dupont Company among others, has a very, very different attitude towards environmental problems nowadays. In fact, they pride themselves now on being environmentalists.

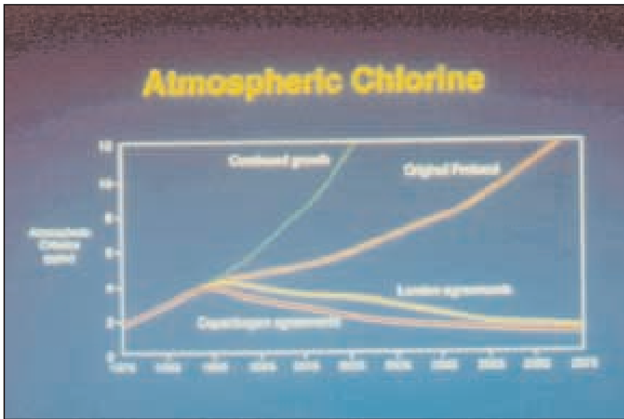


SLIDE 33: *John Gille: We've Found the Corpse*

ROWLAND The ozone question also was international. Prime Minister Margaret Thatcher called a meeting on "Saving the Ozone" in London early in 1989. On Tuesday, Prince Charles had spoken to the delegates, saying that the British government was acting too late, and the next day the Prime Minister said, no, we are doing it at just the right time.

Around that time, Bob Watson, who had chaired the Ozone Trends Panel , born in England but now a naturalized US citizen, was present at a meeting in England at which Prime Minister Thatcher was listening to the arguments, and found out that a very long time scale, stretching to a century or more, was involved. She then said, "Time is not on our side. We must act now." I think the UK policy on ozone depletion changed on that night.

SLIDE 34: *Prime Minister Thatcher attacks Prince Charles over protection of stratospheric ozone*

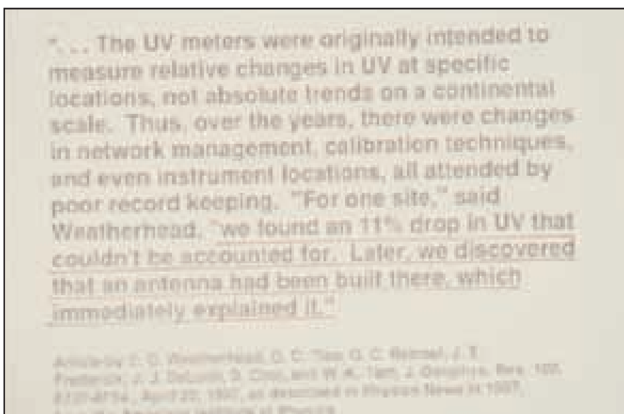


SLIDE 35: *Projected tropospheric chlorine concentration for various regulatory options*

MOLINA This graph illustrates these time scales. We have here the levels of chlorine expected to be present in the atmosphere, including projections from the year 2000 on, depending on what society does. Without any regulations we would expect a continuing, very significant increase, the green line in the figure. The original version of the Montreal Protocol was relatively weak. It only called for a partial limitation [50% reduction] to the production of CFCs, but when the scientific evidence began to accumulate, the Protocol was strengthened, first in London in 1990, and then in Copenhagen.

The international agreement reached there in 1992 called for a complete ban in the production of CFCs by industrialized countries by the end of 1995, with developing countries having some allowance to continue limited production of these compounds. You can see the very long time scale over most of the 21st century to return to the pre-1975 chlorine concentrations.

As Sherry showed initially, these compounds, the CFCs, remain in the environment for a very long time. They must be essentially inert for them to survive unchanged in the lower atmosphere long enough to get into the stratosphere. So we're talking about recovery times that are measured in many decades, even if the production stops, so the prediction is that the ozone hole over Antarctica will not disappear until the middle of this century.



SLIDE 36: *Recalibration of* R-B *meters explains an apparent* 11 *percent drop in ozone*

ROWLAND When you ask, what are the possible consequences of the loss of ozone, the prime consequence for humans is more ultraviolet radiation penetrating to the surface of the earth, especially ultraviolet-B radiation, which are the wavelengths that can be absorbed in the skin and damage DNA there. This ultraviolet-B radiation is the cause of human skin cancer. So increasing exposure to UV-B was a major concern.

A study came out in *Science* magazine in 1988 that had followed for a number of years, several ultraviolet B measurement instruments that really weren't designed and calibrated to handle data year after year after year. But that study was published and showed no change in UV-B radiation over the U.S. Then another research group later went back and looked at the data, and concluded that these instruments were not good for measuring absolute trends over a decade on a continental scale.

There were serious changes in network management and flaws in calibration. For instance, this group did some statistical analysis and concluded that with one of the instruments a significant change had happened during a particular short interval of time. It looked as though there was a sudden UV-B change by 11 percent. They then visited the actual location, and found the cause of this 11 percent drop in UV that couldn't be accounted for. This is an instrument that sits out in the open collecting UV-B from all angles, and an antenna had been built nearby that partially shielded it. This change hadn't been recorded, and the calibration change taken into account.

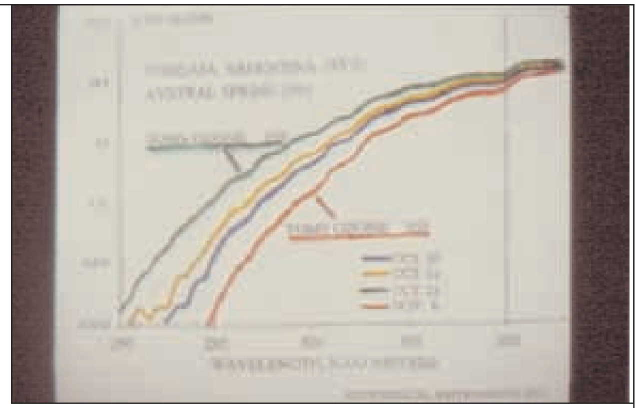
This kind of investigation took care of the concern about why it was that we weren't getting more UV-B radiation if the amount of ozone was decreasing. We were receiving more UV-B. It was just that this was a flawed measurement.

MOLINA One of the questions that was commonly asked, and is still commonly asked, is, "If this ozone hole and the increasing ultraviolet radiation occur over Antarctica, perhaps we shouldn't worry about it that much." I can mention a couple of reasons why that is not the case. It is indeed the case that not many people live in the Antarctic continent.

But first of all, to me, it is symbolic that the place where these chemicals are having the largest effect is as far as possible from the sources, way out in the southern hemisphere. So we are truly having a global problem. Second, if any of you have been to Antarctica, what is really impressive in the oceans surrounding the continent is that they are teeming with life. So even though there are not many humans, it really is a very important portion of our planet in terms of ecosystems.

Changes there really have repercussions for life anywhere in our planet. If we affect their ecosystem by increasing the levels of ultraviolet radiation, that is something to worry about, and indeed there are experiments to show that this is the case.

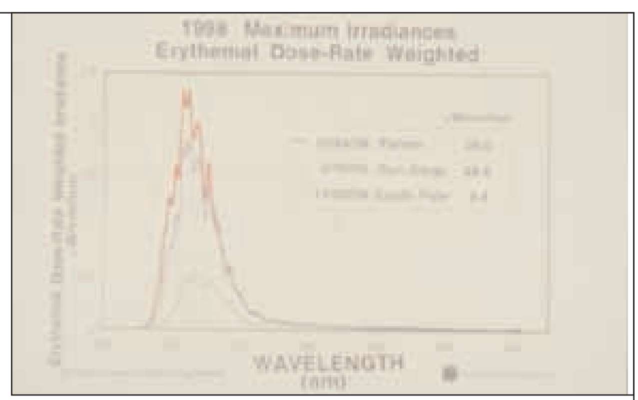
But in fact we have to worry about people themselves because occasionally this ozone hole and the Polar vortex reach over the southern tip of South America, and over cities such as Ushuaia in Argentina where instrumental measurements show the increased levels of ultraviolet-B radiation. When you contrast the red with the green line, at wavelengths around 295 mm, the intensity increases by two orders of magnitude. The corresponding change in ozone by almost a factor of two from 189 to 355 Dobson units over just a few days is very, very large. But the increase in intensity in the ultraviolet-B wavelengths is very much greater. It is a very non-linear phenomenon.



SLIDE 37: *UV-B measurements at Ushuaia, Argentina, Spring 1991*

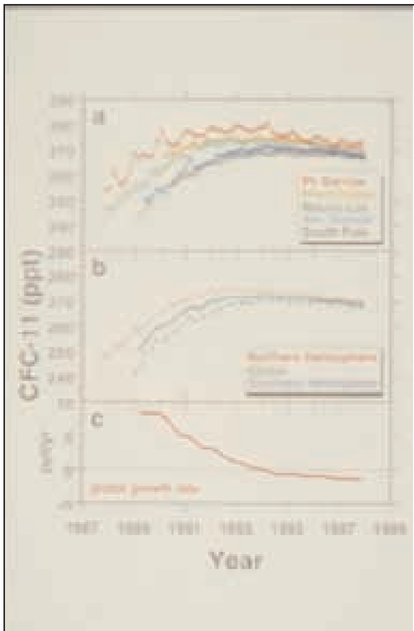
ROWLAND The current measurements now show just how much change has taken place. The data in this slide were taken with three comparable instruments, one in San Diego, California, one in Palmer (which is in the Antarctic Peninsula) and one at the South Pole. For each instrument, the measured UV-B wavelength intensities have been weighted by the erythemal index which is how your skin responds in terms of sunburn. For each location, the data represent the most intense UV-B day experienced during that entire calendar year.

What the figure shows is that on the most intense day in the Antarctic Peninsula, the ultraviolet radiation was 25% greater than on the most intense day in southern California. And the South Pole was not too far behind, because the South Pole sits in the Antarctic ozone hole for many weeks. So what we have done is produce a situation in which UV-B radiation can be on



SLIDE 38: *Maximum irradiances at three locations, 1998*

occasion very high in Antarctica, stretching out into places like Ushuaia and Punta Arenas in Chile, reaching levels normally associated only with the tropics.



SLIDE 39: *Decline in atmosphere CFC-11, 1989 to 1998*

MOLINA We could ask next, “Is the Montreal Protocol working?” The answer is, “Yes,” and this is an extremely important precedent, this international agreement. This figure shows the measured levels of one of the CFCs, CFC-11, as a function of the calendar year—measurements made, in this case, by NOAA (the National Oceanic and Atmospheric Administration). The data show the concentration increases in the earlier years as expected from the steady industrial production.

They then level off in anticipation, of course, of the prohibitions of the Montreal Protocol against further CFC release. In the red curve at the bottom of the figure, you can see the growth rate begin decreasing even before the Protocol became active, and then actually going negative, the rate of loss from the atmosphere now exceeds the slight further losses from residual leaking in older installations.

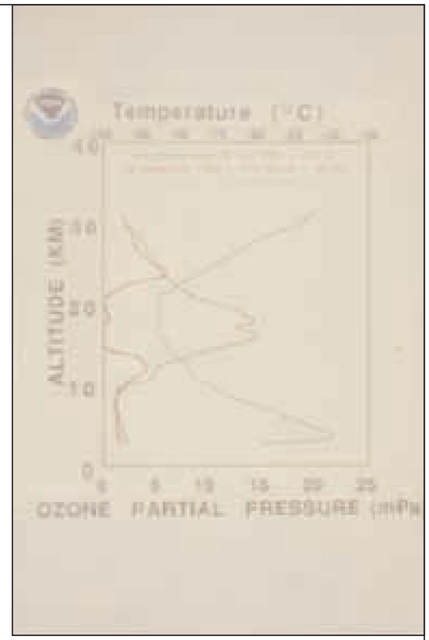
We can actually measure, then, in the atmosphere itself, a leveling off of these chlorine-containing compounds. In fact, there is another compound, methylchloroform that is also regulated by the Montreal Protocol and is much shorter-lived than the CFCs. Its concentrations have already decreased very substantially from the peak levels measured in the early 1990s. The Montreal Protocol really has been a very successful international agreement.

SLIDE 40: *FSR and MJM at Nobel Press Conference, Stockholm, December 1995*

ROWLAND We have skipped ahead here to December 1995. Mario and I together with Paul Crutzen spent a week in Stockholm. This photograph was taken during the press conference there. It is a signal to us that time is passing, not only in years, but here tonight. We want to give you a quick run down on what is happening now because there has been some information in the press about the Antarctic ozone hole this year. We’ll have a few quick slides here and then we’ll be ready to close up.

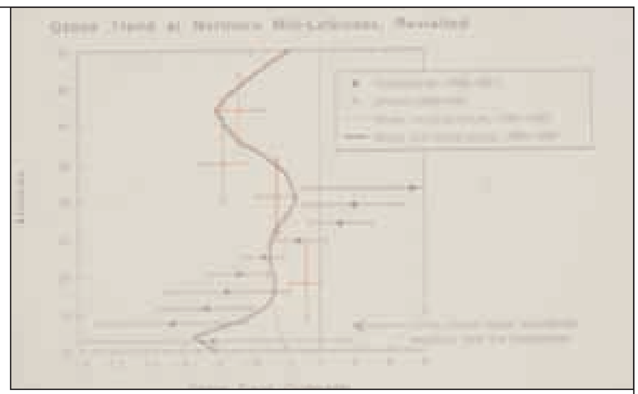
MOLINA This figure shows the ozone profiles and again this is over Antarctica. The green line is temperature, and you can see the temperature being very low around 20 kilometers above the earth's surface. The blue line is a normal-looking ozone profile in mid-winter [August 28, 1999] that is where we expect the ozone to be, but after several weeks [September 29, 1999] of this ozone being exposed to chlorine, you can see that over a certain altitude range, actually more than 99% of the ozone disappears.

That is why it is labeled "ozone hole." Ozone is essentially gone there, and that again points out the importance of low temperatures, which is where these clouds form, and, it is, indeed, a very spectacular phenomenon. At lower altitudes where there are no clouds, the ozone is not affected.



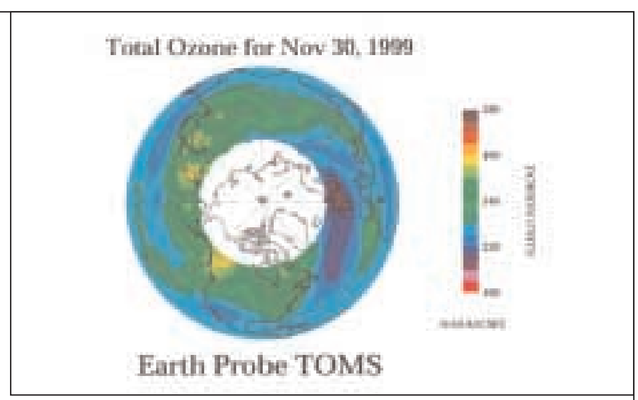
SLIDE 41: Balloon-measured ozone over South Pole, July 28 and September 29,1999

ROWLAND The measurements in the atmosphere in mid-latitudes show not only an ozone loss down around 20 kilometers, but there is also an ozone loss up around 40 kilometers which is the location for ozone loss in our prediction that we made originally back in 1974. That is where the main gas phase reactions occur both in the models and as observed in the atmosphere.

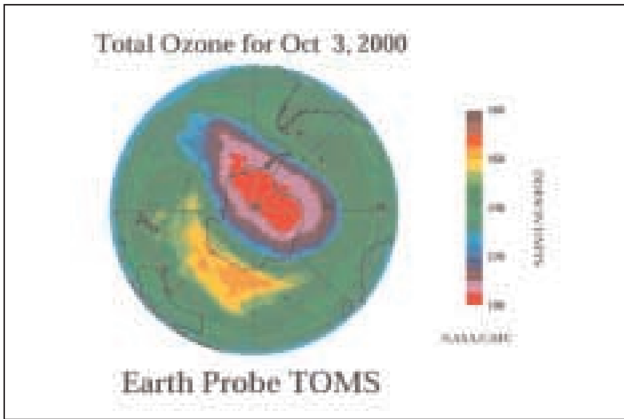


SLIDE 42: Ozone trends versus altitude over Northern Hemisphere showing ozone loss at 40 kilometers

MOLINA This figure shows measurement of substantial loss of total ozone in the northern hemisphere measured by satellite measurements, indicating that, as stated before, that ozone loss is not constrained to the southern hemisphere. Indeed, it is worrisome that significant depletions will occur in the future and the losses depend on whether you have a cold year or a warm year in the stratosphere.

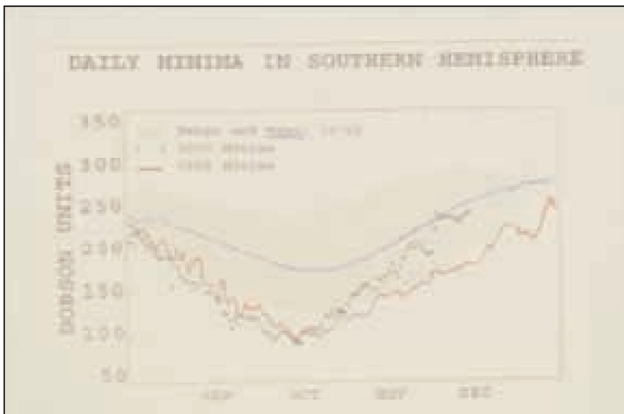


SLIDE 43: Low ozone levels over northwestern Europe, November 30, 1999 (No data obtainable from dark polar regions)



SLIDE 44: *Southern Hemisphere ozone, October 3, 2000*

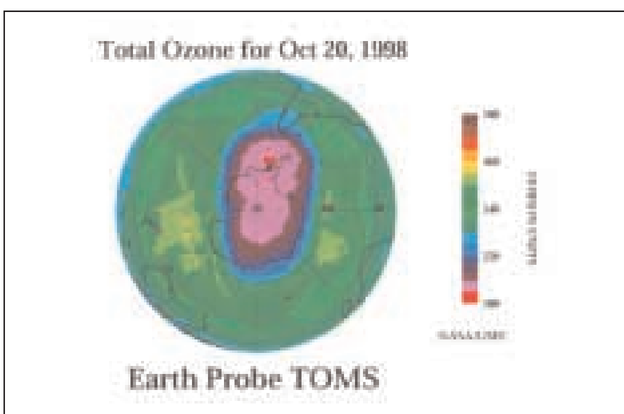
ROWLAND This figure shows that this year's ozone hole which you have probably heard announced as having the greatest area formed very quickly. This is the ozone hole during the first week in October.



SLIDE 45: *Ozone Hole Daily Minima 2000*

ROWLAND If one looks at how deep the ozone hole was this year, then what you see in this figure is the minimum value recorded on successive days throughout the period from August to December. The gray region is the day-to-day range of minimum values recorded during the years from 1979 through 1992; the central line is the daily mean value for all of these minima. The red line shows the daily minima for 1999, and you can see that in September it was deeper than ever early, but when it reached the deepest part when the minima were about the same as in previous years.

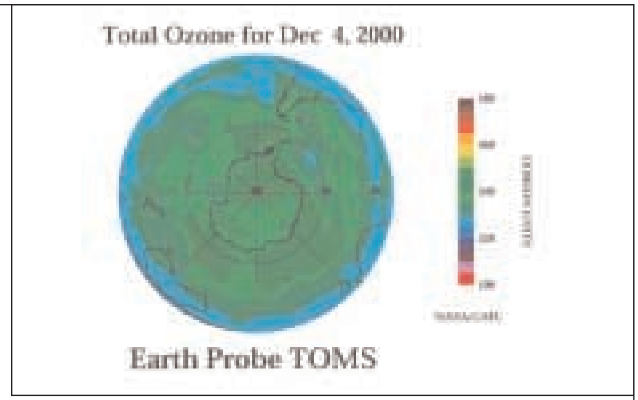
In the end, the hole wasn't any deeper in 1999, but it got there sooner. The same thing happened in 2000, as shown by the little crosses in the figure. In September, the minima in total ozone were even lower than in 1999, but this time the recovery was much quicker with much higher minimum ozone values in December 2000 than one year earlier.



SLIDE 46: *Southern Polar* O_3*, October 20, 1998*

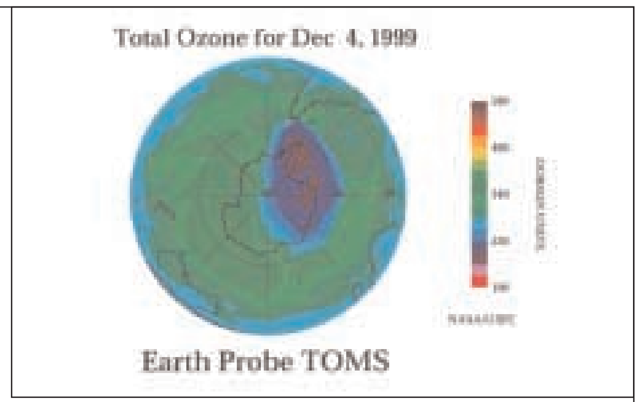
MOLINA On this day, the elongated, off-center ozone hole reaches to the southern tip of South America. The people living in Punta Arenas, Chile are really worried when ozone levels drop down to something like 170 Dobson units. The local government really wants everybody to wear sunglasses on days with such low amounts of ozone overhead, but they cannot afford them. Perhaps it is the responsibility of developed nations to help these countries cope with the new situation; after all, almost all of the CFCs came from the northern hemisphere.

ROWLAND The situation actually is that you can now see yesterday's ozone values [and all of the other satellite data back to November 1979] directly on the Internet. This figure shows the data for Monday of this week. The ozone hole is already gone for the year 2000.



SLIDE 47: *Southern Polar* O_3*, December 4*, 2000

ROWLAND This is the way it looked one year ago, December 4, 1999.

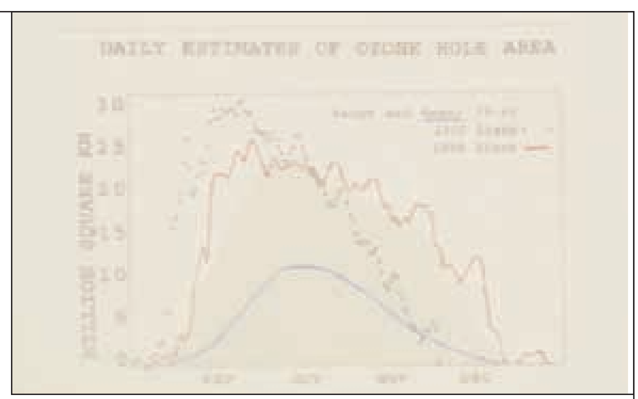


SLIDE 48: *Southern Polar* O_3*, December 4*, 1999

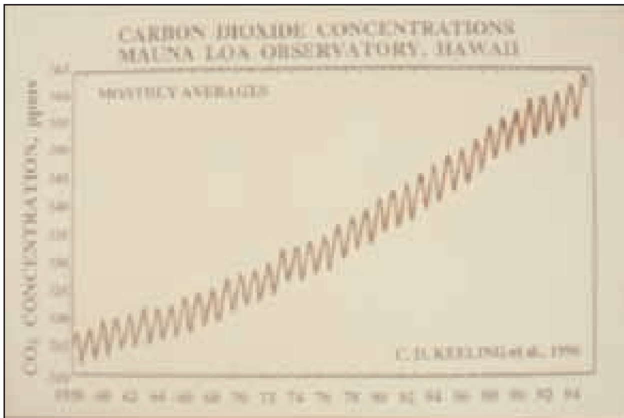
ROWLAND The next figure shows the area of the ozone hole, defined as the region with ozone values below 220 Dobson units. The symbols here for daily area measurements are the same as those used earlier for daily minima: gray area for the daily area values from 1979 through 1992, central line for the median values over that time period, red line for 1999, and small crosses for the year 2000.

You can see that the low ozone values did take up a very big area—30 million square kilometers, or 12 million square miles (the area of the United States is 3 million)—but then plunged sharply this year and the hole disappeared in mid-November.

This is meteorology that is involved here. In 1999, the region of low ozone over Antarctica lasted into early December; this year it disappeared two or three weeks earlier. The behavior of the Antarctic ozone hole was different in 1999 and again in 2000, but the magnitude of the loss at its deepest and the area of loss at the time of the lowest minima were not very much different in terms of the overall change.



SLIDE 49: *Daily estimate of* O_3 *over Antarctic ozone hole area*, 2000

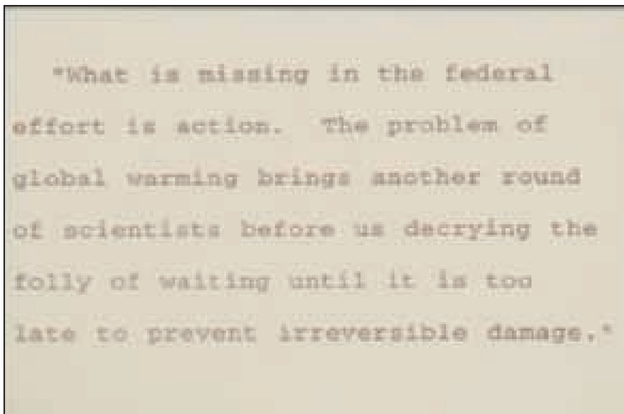


SLIDE 50: CO_2 *Measurements over Mauna Loa, Hawaii 1958–1995*

MOLINA We will move on now. These are measurements of atmospheric carbon dioxide concentrations since 1958, Dave Keeling's measurements, made near the peak of the volcano Mauna Loa in Hawaii. These are historic measurements that show another situation similar to CFCs; namely, in steady increases over time in the concentration of carbon dioxide in Earth's atmosphere, clearly attributable to human activities. This increase, of course, has consequences for the climate. There are indeed some scientific uncertainties about how our climate system will respond, but the measurements are there, and changes are under way.

ROWLAND This is the last slide and the next to last comment. "What is missing in the federal effort is action. The problem of global warming brings another round of scientists before us decrying the folly of waiting until it is too late to prevent irreversible damage." That could have been a statement made, I think, anytime in the last several years, but it was actually made by one of the junior members of the Senate at those hearings Senator Chafee held in June 1986, more than 14 years ago.

The statement was made by George Mitchell, who was then Senator from Maine, not yet at that time the Majority Leader of the U.S. Senate. This was a time when the Senator from Maine, the Senator from Montana, Max Baucus, Senator Chafee from Rhode Island and the Senator from Vermont, Bob Stafford—Senators from both sides of the aisle—were working together on the problems of the environment.



SLIDE 51: *Senator George Mitchell's statement at Senator John Chafee hearing, June 1986*

MOLINA I want to finish with a quote from Senator John Chafee, also from those hearings in 1986. Keep in mind this is almost 15 years ago, and I quote.

> *If we were masters of the world, we would do something about carbon dioxide. But we are not. We can't tell the Soviets what to do or the Chinese. But it seems to me that is not an excuse for no action at all on the part of the United States. That is why I find fault with the view that if we take action, the Europeans may not. But that is not a call to inaction, it seems to me. We ought to do what we can and set an example.*

ROWLAND & MOLINA Thank you.

QUESTIONS AND ANSWERS

Moderated by the Honorable Richard E. Benedick, President, National Council for Science and the Environment, Ambassador (retired), and Battelle Pacific Northwest National Laboratory:

Thank you very much, Sherry and Mario. It is really a remarkable story when you think of how close we came to not solving that problem and what the consequences would have been if it were not for courageous scientists like Sherry Rowland and Mario Molina coming at the right time and the right place, and finding their counterparts in the policy sector, in the Congress, and people like Senator John Chafee and his colleagues that together we were able to effectuate this marvelous success story. It's truth being stranger than fiction.

Mario and Sherry have offered to answer any question from viewing this history, this story. If you want to get something off your chest, this is the time to do it. And you have two Nobel Laureates to answer your questions. It would be good if you would identify yourself.

QUESTION **Jonathan Patz, Johns Hopkins School of Public Health.** We've very concerned about UV obviously, because of health effects. You showed a slide about the temperature sensitivity; showing that, in fact, it's the cold stratosphere and the ice crystals that the reaction takes place. That's a problem. I've been involved with the IPCC and global warming, and one of the questions that I have is, with global warming trapping the heat in the lower atmosphere, will the subsequent cooling of the stratosphere have any prolonging of the recovery of the ozone?

ROWLAND Yes, it's a possibility. The question that he has asked is, in the existing atmosphere with increasing concentrations of carbon dioxide, the effect is to warm the air at the surface and to cool the air at the lower stratosphere and because chlorine is most efficient at destroying ozone when the temperature is low, then the possibility exists that there will be an increased volume of air that exists at that low temperature.

But if you look closely, you will see that the temperature change is pretty rapid with altitude as you go above and below the region, so it's going to be hard to cool very much more air. So my own feeling is that probably this will be overwhelmed by the reduction in chlorine from the removal of the CFCs. The other part of it is, that if something happens to put a large amount of surface, it doesn't have to be ice, if a big volcano goes off, then there may be particles put into the air—that would make chlorine very much more efficient and we might get ozone losses then with that volcano.

This happened after Mount Pinatubo, the volcanic eruption in 1991 in the Philippines. It also happened to a much lesser extent in 1982. Those are the last two big volcanoes, but if there is a really big one that comes in the next 20 years, then there might be an effect.

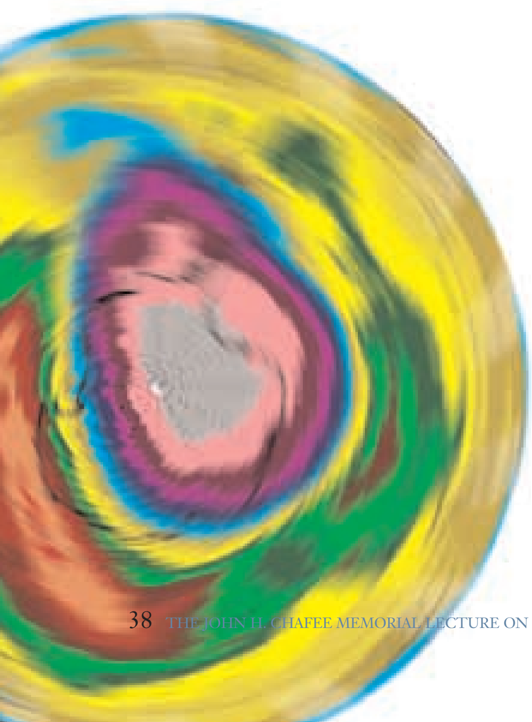
QUESTION **I'm Brian Goodman from Representative Vic Snyder's office in Arkansas.** My questions is, why do you think there is resistance from certain elements of the public in making changes that will protect the ozone layer?

MOLINA In terms of protecting the ozone layer, I think the most important fact is that there is this international agreement so you might ask this question historically. But at present, in fact, even the developing nations that are not constrained to stop their production, many of them are moving ahead of schedule. The science is very clear. The International community is behind it.

In terms of the public, my own opinion, perhaps it's just a lack of information. It's a different story when you talk about all the other global problems where the science is more complicated. But I think we can use the CFC ozone depletion issue as a brilliant example. It's a very important precedent that shows us that society can indeed solve these global problems.

QUESTION **Mignon Bush Davis, United Nations Association:** An enormous amount of chlorine is being used in our drinking water as well as in our swimming pools and is evaporating into the air. Need we be concerned to find alternatives?

ROWLAND In order to get to the stratosphere, the chlorine needs to be in a form that will not dissolve in rainwater, won't interact with sunlight. Hydrogen chloride dissolves in rainwater, and is removed from the atmosphere when it rains. Molecular chlorine (found in swimming pools) photolyzes in an hour. The CFCs, unfortunately, were beautifully designed to be stable and get to the stratosphere, but most other forms of chlorine don't do that. The ones from your swimming pool won't make it out of state, let alone to the stratosphere.



QUESTION **Henry Tang, The George Washington University.** The concentrations of CFCs have actually been decreasing since 1993, but the problem of ozone hole seems to become more and more terrible, especially this year. Can you tell us something about that?

MOLINA Yes, the actual amount of chlorine in the stratosphere is rather well measured. It didn't really decrease until very recently. It is beginning to level off. So it is the production that started really decreasing in those early years. And there are other compounds. We would not, of course, explain all the details, but there are compounds containing bromine whose concentrations are only now beginning to level off.

So the fact that we have some years with more ozone depletion, or a larger ozone hole, has to do with the variability of the natural system, the weather, years that are colder. But we do expect that perhaps these coming years, the beginning of the century, are the worst ones from that point of view, and that, slowly, the atmosphere will recover with these natural fluctuations.

ROWLAND The measurements that you saw were all made at the surface of the earth and there is a delay period which averages something like five to seven or eight years before there is a sort of equilibrium between the stratospheric chlorine and the tropospheric chlorine. So, if you go through a ground-level maximum in 1994, then 2000 to 2002 is about the time when you would expect the stratosphere to go through a maximum.

QUESTION **I'm Ronald Pulliam from the University of Georgia.** I know that you have been criticized for speculating, and you may have to speculate on my question, but I will ask it anyway. The question is very simple and largely aimed at Dr. Rowland. What if you had not been at that lecture of James Lovelock? How do you think these events might have unfolded?

ROWLAND Well, Mario might have thought of this completely. But actually, a group of us did a calculation, and it was published in *Nature* in 1996, about what would have happened if Mario had decided that one of the radiochemistry problems was the most interesting. What we think is, the question is, if this situation was just lying there, when would somebody have noticed it? Well, probably that would have been when Farman noticed it. He was doing those measurements and as long as he was doing them, at some point he was going to say, "something crazy is going on here."

Because we'd had ten years of thinking that it might be chlorine, we had an elimination contest in which the scientists around the world who were trying to measure chlorine in the stratosphere, some of them had succeeded, and they were the ones that were sent to Antarctica. If chlorine hadn't been the suspect, then we wouldn't have had the equipment ready to go. We wouldn't have been able to have people there two years later saying this is what it is. So, probably, we'd say another ten years, and probably the amount of CFCs in the atmosphere would have been up by a factor of two, maybe two-and-one-half, and we don't know what that would have done.

QUESTION **I'm John Mimikakis and I work for another Sherwood, Sherwood Boehlert, a Representative in Congress from upstate New York**, and my question is–I'm not sure exactly how to ask this–but you saw how the science in terms of ozone destruction progressed from hypothesis to become more and more certain, and you saw the parallel with how serious your warnings were taken by the public and the government progress to a greater and greater degree of sincerity and action. I was wondering if you could compare now with climate change, the state of the science and the reaction you see from both the government and the public, and if you can compare that to the progress you saw?

MOLINA The science, of course, with the climate change issue, as I mentioned before, is not nearly as certain. Perhaps it's in the state that we had in the early 1980s. To me there is enough information for society to act, if nothing else, on the basis of some form of a precautionary principle. If nothing else, society should get ready. Let me clarify. The question you are asking is no longer science. It has to do with value judgments and attitudes but we scientists also have opinions, so I think it is very valuable for us to keep those opinions.

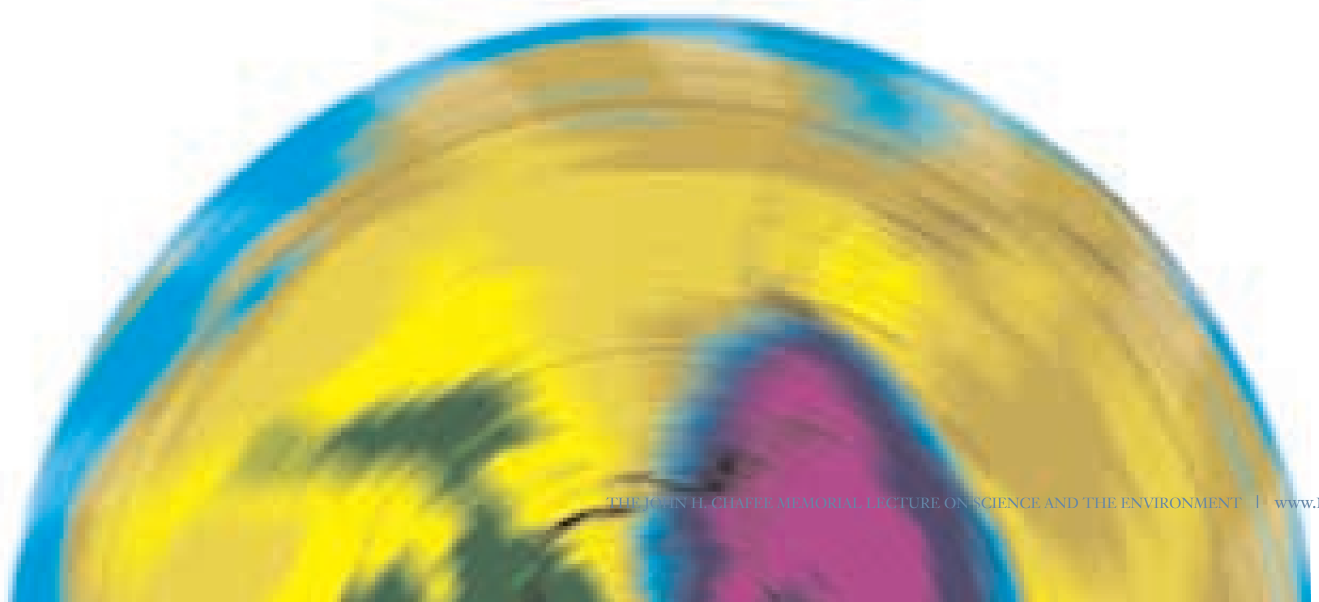
We just have to make it clear when is it we are speaking as scientists and when is it that we are expressing values. In my own opinion, when I am asked the question, "Do we have enough evidence that global warming is taking place and consequently should we do something about changing the way we go about consuming energy," to me, the right question is, "Do we have enough evidence that we are not messing up the system?" It's just too risky, and so it is imperative that at least we get ready, that at least we get prepared to do these changes, if nothing else because this is an analogy.

We don't quite have the same situation as the ozone hole yet, but do we do have lots of indications and perhaps you can see that from the latest reports of the scientific groups, (which by the way, the IPCC is analogous to the scientific community reports that we had in the case of ozone depletion) that the consensus is there. We certainly need to worry about those issues.

ROWLAND: And we depend on people like Representative Boehlert who has been one of the strongest environmental participants, in the sense of trying to control things, so we rely on him in the House of Representatives to carry the ball for this group.

QUESTION **Mimikakis continues**—The two of you are scientists, you are chemists, and yet you made, I presume, a conscious decision to move out of the laboratory and out of the ivory tower, and into the arena of advocacy. Can you talk to us a little about the thought processes that you went through as you moved out and, obviously, then later in your careers, you've moved back and forth.

ROWLAND If not us, who? If not now, when?



left to right:
Jan Hartke, Executive Director, EarthVoice; Katy Moran, Executive Director, Renew the Earth; and Doug Durante, Executive Director, Clean Fuels Development Coalition.

Senator Lincoln D. Chafee flanked by members of the Young Marines Color Guard.

left to right:
Senator Lincoln D. Chafee, Dr. A. Karim Ahmed, Dr. Mario J. Molina, Mrs. John H. Chafee and Dr. F. Sherwood Rowland.

APPENDIX 1

John Chafee: The Gentle Warrior

By Steven Shimberg with comments by Senator Max Baucus

Steve Shimberg is the National Wildlife Federation's Vice President for Federal and Legislative Affairs. For more than 16 years, he served Senator Chafee on the Committee on Environment and Public Works as his Counsel (1981-97) and Staff Director (1991-97).

John Chafee, who chaired the Senate Environment Committee until his death last fall, managed to achieve environmental progress under the most adverse political circumstances. In an era of soundbites and personal attacks, he showed that civility and consensus are the keys to legislative success.

John Chafee loved to quote Teddy Roosevelt's observation that "of all the great questions which can come before this nation, short of the actual preservation of its existence in a great war, there is none which compares in importance with the central task of leaving this land even a better land for our descendants than it is for us." Or as the senator put it himself, "Given half a chance, nature will rebound and overcome tremendous setbacks, but we must—at the very least—give it that half a chance."

As a veteran of Guadalcanal who went on to serve in the Korean War, Chafee knew that, in the U.S. Senate, it is more important to win the war than any particular battle. He knew the importance of timing: when to engage your opponent; when to hold the line; when to retreat; and when to go on the offensive. That knowledge served him well as he fought in the Senate for 23 years to protect public health and our environment and natural resources.

He also knew the value of decency and fair play. When he arrived in the Senate in 1977, Chafee joined the Committee on Environment and Public Works. As a freshman, he admired and learned from the skills of colleagues such as Edmund Muskie, Robert Stafford, Jennings Randolph, and others. After the Supreme Court's famous 1978 decision in Tennessee Valley Authority v. Hill, the Tellico Dam snail darter case, he soon found himself in the middle of a battle with the senior senator from that state, the powerful Republican leader Howard Baker. Placing substance above party politics, Chafee fought to protect the integrity of the Endangered Species Act. He worked on an elaborate solution that created the act's "exemption committee"—sometimes known as "the God Squad." Despite complaints from many in the environmental community at the time, everyone now agrees that Chafee won the war, and saved the ESA. It was the first of many such victories.

Saving the landmark environmental laws of the 1970s became a full-time job after the 1980 election, when President Reagan moved into the White House and appointed James Watt as interior secretary and Anne Gorsuch as EPA administrator. The Republican party also took over the Senate. Fortunately, Stafford became chairman of the Environment Committee and Chafee became chairman of the subcommittee on environmental pollution. Working together, they took advantage of the fact that it is much harder to enact legislation than it is to block it. Over the next several years, they worked with committee Democrats to stymie several attempts to amend and weaken key statutes.

At the same time, Chafee began to compile a remarkable record of environmental accomplishments, many a direct response to Executive Branch proposals to weaken existing regulations or failure to implement or enforce the law. Quietly but methodically, Chafee worked with Democrats in the Senate and House and with fellow moderate Republicans on the Environment Committee to enact legislation to strengthen provisions of the Clean Water Act dealing with toxic pollution in 1981 and 1986; to force listing decisions and promote reintroduction of species to their historic habitat under the ESA in 1982; and to change hazardous waste management and disposal practices for both large and small generators under the Resource Conservation and Recovery Act in 1984.

Chafee didn't seek to embarrass or browbeat his opponents. Instead, he would carefully build a record of facts and expert opinion to support his position. Perhaps more importantly, he would always seek to address the legitimate concerns of whoever voiced opposition to his legislation. His gentle manner and sincere interest in addressing their concerns had a disarming effect on his opponents.

As a fiscally conservative Republican, Chafee could, on occasion, enlist the support of unusual allies. For example, he was able to convince Secretary Watt to support a novel approach to protecting the fragile barrier islands and beaches along the Atlantic and Gulf coasts — eliminate federal subsidies which were helping to underwrite the private development of these areas. The result was enactment of the Coastal Barrier Resources Act in 1982.

John Chafee was an old school politician. He didn't use opinion polls or media campaigns to pick his issues or to win his legislative battles. Rather, he would choose his issues on the basis of an uncanny personal compass and an innate sense of what was important — to people and to the global environment. That is what led him to convene hearings and to push for action to address stratospheric ozone depletion and global warming before either was a widely recognized problem.

In 1986, Chafee began educating his colleagues about the dangers of ozone depletion and slowly built support in the Senate for a strong international treaty to control chlorofluorocarbons and other ozone destroying compounds. In 1987, when Secretary of the Interior Don Hodel suggested that increased use of sunglasses and hats was an acceptable alternative to controlling CFCs, Chafee pounced on that blunder and, with the help of Senator Max Baucus, successfully steered through the Senate a series of resolutions that helped produce the Montreal Protocol.

The Democrats regained control of the Senate after the 1986 elections but there was little that changed on the environmental legislative front. There may have been fewer defensive battles but the struggle to enact new laws continued. In 1989, Chafee was presented with two legislative opportunities and, working closely with Baucus and Majority Leader George Mitchell, successfully seized both of them.

First, the Exxon Valdez oil spill created the opportunity to overhaul and strengthen oil spill legislation. Second, President Bush offered a limited Clean Air Act proposal and created the opportunity to finally amend a law that was badly out of date and in need of strengthening amendments. The Clean Air Act Amendments of 1990 were as far-reaching and significant as any environmental law ever enacted. The law requires aggressive efforts to reduce urban smog, more stringent tailpipe pollution standards, and dramatic reductions in pollutants that cause acid rain.

Chafee would often comment on the criticism and low League of Conservation Voter scores that he, Mitchell, and Baucus received from the environmental community during the 1990 Clean Air Act debate. The senators were publicly accused of undermining the effort to pass a strong bill. After the fact, they were hailed as "heroes of clean air." (In subsequent years, he would recount the Clean Air Act story whenever his decisions or votes produced similar public expressions of "outrage" from the environmental community.) But Chafee's leadership on clean air and other environmental issues contributed to a growing displeasure with him among an increasingly conservative Republican caucus, and in 1990, they voted to remove him as chairman of the Republican Conference, a leadership post.

Then came the 1994 elections, which produced Republican majorities in both the Senate and the House of Representatives for the first time in four decades. Chafee became chairman of the Environment Committee at the same time as, over in the House, the Contract With America was producing one anti-environmental bill after another. Despite the large number of Senate colleagues who had come from the House and thought it the Senate's duty to follow the House's lead, Chafee was quick to observe that he, too, had faced the voters that November and he had heard no public outcry for the enactment of anti-environmental legislation.

Convinced the attack on the environment was unwarranted and unwise, he repeatedly tried to convince the Republican caucus to change course. Failing that, he refused to move the legislation through his committee and, when they tried to avoid the committee by bringing amendments directly to the floor, he would not let them get away without a fight. He did not enjoy these fights but he was always ready to lead the charge. The locker room mentality of the Senate cloakroom produced a lot of unpleasant banter and tremendous peer pressure to "look the other way" or "let the Democrats take the lead." But John Chafee wouldn't back down. He always told his staff to do the right thing, and he held himself to the same standard.

Whenever a tough environmental issue was coming to the floor, many Democrats and a handful of Republicans would refuse to commit to a position until they knew where Chafee stood. The refrain "Where is Chafee?" became a familiar one. A modest man, Chafee would scoff at the idea that so many senators were waiting for his leadership. Recognizing the enormity of the political and societal challenges facing the environmental and conservation community, he felt it was part of his responsibility to keep "the troops" energized and excited. Each speech would start with a review of the successes we have achieved over the past 30 years. "Sure," he would acknowledge, "there are more challenges to face but, no challenge, no job!" John Chafee was an eternal optimist. He would always remind us that the glass was half full.

Chafee was a natural leader and the failure of his Republican colleagues to recognize that fact was their loss. He rarely spoke of his combat experiences but one night, in the privacy of his office, he shared the following story. In Korea, his Marine company was moving across snow-covered ground that was believed to be covered with land mines. No one in the company was eager to march through the area, so Captain Chafee took point and led his men through the snow. When the Marines reached the top of the hill, he looked back and observed that the entire company had left only one set of tracks as each marine had carefully stepped exactly in his footprints.

We would all be well served if more of our political leaders tried to follow in John Chafee's footsteps. He set the standard for decency, civility, and kindness, and the example of how to disagree without rancor. That he accomplished so much for the environment shows that his approach was the right one.

A Quiet Man Who Spoke Through His Deeds On The Environment Committee

By Max Baucus

When Senator John Chafee passed away on October 24, the environment lost a great champion, the Senate lost a gifted legislator, and many of us lost a cherished friend. There have, fittingly, been many tributes, describing John's extraordinary career as a soldier, governor, secretary of the navy, and senator. I appreciate the opportunity to add a few additional thoughts for The Environmental Forum's readers about his service on the Senate Environment and Public Works Committee.

John joined the committee when he came to the Senate in 1977. I joined about 18 months later. Back then, I never guessed that we'd develop a close relationship. We were junior members, sitting way across the dais from one another. Our states and our backgrounds were very different. Montana has ranches bigger than Rhode Island.

Nevertheless, circumstance and seniority brought us together. We worked together on the committee for more than twenty years, each eventually serving as chairman. During this time, John improved our environmental laws in many ways. Three examples stand out.

The first was John's work, beginning in 1981, as chairman of the committee's Environmental Protection Subcommittee. Although (as Steve Shimberg explains elsewhere in this issue) John was prepared to stand up against his own party's administration in the 1980s when it tried to undermine our environmental laws, he stressed a positive, creative approach. He looked for opportunities to get beyond partisanship and bring people together. For example, in 1982, under the leadership of John and the ranking member of the subcommittee, George Mitchell, the subcommittee developed a set of common-sense amendments to the Endangered Species Act. Over several years, the subcommittee developed a set of amendments to the Clean Water Act that, among other things, established the innovative state revolving loan fund. In 1984, the subcommittee wrote major amendments to the Resource Conservation and Recovery Act.

And John wasn't just interested in the big issues that bring headlines and accolades. He also worked hard on bills that seemed relatively unimportant in the overall scheme of things, but that improved the environment in significant ways. One such bill that John developed during this period is the 1982 Coastal Barriers Resources Act. Very few people have heard about it, but, by prohibiting certain types of federal assistance in the 2,500-mile coastal barrier resources system, the act fragile areas and saves taxpayers' money. There were others, including bills to improve the Lacey Act (which makes it illegal to transport wildlife taken in violation of state law), to improve the Sikes Act (which provides for conservation on military reservations), and to establish the National Fish and Wildlife Foundation.

The second example is John's work on the Clean Air Act. John had been involved in the debate for years, leading the way on issues like acid rain and ozone depletion. By the time that the long debate finally came to a head, in 1989-90, I had become chairman of the Environmental Protection Subcommittee and John the ranking Republican member of the full committee. We worked closely together. It was tough going, especially once we took the bill to the Senate floor. Lacking the votes to invoke cloture, we had to engage in what turned out to be more than a month of negotiations.

We sat there in a small room just off the Senate floor, facing wave after wave of unhappy senators, sometimes until one or two in the morning, working out compromises on acid rain, permits, mobile sources, enforcement, and scores of other issues. When we finally took the bill back to the Senate floor, we found that, in order to protect the compromise, we had to vote against amendments that we personally supported. There were some very close votes. But John never wavered, and he never lost his patience. In the end, he persuaded President Bush and Republican senators to support a strong bill.

The third example is John's work, beginning in 1995, as chairman of the full committee. He was able to steer the committee clear of radical efforts to roll back environmental laws. He refused to consider the House bill that weakened the Clean Water Act. He took a cautious approach to wetlands reform. And he took strong stands against the excesses of takings and regulatory reform legislation proposed by other committees. He held hearings to examine the impact of takings legislation on Section 404 of the Clean Water Act, the Endangered Species Act, and other environmental laws. During the 1995 regulatory reform debate, he proposed the Glenn-Chafee substitute that came within a few votes of passing. In 1998, he and I sent a letter to the Government Affairs Committee explaining how that committee's regulatory reform bill could undermine environmental laws.

But John also understood the need to respond to the legitimate criticism that our environmental laws can be improved. He led the committee in developing amendments to the Safe Drinking Water Act that made that law more efficient and more effective; the amendments contain innovative provisions allowing the targeted use of cost-benefit analysis, establishing a multimedia approach to the regulation of radon, enhancing citizens' right to know about the quality of their drinking water, and giving states the flexibility to transfer funds between their drinking water and sewage treatment funds, so that they can respond to their own most pressing needs. Ultimately, the bill won the support of states, local governments, and the environmental community. He also led the committee in developing a series of amendments to the Endangered Species Act that, although not enacted into law, attracted bipartisan support with its balanced approach.

We had our disagreements, especially over Superfund. But, by and large, during John Chafee's chairmanship, the Environment and Public Works Committee was an oasis of civility, moderation, and bipartisanship.

John's legislative accomplishments on the committee were impressive. But, to me, it is the man that mattered most. Like one of his heroes, Theodore Roosevelt, John had a genuine love for the outdoors. I saw this first hand back in 1985. We were having problems with the management of the grizzly bear population on Montana's Rocky Mountain Front. So John decided to learn about the problem first- hand. We held a hearing in Great Falls. John presided. But he didn't just fly in, hold the gavel for a few hours, and fly out. After the hearing, he went down to the Pine Butte Nature Preserve, to learn more about grizzlies and their habitat. He rode into the Bob Marshall Wilderness. I have never seen anyone with more reverence and enthusiasm for the land and its natural beauty. In fact, at one point during the ride, John turned to me and exclaimed, "Max, I wish Rhode Island had some wilderness, so that we could protect it!"

Most of all, John Chafee was a decent, civil, common-sense gentleman. As those of you who attended our hearings know, he always started on time and was unfailingly courteous to witnesses; small points, perhaps, but characteristic. He never raised his voice. He never lost his temper. He listened carefully to the other person's point of view. He wouldn't let conversations drift to gossip or extraneous matters that prevented us from accomplishing our objective. He tried to find solutions, to bring people together. And, even during the most difficult negotiations or floor debates, he often had a good-natured twinkle in his eye; to me, it showed that he kept things in perspective, never taking himself too seriously.

John Chafee's passing leaves a large void on our committee. But he left us a model of legislative accomplishment and personal character that we should strive to match.

Max Baucus (D-Montana) is the Ranking Minority Member on the Senate Environment Committee.

APPENDIX 2


Mrs. Georgia Chafee Nassikas and Mrs. John H. Chafee

Biography of Senator John H. Chafee

Senator John H. Chafee (R-RI) was born in Providence, Rhode Island. He was a graduate of Yale University and Harvard Law School.

When the United States entered World War II, he left Yale to enlist in the Marine Corps, and then served in the original invasion forces at Guadalcanal. He was recalled to active duty in 1951 and commanded a rifle company in Korea.

He served six years in the Rhode Island House of Representatives, where he was elected Minority Leader. Running for Governor in 1962, Chafee was elected by 398 votes. He was then reelected in 1964 and 1966, both times by the largest margin in the State's history. In January 1969, he was appointed Secretary of the Navy and served in that post for three-and-a-half years.

John Chafee's Senate career began in 1976. He was reelected to a fourth term in 1994, with sixty-five percent of the vote, and is the only Republican to be elected to the U.S. Senate from Rhode Island in the past 68 years.

As Chairman of the Environment and Public Works Committee, the Senator was a leading voice in crafting the Clean Air Act of 1990, which strengthened pollution emissions standards. He led successful efforts to enact oil spill prevention and response legislation, and a bill to strengthen the Safe Drinking Water Act. Senator Chafee was a long-time advocate for wetlands conservation and open space preservation, and was the recipient of every major environmental award.

As a senior member of the Finance Committee, Senator Chafee worked successfully to expand health care coverage for women and children, and to improve community services for persons with disabilities. In 1990, Senator Chafee spearheaded the Republican Health Care Task Force and became a prominent figure in the national health reform debate. He went on to lead the bipartisan effort to craft a comprehensive health care reform proposal in 1994.

Senator Chafee also was a leader in efforts to reduce the federal budget deficit and co-chaired the centrist coalition, which produced a bipartisan balanced budget plan in 1996. He was an active proponent of free trade and was a strong supporter of the North American Free Trade Agreement (NAFTA). Senator Chafee led the successful effort to repeal the federal luxury tax on boats and jewelry, and thus revitalized two critical industries in Rhode Island and other states.

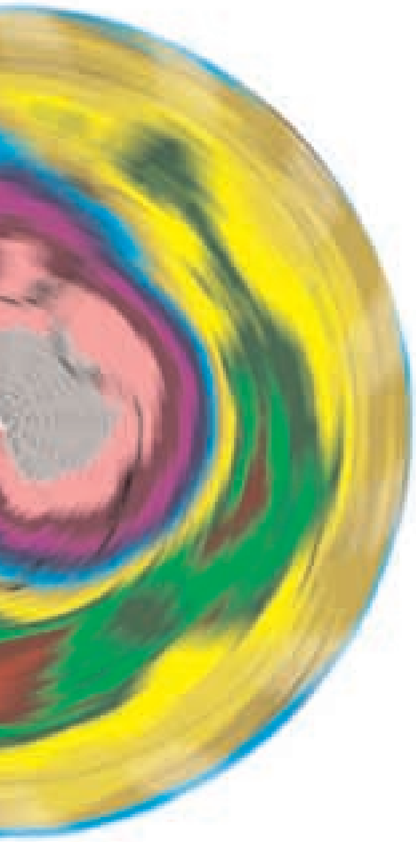
Senator Chafee also served on the Select Committee on Intelligence. He served as Chairman of the Republican Conference for six years.

The Senator received awards and endorsements from such organizations as The National Federation of Independent Business, The American Nurses Association, The League of Conservation Voters, The Sierra Club, Handgun Control Inc., Planned Parenthood, Citizens Against Government Waste, and the National PTA.

On October 24, 1999, Senator John H. Chafee died from congestive heart failure. He leaves his wife Virginia, five children, and twelve grandchildren.

APPENDIX 3

Biography of Dr. F. Sherwood Rowland



Dr. F. Sherwood Rowland is the Donald Bren Research Professor of Chemistry and Earth System Science at the University of California, Irvine. He came to the University of California Irvine in 1964 as the first chair of the Department of Chemistry. He became the Donald Bren Professor of Chemistry in 1989, and was named to the Research Professor position in 1994. He also is currently Foreign Secretary of the National Academy of Sciences, an office to which he was first elected in 1994 for a four-year term, and re-elected in 1998 for a second term.

Dr. Rowland previously held faculty positions at Princeton University (1952-1956) and the University of Kansas (1956-1964). He earned his bachelor's degree from Ohio Wesleyan University and his master's and doctoral degrees from the University of Chicago. In 1995, Rowland shared the Nobel Prize in Chemistry with Mario Molina and Paul Crutzen "for their work in atmospheric chemistry, particularly concerning the formation and decomposition of ozone."

Dr. Rowland is a specialist in atmospheric chemistry and radiochemistry. He and colleague Mario Molina were the first scientists to warn that chlorofluorocarbons (CFCs) released into the atmosphere were depleting the earth's critical ozone layer. Research on CFCs and stratospheric ozone eventually led in the 1970s to legislation in the United States, Canada and Scandinavia regulating the manufacture and use of chlorofluorocarbons as aerosol propellants.

In 1987, the Montreal Protocol of the United Nations Environment Program became the first international agreement for controlling and ameliorating environmental damage to the global atmosphere by calling for reductions in CFC manufacture and release. The terms of the Montreal Protocol were strengthened in 1992 to attain a complete phase out of further CFC production by January 1, 1996. Measurements of organochlorine molecules, including CFCs, in the lower atmosphere confirm that the global response to the terms of this protocol have been excellent.

Rowland also has been investigating the impacts on the atmosphere of methane gas and of other hydrocarbons. These studies have shown that the atmospheric concentrations of methane increased steadily at about 1% per year from 1978 to 1988, and at a slower pace in the past decade. The global methane concentration has more than doubled in the past two centuries. Methane absorbs terrestrial infrared radiation, and increases in its concentration contribute to the "greenhouse effect," the gradual warming of the earth's surface.

The Rowland research group is now investigating the hydrocarbon and halocarbon composition of the atmosphere, both from aircraft in remote locations and on the surface in heavily polluted cities. Studies of the local atmosphere in Mexico City and Santiago, Chile have shown substantial concentrations of liquefied petroleum gas (LPG) through leakage from heating and cooking facilities. The aircraft experiments conducted as part of the NASA Global Tropospheric Experiment have shown extensive smog pollution over both the Atlantic and

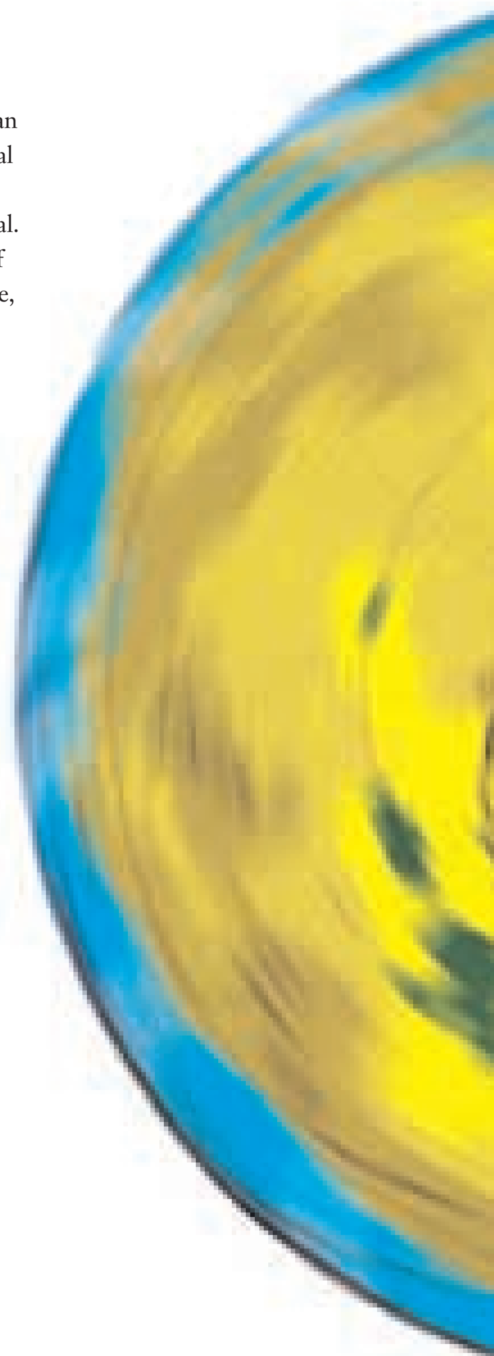
Pacific oceans from the burning of agricultural wastes and forests. Rowland has co-authored more than 350 scientific publications in the areas of atmospheric chemistry, radiochemistry and chemical kinetics.

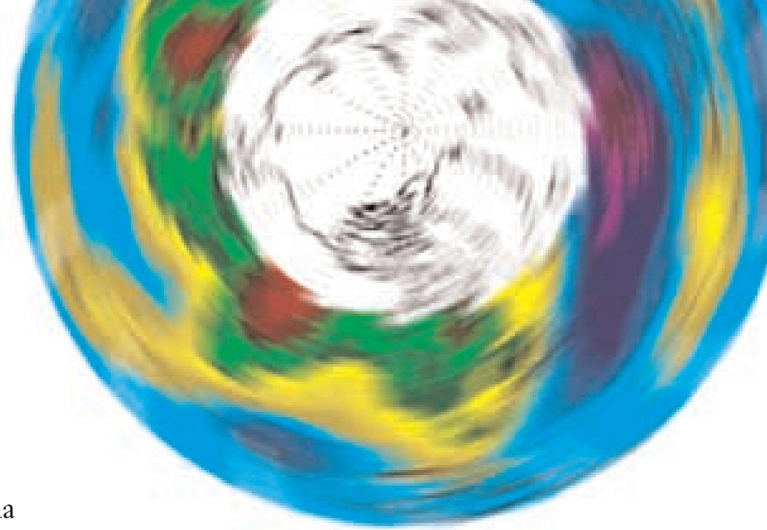
Rowland is a member of the National Academy of Sciences, the American Academy of Arts and Sciences and the American Philosophical Society. As Foreign Secretary of the National Academy of Sciences, he helped create the InterAcademy Panel on International Issues (IAP) in 1995, and co-chaired it from 1995-2000. The IAP is an organization of the Academies of Sciences from more than 80 countries working together to solve trans-national and global problems in scientific policy.

In 1983, Rowland and Molina received both the Tyler World Prize in Ecology and Energy (shared with Harold S. Johnston) and the Award for Creative Advances in Environmental Science and Technology of the American Chemical Society. In 1987, Rowland received the Charles A. Dana Award for Pioneering Achievements in Health, and in 1988, he was made a member of the Global 500, the Honour Role of the United Nations Environment Program. In 1989, he received the Japan Prize in Environmental Science and Technology and in 1994 the Albert Einstein Prize of the World Cultural Council.

During 1991-1993, he served successive one-year terms as President-Elect, President, and Chairman of the Board of the American Association for the Advancement of Science. Rowland has also been awarded the 1979 Szilard Award for Physics in the Public Interest by the American Physical Society, the 1993 Peter Debye Medal in Physical Chemistry by the American Chemical Society and the 1994 Roger Revelle Medal of the American Geophysical Union. He has been awarded the University of Chicago Alumni Medal and the University of California Irvine Medal.

Rowland has received honorary degrees from sixteen institutions, including the University of Chicago, Ohio Wesleyan University, Duke University, Princeton University, Haverford College, Whittier College, Clark University, Gustavus Adolphus College, Carleton College, Occidental College, Simon Fraser University (Canada), University of Calgary (Canada), East Anglia University (UK), University of Urbino (Italy), Kanagawa University (Japan) and LaTrobe University (Australia). In 2000, Rowland was elected to the GTE Academic All-America Hall of Fame for the combination of success in both academics and inter-collegiate athletics while an undergraduate student at Ohio Wesleyan University and as a graduate student at the University of Chicago, together with subsequent scientific achievements.



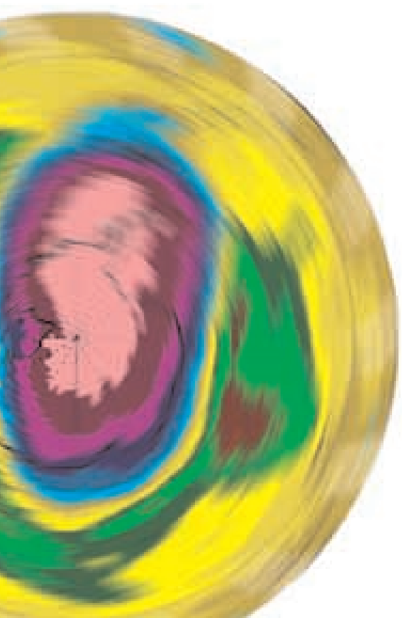


APPENDIX 4

Biography of Dr. Mario J. Molina

Professor Molina has been involved in developing our scientific understanding of the chemistry of the stratospheric ozone layer and its susceptibility to human-made perturbations. He was a co-author, with F. S. Rowland, of the 1974 publication in the British magazine *Nature*, of their research on the threat to the ozone layer from chlorofluorocarbon (CFC) gases that were being used as propellants in spray cans, as refrigerants, as solvents, etc. Subsequently, he and his co-workers proposed and demonstrated in the laboratory a fundamentally new chemical reaction whereby chlorine is activated on the surface of ice cloud particles in the polar stratosphere and a new reaction sequence, which accounts for most of the observed ozone destruction in the Antarctic stratosphere.

Professor Molina has also been involved with the chemistry of air pollution of the lower atmosphere. He also is pursuing interdisciplinary work on tropospheric pollution issues, working with colleagues from several disciplines on the problem of rapidly growing cities with severe air pollution problems. He is the leader of the Integrated Program on Urban, Regional, and Global Air Pollution, a collaborative research and education program based at MIT and aimed at addressing the complex and interrelated environmental issues spawned by the world's burgeoning mega-cities and their impact on the global environment. Mexico City serves as the initial case study fro the Project's research and educational activities.



Professor Molina was born in Mexico City, Mexico. He holds a Chemical Engineer degree (1965) from the Universidad Nacional Autonoma de Mexico and a Ph.D. in Physical Chemistry (1972) from the University of California, Berkeley. He came to MIT in 1989 with a joint appointment in the Department of Earth, Atmospheric and Planetary Sciences and the Department of Chemistry and was named MIT Institute Professor in 1997. Prior to joining MIT, held teaching and research positions at the Universidad Nacional Autonoma de Mexico; the University of California, Irvine; and the Jet Propulsion Laboratory at the California Institute of Technology.

Professor Molina was elected to the National Academy of Sciences in 1993 and the Institute of Medicine in 1996. Currently he serves on the President's Committee of Advisors in Science and Technology, the Secretary of Energy Advisory Board, the National Research Council Board on Environmental Studies and Toxicology, and on the boards of US-Mexico Foundation for Science and other non-profit environmental organizations. He has received several awards for his scientific work including the 1995 Nobel Prize in Chemistry, which he shared with Professors F. Sherwood Rowland and P. Crutzen for their work in atmospheric chemistry, and the 1999 United Nations Environment Program Sasakawa Prize.

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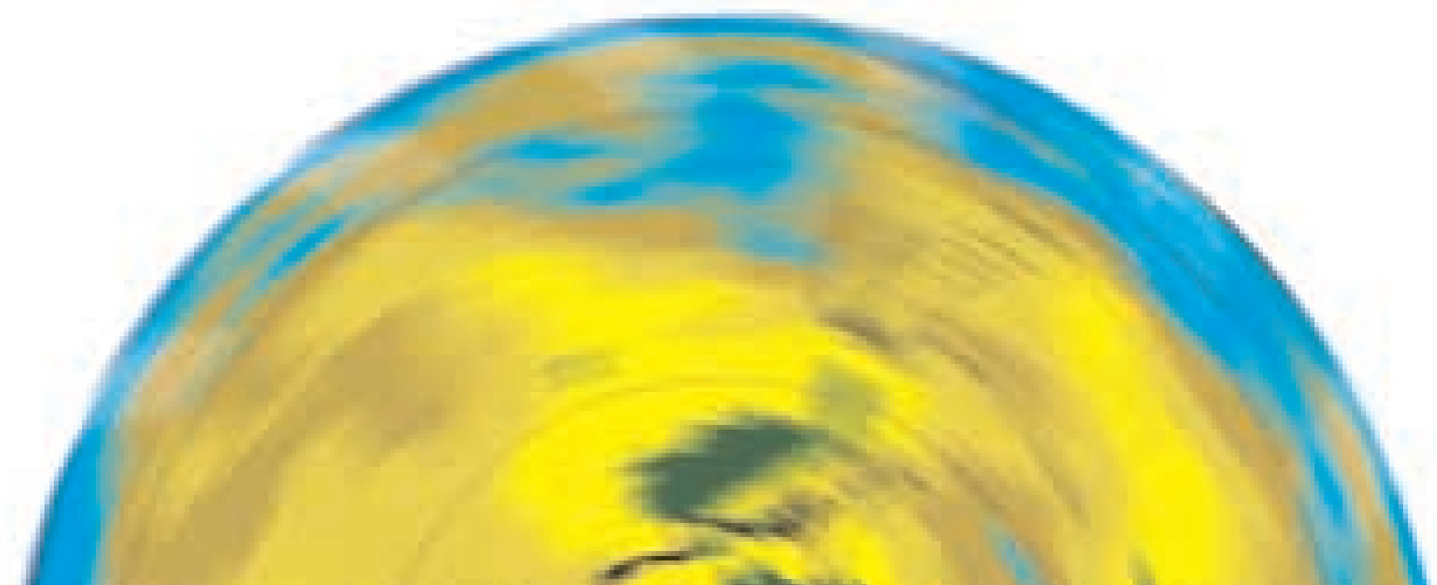

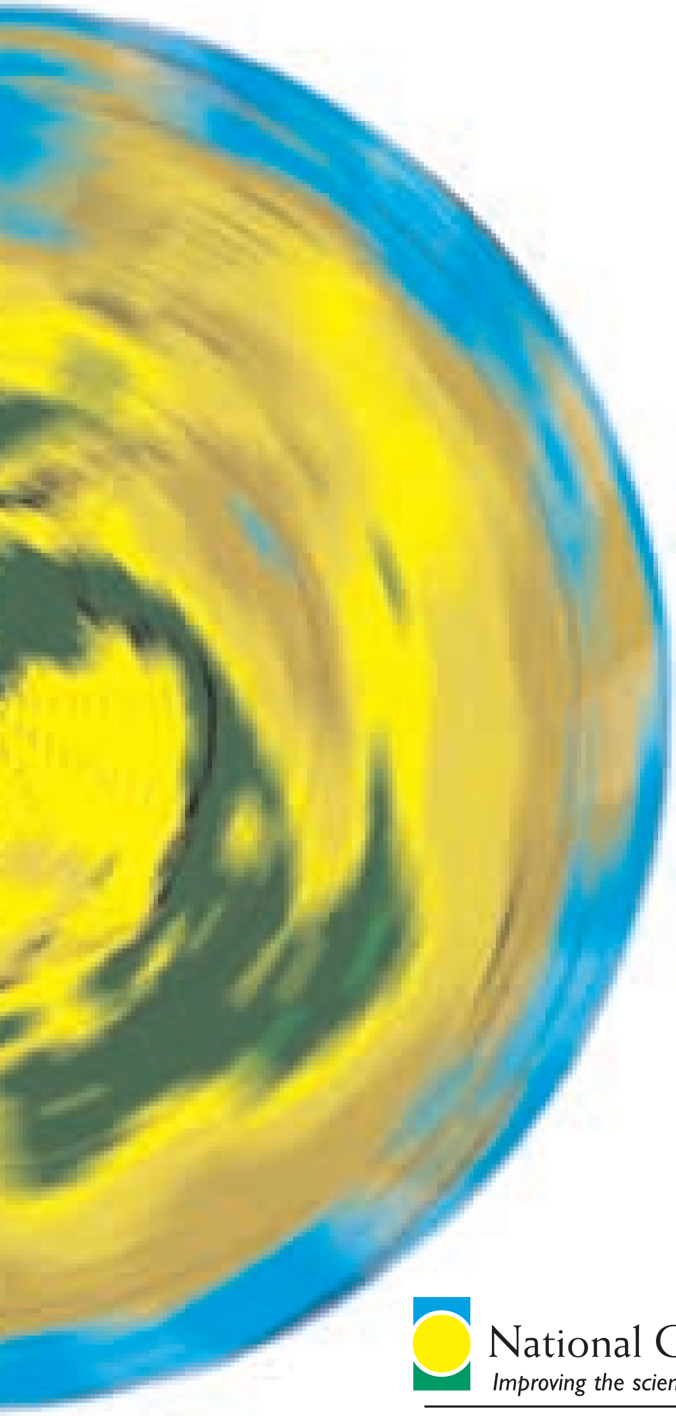

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1725 K Street NW
Suite 212
Washington, DC 20006-1401

202-530-5810
Fax: 202-628-4311

E-mail: info@NCSEonline.org
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