HECHT: My name is Bill Hecht. I'm a member of the class of 1961, and I'm the Chief Executive Officer of the Alumni Association. So it's my great pleasure to welcome you back. After all, I work for all of you.

MIT pays my salary, but I work for all of you. It's a very funny business I'm in. What I want to do this morning is to introduce this program. As you know in the last several years, we've had the great good fortune of enlisting our distinguished faculty as assistants and helpers in putting together a program.

And I have to say that in this case, we enlisted a faculty member who did an extraordinary job for us in putting this program together. In fact, I think it's more his program than it is our program. And Chuck Vest will introduce that faculty member, Francis Ogilvie, Head of the Ocean Engineering Department.

It's my pleasure this morning to introduce the 15th President of MIT, Chuck Vest. Chuck is a person who majored in mechanical engineering at West Virginia University, did his PhD at Michigan. The University of Michigan has given us two presidents now, he and Jerry Wiesner. And he and Becky came to this campus a couple of years ago, and have indelibly put their own stamp on this very special place. It's my great privilege to introduce Chuck Vest.

[APPLAUSE]

VEST: Thank you very much, Bill. It's really a great pleasure to welcome all of you. Or perhaps in the case of a large number of you, to re-welcome you since I've had the great good fortune to visit with quite a few of you over the preceding days.

It's my understanding that we are close to, if not at a record attendance of alumni and alumnae and their families here for the reunions and Technology Day. Somewhere over 3,000 of you in attendance. And that's really terrific and makes it a very exciting day and week for all of us.

And one of the most exciting parts of the week is, indeed, ahead of us today. And also, tomorrow looks to have something very special for everyone, be you an entrepreneur, an explorer, an athlete, or just plain an eater. And there are a lot of those around I've noticed.

We have lived and worked in an era that will be remembered largely as the beginning of the age of exploration of outer space. The exploration of the seas on the other hand, is a human endeavor that dates from earlier millennia. But it is a never-ending quest.

The current decade has seen great advances in the exploration and utilization of this important inner space through the development of a whole new set of tools. These new tools, ranging from deep sea vessels to computer modeling, are giving us a better understanding of our oceans, their vitality for shipping and commerce, their effects on the control of the Earth's environment, and their biological richness.

The oceans hold a great appeal to us scientifically, spiritually, and pragmatically. And MIT faculty, students, staff, alumni, and alumnae are there at the leading edge of every advance in this great adventure.

Today, our speakers are truly a stellar group of experts drawn from the Institute and beyond who have an intimate knowledge of the sea. They will be sharing that knowledge with us as they look at the ocean, its uses, and its resources.

I want to note that not only MIT faculty, but our graduates are among the experts who will be addressing us today, including Bill Koch, the winner of the 1992 America's Cup. And special thanks, indeed as Bill has said, go to Francis Ogilvie, Head of our Department of Ocean Engineering. And to Arthur Winston and the rest of the Technology Day Committee for putting together such an extraordinary array of talks and panel discussions.

I look forward to talking with and learning with many of you throughout the day. And I'll certainly be seeing you again at the Technology Day Luncheon this afternoon. So again, welcome. I want to extend a very warm welcome on behalf of those of us who live and learn and work here at the Institute. We're just terrifically glad that you're here.

It's now my great pleasure to introduce Professor Francis Ogilvie, who will moderate this morning's session. Francis.

[APPLAUSE]

OGILVIE: Well, this is a special pleasure for me. Before we really get onto the program, I should say that this is my first experience at working intensively with the Alumni Association and both the staff and the volunteers. And I found it a remarkable experience. A professional staff. A lot of dedicated, hardworking committee members who are mostly down here in the front except, because of these lights, I can't see them. But I'm sure they're there.

My job this morning mainly is to introduce the speakers. And since we have a couple of professors on the program, to make sure they stay within the time that's allowed.

Chuck Vest has already spoken a little bit of the history of the oceans and how our view of it is changing. Of course, Naval architecture is probably the world's oldest engineering profession.

In more recent decades, it was discovered that ocean engineers-- Naval architects actually, as they were called, were just what was needed for the offshore oil industry as they started going out in the deeper and deeper water to try to find and produce oil and gas.

Now, there are entirely new areas opening up. Part of it is driven simply by our curiosity, our desire to understand the environment. And it's been pointed out by a lot of speakers and writers, we have better maps of the backside of the moon than we do of the bottom of the ocean. In fact, it's now also true that we have better maps of Venus than we do of most of the bottom of the ocean.

We've also come to learn in the last few years what a remarkable effect the ocean has on global weather and climate. That we don't understand a lot of it, but we know that it has a major effect. And we are just really taking the first steps to understanding it.

I think that I can make a comparison that our status in knowledge of the ocean is probably comparable to our knowledge of space in the 1950s. We're really just getting started. We're really just finding out the things we can do. We see lots more questions out there than we do answers.

Now, this morning's program, the first three talks will focus on some of these newer aspects of working in the ocean. And then the last one, as you've already been told and you know from the program, will be on the most ancient of Maritime arts-- sailing-- and how it has been changed by technology.

You all have the program booklets. And so I'm not going to cut into the speaker's time by reading you or paraphrasing the description of the various speakers. So at this point, I'm happy to introduce Dr. Sylvia Earle, who had a remarkable career already in business related to ocean, in government. And actually, in personal exploration of the ocean as you can read. So Dr. Earle, very happy to welcome you.

[APPLAUSE]

EARLE: Thank you so much. I'm very pleased to be here, having just taken the dreaded red eye from California to arrive. You all look pretty good to me.

It's a special honor to be invited to speak here during this week of celebration. Last week, I had the pleasure of introducing one of this Institution's many illustrious alumnae, Physicist and Nobelist Murray Gell-Mann when he received the 1993 Charles A. Lindbergh Award at the Explorers Club in New York for his lifetime of accomplishment in promoting a balance between technological advancement and environmental preservation. It's a challenge that occupied much of Lindbergh's life, and one that is of increasing importance to the future of all of us.

While preparing for Professor Gell-Mann's introduction, I discovered that when he graduated from Yale at the tender age of 18 in 1948, he really wanted to go to Princeton for Advanced Studies, but he was turned down. He was attracted to MIT. But especially after the Ivy League environment at Yale and dreams of Princeton-- and with all due respect, he thought, this institution-- and this is a quote-- was a rather grubby place.

He even went so far as to say that I had a choice between suicide and MIT. But a little reflection convinced me that I could try MIT, and then commit suicide. But not the other way around.

Happily for Gell-Mann, and for this institution and for all of us, he did come here. And it proved to be a win-win-win.

Another for whom this place was just right was Herald, otherwise known as Papa Flash, Edgerton, whose contributions to ocean engineering are the stuff of which legends are made. He, too, loved and helped to generate a certain down to earthiness that seems to be conducive to inspiring great work and an amazing creative atmosphere for faculty and students alike.

There must be a million Edgerton stories, but one of my favorites-- and I understand this is really true-- concerns the occasion when several distinguished visitors from Europe came looking for Dr. Edgerton with suits, ties, polished shoes, and an attitude befitting distinguished visitors about to meet the famous MIT professor and engineering wizard. But just outside the building, they encountered a janitor wearing a plaid shirt and khakis. You know, grubby. He was moving some boxes And they asked if he would please show them the way to Edgerton's lab. Better yet, the janitor replied, I'll take you there. It's only when they arrived at Edgerton's office, the janitor sat down behind the desk that they realized they been had.

I witnessed something of the special magic of this place myself a few years ago when I accompanied a distinguished European visitor to the Ocean Engineering Lab. We had the ultra-grand tour with a demonstration of some of the remarkable manipulator technology that has been developed for use on underwater vehicles. Dana Yoerger showed us around. And we visited with some of the students and walked the hallowed halls listening to the sizzle of creative blue fire emanating from the rather ordinary-looking, some might say grubby-looking, spaces.

In fact, my European colleague looked increasingly distressed and perplexed as we neared the end of the tour. And as we kind of came to the end of it, he waited until Dana was just out of hearing range and he leaned over and he kind whispered, is this all there is?

I don't know exactly what he expected, but what I, and the world generally have come to rely on from this institution, is not what is expected. Rather, it's the unexpected. The departure from the predictable. The fresh ways of looking at things that continue to keep the legends coming from these seemingly ordinary-looking labs and offices generation after generation.

This institution has, in fact, over the past century-- think of it, a century of work on ocean engineering issues-- has had a remarkable impact on underwater exploration. And thus, on exploration of the planet as a whole.

I personally am intrigued with the history of ocean exploration and the technology that makes such exploration possible, partly because most of it has yet to be. Most of what has been discovered concerning the oceans has occurred during the last 100 years. All the history of humankind, most of the action has been during the history of the ocean during labs here. But the pace has picked up.

More has been learned perhaps about the sea in the last two decades than in during all preceding history. Perhaps, that Bob "I found the Titanic" Ballard, says-- and it may be an overstatement-- that less than 1/10 of 1% of the deep sea has been explored. And yet, last fall at an Explorers Club dinner honoring space exploration, Carl Sagan made an eloquent plea for turning our attention skyward as a species to other planets and beyond. Because after all, he said, exploration of this planet is essentially complete.

Well, some of us nearly leaped straight out of our chairs, anxious to point out that the great unknowns that lurk a few feet from any shore. We can start with an image or two to illustrate some of these points.

During this era, we have a range of sophisticated new technology available. A lot of what is now being discovered doesn't even involve getting wet, nor even being close to the sea. Not like the good old days when half the fun of being an oceanographer used to be getting seasick. You clever engineers out there are taking the macho out of being a marine explorer.

It used to be a really good detective adventure to go out and try to figure out what life in the oceans was about by looking at gobs of gelatinous goo scooped up by nets dragged through the ocean. Not that a lot of fine ocean science hasn't been accomplished by staring into a bucket. That's not a seasick scientist, by the way.

But just imagine trying to discover something about your backyard, or mine-- that is San Francisco, of course-- by using standard, traditional oceanographic techniques, flying overhead in an airplane instead of a ship over the bottom of the sea, blindly dragging nets, snagging a bit of this or that, or the other thing. What could we know about the inner workings of Boston or Cambridge given such approaches based on, say, a sample snagged from a Saturday night out on the square?

We've gotten better at this approach over time. And Doc Edgerton is one example of refining that technique very well with his famous deep-sea cameras that were deployed from the decks of ships, providing unprecedented new information about critters, about sunken ships, and about the nature of the sea itself.

But no longer is it necessary to stare wistfully over the deck, from the deck of the ship or longingly from the side. Ocean exploration during our lifetime has taken some different and wonderful twists so that we can take ourselves directly. And we have a great array of machines that can indirectly, vicariously explore for us.

Getting into the sea with ourselves and increasingly effective cameras and variations on the theme of technology has revolutionized knowledge and understanding about the nature of the planet and life that we share. Even now, many who think they know quite a lot about the sea, do not fully appreciate the significance of life in the sea. As a medium, the ocean is more than just water. It's a living soup, a three-dimensional creepy-crawly minestrone. Eat your heart out, Luke Skywalker. Some of the creations that are down there make engineers sigh with envy.

But with all due respect to fish and whales, most life in the sea-- and of course, most of what transforms the nature of seawater into something not quite seawater, but kind of a living soup-- is small, microscopic. And therefore, not taken into account by most people, including most biologists. Until recently, anyway.

Now, one of the many great incentives to speed up effective access to the sea has to do with getting acquainted with the immense diversity of life that is in the sea. It can't be compared with any place on the land. The greatest major divisions of diversity are without any question in the ocean where the history of life is literally written in the lives of creatures that have deep roots in time, like half a billion years for sponges.

But pick up almost any rock, even on a salt marsh, let alone out in the deep sea, and find yourself travelling back in time to do a cross-section in terms of the history of who's who and what's what with respect to ancestry that makes ours really get into perspective. We are truly newcomers, even with respect to fellow vertebrates.

Well, I'm one of those vertebrates who has a history of liking to get out in the ocean directly. And part of that history has led me to appreciating the variations on the theme of new technology to take ourselves vicariously.

I enjoy the close-up view. I am, by nature, a botanist. And I've spent quite a lot of time cruising around using the senses with which I was born. And I'm among those who have enjoyed the pleasures of staying underwater for longer than most can just using scuba tanks. That is, living underwater for prolonged periods. Using space-age type re-breathers to prolong individual excursions to hours instead of minutes. And using some of the new material, such as acrylics, to put true windows in the sea from looking from the inside out.

In fact, just recently this nation's latest adventure along those lines, the Aquarius Underwater Habitat, analogous to Skylab or the Space Shuttle. And certainly, to the Space Station, has gone back into the water after being in dry dock for a year or so, to enable scientists and others to go and live underwater for some period of time in the Florida Keys.

I know, I'm supposed to be talking about ocean exploration and unmanned systems. And I'm getting there. But I want to put things a bit in perspective. Again, suppose knowledge of the land were limited to conventional diving techniques. Limited to close-up views. Limited to what you can sense only with your own eyes and fingertips and ears and so on. As good and as important-- in fact, vital as this approach is, as far as either space exploration or for ocean exploration, it represents one variation on the theme of a tool in the box. By no means, not the only one.

There are debates, of course, that rage, both in terms of space technology and in ocean technology, about whether to have manned systems or unmanned systems. What is cost effective?

Well, I think astronauts have made their case more effectively than their aquatic counterparts. I mean, I look at the budgets for, let's say, the Space Shuttle's toilet, $23 million, and dream about what I could do with that for underwater exploration.

But it's not just limited to people in space. It's also those who favor the unmanned approach, the use of satellites, as compared to, let's say, ocean buoys or remotely-operated vehicles, or autonomous vehicles. The dollars that we, as a nation, as a species, have been willing to commit to space have certainly far and away surpassed what we have been willing to commit to ocean exploration and ocean technology.

There are many haunting parallels, however, putting dollars aside. Aside from that orders of magnitude difference in terms of costs. I've had the pleasure of experiencing some of these parallels directly. Living underwater is one. But to go into the so-called "hostile environment" of the sea or of space requires packaging human beings and instruments in some cases to withstand the absence of pressure in space or the great addition of unfamiliar space if we venture deep into the sea.

This system is one that was developed actually at about the time Charles Lindbergh was crossing the Atlantic in 1927. And it does illustrate the point that while some refer to this as the cutting edge of ocean technology. If it is, we're in trouble. And it really isn't. There are other variations on the theme of both manned exploration and that which leaves us sitting on the surface deploying instruments subsurface that in the last two decades have advanced considerably.

But we are still handicapped when it comes to venturing deep in the sea. Only once in the history of humankind has it been possible to package people-- two of them-- in a protective container to go as far as the greatest ocean depth. A mere 7 miles, about 11,000 meters, withstanding 16,000 pounds per square inch on the shell of the container that holds them. That little sphere in the base of the Trieste.

That was 1960 for 20 minutes. Once and never more. At least not so far. Technologically, the capability exists, but so far not the will. Either to take ourselves or to package instruments to go to the deepest part of the sea. Perhaps it will be possible in the very near future.

Japan is on the very edge of launching a system, this summer in fact, on a tether that will go to the deepest part of the sea.

The famous Alvin submersible. And many of you here have had something to do with this delightful creature launched in 1964. It goes to merely the average depth of the sea, 4,000 meters.

And here, the deepest-diving manned submersible in existence now. It's the Shinkai 6500. It's the deepest diving that presently exists to take people. Although, there are some systems that can venture further. And as I indicated, this summer a tethered unmanned vehicle will be deployed for access to 11,000 meters on a voyage back to the Marianas Trench.

The cable connecting the vehicle to the surface is at least as impressive as the vehicle itself. Can you imagine the cable that will go 11,000 meters with power down the line and all the rest?

Well, one of the limiting factors in using manned subs and even large, remotely-operated vehicles, despite the disparity with space budgets is cost. Mostly, because of the large support ships and the crew required.

When I used the Shinkai 6500 two years ago, the cost was $100,000 a day. And now, it is said to be $150,000 a day. That gives National Science Foundation and other granting agencies a little heartburn. Cost is what has driven the development of small systems, manned and unmanned.

Here's an example. One that is near and dear to my heart because I have tracked it from a sketch on a napkin at the Jefferson Hotel in Washington, DC, to having the fun of piloting the little beast down to 1,000 meters. This is an example of, obviously, one with a human being inside that can be deployed from a platform that cost about $1,000 for exploration of Crater Lake.

It provides a tiny window in the sea. Again, not at all comparable to some of the new autonomous vehicle technology that travels over wide distances, or even the remotely-operated vehicle technology that enables instruments and other devices to record what's going on for much longer than human beings can tolerate. Such systems, however, are useful in part because they're so simple to drive. Even a scientist can operate Deep Rover.

And you can wear whatever you like. And of course, it's possible to instantly transform the system into an unmanned vehicle by sending a woman.

[APPLAUSE]

There are places in the sea, however, where taking people, male or female, certainly has risks. Alvin melted a metal temperature probe during one of its first ventures trying to see what the temperature of hydrothermal vents happened to be. At Deep Ocean Engineering, we're now building two acrylic spheres of manned submersibles. We may find out how acrylic reacts to the hot spots in the deep sea. We'll see. But in any case, it's much more comforting to view such places from a safe distance.

There are a lot of places in the sea that divers in or out of subs would rather not have to go, such as the Persian Gulf after the big spill. Time is another factor. Vehicles may get cold, but they don't eat or use restrooms or sleep. They can stay down a long time. Whereas, human beings have certain built-in limits.

Safety is recurrent, and I think maybe a spurious, justification for unmanned underwater vehicles considering what we're willing to do in other directions. Most of you drove on the freeway to get here, right? Now, that's a risk. But we accept it.

And then there are giant squids to consider underwater. But whatever the risks are, no dangers of the deep need to be dredged up to justify unmanned systems, not when a small and growing fleet of passenger subs is safely taking little kids and grandparents for excursions into the sea.

I applaud this approach. There are a couple of dozen of these little passenger subs operating around the world. Rather, unmanned vehicles have proven themselves for their own attributes, for unprecedented time. And in some cases, unprecedented ability to cover distances. The famous SOFAR Floats that drift in ocean currents keeping the recording data beeping out information. Or their clever counterparts, that's SOFAR spelled backwards, RAFOS, R-A-F-O-S, that receives signals from moored transmitters as they bob about in depths to as great as 3,500 meters.

This isn't appropriate work for manned subs or divers. The key to ocean exploration and the technology that goes along with it is to choose the right tool for the job at hand.

Certainly, in the last decade, this institution has been much involved with the development of systems that are helping to make a huge difference in what we know or suspect about the nature of the sea. As was indicated in the earlier remarks, the oil and gas industry helped to spur the development of much of this. But the need to know how the planet works from the inside out continues to push that development.

This little sub designed for use in the oil patch, ultimately has made its way into scientific circles with one at Harbor Branch Oceanographic Institution, one at the Monterey Bay Research Institute, with new systems there being developed that really are extraordinary. With video monitors to enable people to fly from a distance the systems that are operating in the depths below.

But just as with the examples with the manned systems, small is beautiful in some respects. Here is one, an industrial workhorse. More than a hundred of these systems were used for years in support of the offshore oil and gas industry. And to some extent, for basic exploration.

And here is one of Deep Ocean Engineering's fleet of 256 little ROVs, like MIT's famous autonomous vehicle, Odyssey. A little, bitty boat will do. You don't need a big support platform.

I don't have a photograph of Odyssey, but I've seen enough images on the screen as we were walking in and on t-shirts walking about outside of the Odyssey, so I'm sure that if you don't know what Odyssey looks like, you soon should find out. It looks rather like a tuna fish. It's sleek, tapered, with propulsion at the aft end. A system that made history this past winter.

I really regret that I don't have a picture to show you, but I'll keep the little Phantom up there because both shared a little piece of history-making event this winter. Not by doing the same project, but in the same environment in Antarctica. The Odyssey vehicle will warm the hearts of flinty-eyed National Science Foundation funders with a component cost of a mere $50,000, a range of 270 kilometers. It can't go as far as a tuna fish, but they're getting there. A depth range, however, that exceeds that that a tuna fish can achieve, unless it's a one-way trip for the tuna. That is, 6,000 meters.

Move over Shinkai 6500. This system, the Odyssey, can be deployed from a zodiac in Antarctica. Talk about a tough environment.

Well, this year, this little vehicle, the Phantom, made history side by side with the Odyssey in terms of its launching pad. In this case, NASA provided funding because of their interest in remoting human capability to faraway places such as Mars.

There are, happily, spin-offs to this technology and this support here on this planet, Earth. Using virtual reality-type helmets, pilots tilted their head one way or the other and the vehicle's cameras responded accordingly some distance away, under the water and below the ice. But instead of virtual reality, the pilots with their video monitors were witnessing reality-reality.

In fact, the part that made history was accomplished with the help of microwave links and satellite links when a pilot sitting in California caused the vehicle in Antarctica to go through its paces, move its cameras as the pilot in California moved his head left, right, up, down, and so on.

Well, if you go to Spielberg movies, you think, well, of course we've done that for a long time. But the fact is we haven't. We're just getting there. We can envision it, but in many cases, we are just on the cutting edge of being able to do some of the things that people in science fiction terms have thought about for many years.

Video eyes have not yet fully replaced human sensors. It is likely there will always be a place for both because, well-- I, at least for one, certainly hope so. I hope that the either/or attitude gets squashed, that manned versus unmanned. We need all the tools in the box we can muster.

This little manned vehicle called DeepFlight is an example of kind of getting it together both ways. Much can be learned about autonomous vehicle handling by putting a human computer inside the sub for a while, and then substituting as the technology reaches that point, the mechanical substitutes, the artificial intelligence.

Actually, it's a great test bed and a way to work together instead of working in isolation one from the other. And I'm happy to say that, in fact, that is the case, that people do talk in spite of the lines that seem to be drawn between putting human beings underwater and keeping them out of the water, just as is true in space.

There is, of course, much to be learned from watching the ultimate in ocean engineering in action. And here are my personal favorite, the Atlantic bluefin tuna. Again, I have heard engineers sigh with envy as they admire the sleekness, the design, the propulsion system, the ability to go for thousands of miles on a diet of herring, no batteries required as such.

But these particular fish illustrate one reason why we must hurry with our technology. The sea is changing. Ecosystems are feeling the crunch underwater. Those beautiful tuna, for example, the Atlantic bluefin tuna, the breeding population in the last 20 years, despite efforts to protect them, have dropped to 10% of what they were.

We've seen changes on the land as well. As MIT's Ocean Engineering Department enter its second century, the pace is quickening as far as global change is concerned. And with it, the need to know and to understand the nature of our planet, our life support system.

Technology is vital to achieve survival on this shrinking changing planet. I want to end with a salute, especially to those here who see that we need all the tools in the box. Especially to those who, like Murray Gell-Mann, and Doc Edgerton, and others who are seeking and finding the balance, and are helping to engineer a habitable, enduring planet. Thank you.

[APPLAUSE]

OGILVIE: Well, thank you, Dr. Earle. I enjoyed that very much, and I hope everybody else did.

I should point out that the Odyssey vehicle that she referred to is on display in the Building 7 lobby. So if you get a chance to go through there today, and I think tomorrow morning, you can see it. It just happens to be between missions and so it was available, along with several other vehicles, from the MIT Sea Grant program.

It's a sleek-looking body incidentally because one of the problems of going down deep in the ocean is you have to carry your energy with you. It's an advantage that the people in space have that we don't have. If you put a spacecraft up, and if you put enough photo cells on it, you can get all the energy you need. You can't do that in the ocean.

So you either have to have a cable. And that becomes impossible at a certain point. Or you have to carry it with you. And actually, the MIT approach has been, at least in the Ocean Engineering Department, we were not going to become battery chemists. And we didn't think very much of the idea of trying to put some sort of nuclear device in little beasts that would run around unattended. And so we decided to go in the direction of making the most efficient use we could of the energy that was available.

There is a project in the department related to fish swimming, which is rather interesting. For decades, it's been recognized that fish swim with efficiencies that have been considered to be impossible by engineers. And a lot of people have looked at it. Coding problems, and flexible surfaces, and all sorts of things have been proposed and none of them worked. I think we know the answer now.

Unfortunately, it requires that the tail flap. And we haven't figured out how to make submarines with flapping tails. But at least, I think we are getting a much better understanding of the process.

Well, it's my pleasure now to introduce our next speaker, Bob Spindel. Dr. Spindel was-- I first got to know him when he was at Woods Hole. He was the chairman of the Ocean Engineering Department there.

A few years back, he went over to the competition at the University of Washington. But fortunately, we still work with him closely. In fact, we have joint projects with him. And he was a natural, I thought, when I wanted somebody to speak to us about measuring the ocean environment. It's my pleasure to introduce Dr. Bob Spindel.

[APPLAUSE]

SPINDEL: [INAUDIBLE].

OGILVIE: Okay. Here's a pointer. Whoops. [INAUDIBLE].

SPINDEL: Thank you very much, Frances. And with all this technology that we're going to hear about this morning, still the most untechnological item that a speaker has to deal with is this little box, which is wireless remote control.

It's really a thrill for me to be here this morning. It's always a thrill for me to be at MIT.

I grew up in New York City. I always wanted to be an engineer, always thought that MIT was the place to go. And when I graduated from high school, I sent my application to MIT, but I also sent an application to the Cooper Union. And I think it was a result of the foresight of Peter Cooper who established a tuition for his school that has kept me from sitting in the audience as an alumni as you are doing today. But it's wonderful to be here, even though I'm not in the audience as an alumni.

What I'd like to do is talk to you a little bit about how we measure the ocean and why I think that if there ever was a time to be excited about being an oceanographer, to be excited about being able to measure the sea, that time is right now. We are on the verge of, really, a complete new understanding, not just a complete new vision of the ocean as Sylvia was trying to impress us with, but a complete new understanding of how the oceans operate, how they drive the forces of the planet, how they control our weather, how they control our climate.

And the reason we're on that verge is because of a few new technologies. One of which is the satellite and the other one are technologies that allow us to actually see into the interior of the ocean. And not just see little pieces of it, not just see that 1/10 of 1% of the bottom that has been explored, but to actually see the ocean as a whole. And let me try to give you some idea of what I mean.

This is still the way we measure the ocean. This is the Challenger. It was the first great ocean-measuring expedition launched in 1872. It lasted about three years. It really is the forerunner, the precedent of the kinds of expeditions that we still carry on today. It's men in ships that still measure the ocean.

There are many expeditions, such as Shackleton's expedition in 1915, which were billed as scientific expeditions, but they weren't. They were really expeditions of exploration. Shackleton was trying to get to the pole, not measure the oceans.

Some of the expeditions ended successfully, like the Challenger. Some, not so successfully, like the Endurance in 1915.

But this is a modern ship. This is the Woods Hole Oceanographic's first research vessel. It doesn't look any different than the Challenger. And it doesn't look any different than Shackleton's Endurance. And the ships that oceanographers sail in today look exactly like that. They just don't have masts. They have not changed at all in all those years. And it still requires men going to sea, being uncomfortable, using buckets. It still requires putting instruments over the side of a ship in the worst kinds of conditions. And through it all, making just a very tiny measurement.

This is an example of an instrument that is the mainstay of the oceanographic world. It is lowered from the ship on a wire. It measures salinity. It measures temperature. And it measures the depth that it's at. And it has little bottles attached to it so it can collect little samples of water and bring them up. It takes about two hours to lower that instrument from the surface to the bottom. It takes about another two hours to bring that instrument back up to the surface. You can imagine how time-consuming and how energy-consuming and how expensive it is just to make a simple little measurement like that in one part of the ocean.

If you make many such measurements, you can begin to view the ocean as a three-dimensional entity. This is a block of water. Temperature of a block of water in the Fram Strait, which is the narrow inlet and outlet to the Arctic Ocean that exists between Greenland and Spitsbergen. And it was created by making hundreds of lowerings with an instrument such as the one you saw in the previous picture.

And to give you some idea of what the interior of the ocean looks like and how complicated it is, you can, with a computer, produce an image like this. And you can begin to peel away layers of water.

If you peel away water that is above a certain temperature, say above 6 or 7 degrees centigrade, you're left with only that water that is colder.

If you begin to peel that away and only leave water that's 3 or 4 degrees centigrade, you achieve an image like this. And in order to do that, if you look at that slide, you see these vertical lines. Each one of those vertical lines represents a lowering of one of those instruments. It took many hours to do this. It took many days to complete this survey.

In fact, the ocean that was being measured at the beginning of the survey was probably very different than the one that existed at the end. And so instead of seeing a photograph of the interior of the ocean, you're seeing a blurred, smeared picture.

Well, what has man done? What have we done as oceanographers to get away from this, having to use ships? The first step, really, was to use ocean moorings, which was to replace a ship with something that's fixed in the water.

This is an example of an ocean mooring. It's a wire that extends basically from the surface to the bottom with an anchor at the bottom and instruments all along it. There are hundreds of these in use today. They are a tool with the oceanographer users, but they are fixed in place. And they only measure the ocean in one particular place.

Here we see an ocean mooring being deployed. Those yellow things are glass balls which are used for flotation. And they are really something, a piece of technology that was largely developed by an MIT graduate, Sam Raymond, who was actually a student of Doc Edgerton that Sylvia spoke about.

Not all moorings are beneath the surface, some are above it. And here's an example of an ocean mooring, a ship basically fixed in position that is used to measure temperature, salinity. This is a mooring that is installed in the Southern Pacific Ocean along the equator. It has a transmitter to transmit its data directly from the mooring through a satellite back to shore. So the oceanographer can sit in his laboratory, not on a ship, and receive data that way.

Not all oceanographers sit in laboratories, not all of them are on ships. Some are even on moorings in the middle of the ocean.

That particular mooring is one of an array that exists, as I said, on the equator in the ocean. It's designed to measure the southern oscillation, the El Nino, that occurs in the Pacific. The phenomenon that occurs because the winds that are generally running from the east towards the west pile up warm water on the Western side of the Pacific. And then for some unknown reason that we don't understand, every now and then those winds relax and that warm water sloshes back across the Pacific Ocean, up against the West Coast of both the United States and South America. It's what destroys the anchovy fishery.

It happened last year. It wreaked havoc with the salmon fishery on the West Coast. And in fact, people believe it may have been the cause of many of the storms that occurred in Southern California last year.

You can see the number of moorings that have to be put in the ocean just to measure a simple little phenomena like that. You can see the kind of data that those moorings bring back.

This is a plot of temperature depth. The red is warm, the blue is cool. And if you look, you can see periods where the Pacific Ocean warmed up. It warmed up during the early '80s, an El Nino year. It warmed up in the mid-'80s, another El Nino cycle. And then again just last year, the El Nino cycle that I just spoke about.

Not all moorings are successful. Here's an example of one that came up a bit of a snarl. Not all instruments work all the time.

As high as our technology is, here's an example of an instrument that simply imploded due to the pressure at depth. Not all moorings are buoyed up from the bottom. Some are actually suspended from the ice.

Some are actually put in by MIT people. And maybe you recognize some of your classmates here.

Not all instruments are moored on the bottom. Some just sit on the bottom. This is an example of a typical bottom-measuring instrument. It's a little tripod, a little tower that sits on the bottom. It has lots of devices on it. This particular one has devices to measure currents. It has devices to measure suspended sediments. It has devices to measure biological activity on the bottom.

Another example of a bottom instrument shown here is one that has been designed to measure the heat diffusion rates within ocean sediments. It was an instrument that was used to determine what would happen if we disposed of nuclear waste at sea. And the canisters in which the waste were held broke, or leaked. How would the radioactive material diffuse through the sediments?

Well, we had ships that got men sick and only measured things in small places. And we had moorings and things on the bottom that were fixed in position and only measured small parts of the ocean. And then we took a step forward, about 20 years ago, to produce instruments such as this one, which drift freely in the ocean. They are ballasted to be neutrally buoyant at certain depths. They drift with the currents at those depths. They measure the ocean temperature and pressure and salinity at those depths. And they transmit that information back to shore, sometimes acoustically. Sometimes, they bob to the surface and transmit the data by satellites. So we've replaced the ship basically with an unmanned, autonomous, freely-drifting instrument.

To ballast these things at neutral buoyancy is a very critical and I think interesting technological feat. They generally have to be balanced to within about a gram. Otherwise, they will rise to the surface if they're too light or sink if they're too heavy. And the balancing has to be done at the surface where there is no pressure and where the temperature is certainly different than it is at depth. So one has to know the characteristics of the materials that are being used to predict how that instrument will behave when it is at its in situ temperature and depth.

This is an example of the kind of data that's returned from instruments like this. These are the tracks or the pads of these floats that have been drifting around the Atlantic Ocean now for the order of 10 years.

Not all floats transmit their data acoustically. Some, as I said, actually bob to the surface. This is an example of one that goes up and down 10, 12, 15 times in the course of its life. Records data when it's beneath the sea, transmits the data through satellites when it reaches the surface.

Well, those are the instruments that are in the ocean. The real revolution, I think, is going to take place with instruments that are above the ocean with satellites. And they're not new. They've been observing the earth for a long time. What is new is the fact that over the next decade, over the next 15 years, we have scheduled, here in the United States and worldwide, the launch of over a dozen satellites with instruments that are devoted specifically to measuring the ocean. For the first time, we will really be able to see the ocean basically all at once.

This is an infrared image that was taken with a satellite. You can see the Gulf Stream very clearly. In fact, you can see Cape Code very clearly.

Radar scatterometers. Basically, radars on the satellites allow you to measure ocean winds. Allow you to understand something about the interaction between the atmosphere and the ocean and the exchange of gas and heat and chemicals that occur at the ocean surface.

Radar altimeters allow you to measure the height of the ocean's surface. The top of that view graph shows the surface ocean height measured from a satellite. And the bottom of the view graph shows the bottom of the ocean that was measured over a period of hundreds of years with ships.

What actually happens is that the ocean's surface conforms to the shape of the ocean bottom. Using a satellite, a remote sensor, we see the bottom of the ocean from 1,000 kilometers in space.

Something as lowly as a camera on a satellite can tell us something about the ocean that we wouldn't otherwise know. Here, you can see waves entering the Mediterranean from the Atlantic Ocean. These waves are inside the ocean. They're not on the surface. You wouldn't see them if you were on the surface.

Or we can learn something about how sediments and wastes are distributed in the ocean. Here you can see the outflow of the Po River. You can see the sediments that are spilling out. And fortunately, going south of Venice and not up into the Venice area.

Satellites offer another opportunity, which oceanographers are going to be very quick to take advantage of. And that's communications. They provide a means of getting the data back from sea. At the moment, there are very few satellites that are equipped to transmit oceanographic data. But over the next 10 years, when land mobile-based satellites, telephone services are extended worldwide, oceanographers will be using those to basically dial up from instruments at sea, to transmit through the satellites data back to their laboratories at shore.

So the satellite, I think, is really going to make a tremendous difference in the way we see the ocean and the way we view it. And then there's one other piece of technology, I think, that's going to make a tremendous difference. And that's a new way of using underwater sound.

Sound is the only form of energy that transmits-- that can be propagated for any distance underwater. Light can't go very far. And clearly, electromagnetic energy can't be transmitted very far. But sound basically goes forever underwater.

And as the sound passes through the water, it has imprinted upon it all the patterns of the ocean. It has imprinted upon it changes in the ocean's temperature, in the ocean's density, in the ocean's salinity.

This is a satellite picture of just the surface. And I'm going to show you a picture of what you can do with underwater sound that will not look unlike this one. Acoustic instruments can be put into the sea. They can talk to one another, and they can record variations in the ocean that occur with time, that occur with space. And they can basically view a whole ocean area in the same way that x-rays are used to view the interior of the body.

The technologies that are required to do this are unique and interesting. And MIT has contributed greatly to them.

This is an underwater sound transmitter that can transmit sound thousands of kilometers. Another example of a transmitter.

Now, this is the satellite picture that I showed you a moment ago.

We'll try it this way. And this is a picture that was obtained with underwater sound, not of the ocean's surface but at a depth, in this case, of 700 meters. And what I wanted to show you was how much alike this picture is to the satellite picture. Sound is doing for us the same thing that the satellite was able to do. This opens up a whole new realm of possibilities in being able to understand the inside of the ocean, not just the surface of the ocean.

What I'd like to do is give you a final example of how we're using sound nowadays to learn something new about the world.

We hear about global warming, and about the planet heating up. This is the data upon which much of the speculation of global warming is based. It shows the temperature over the last 100 years. Temperature that was measured mostly in the Northern Hemisphere because that's where the measuring stations were. Temperatures that were measured mostly in cities because that's where the laboratories exist.

And it shows a gradual rise of maybe a half a degree over the 100-year period. If we had looked at this record only this long, up to here, we would not be concerned because it looks like the temperature is turning around.

The fact is though, over the last few years, it looks like maybe the temperature is going up. Will it turn around and come back? We don't know.

What can the oceans tell us about it? And what can underwater sound do for us? It's almost impossible to make this kind of measurement in the atmosphere. It would require putting thermometers globally, worldwide, measuring them daily, averaging them, and doing it for a long period of time to see whether there was really a small trend in what amounts to a very noisy measurement.

Sound offers us an opportunity to actually make that measurement because it is affected by the change in temperature of the ocean. If the ocean warms up, sound travels through it differently than if the ocean is cooling.

And the notion of making that measurement is to put neurotransmitters in the water and to put receivers in the water. And to measure the effect of the ocean on the sound as it's transmitted from one transmitter to another, one transmitter to a receiver.

This is an example of an experiment that was done not too long ago in which an attempt was made to do just that in which transmitters were put in the ocean near Heard Island, which is in the Southern Indian Ocean. Receivers were placed at the little spots where the dots exist. Sound went 10,000 kilometers from Heard Island to the various listening stations. It was received with clarity and with fidelity, and gave oceanographers a picture of what happens along all these sound paths. It gives us the hope that we can make a measurement like this to learn something about the global oceans. That we can transform a start like this into a finish like this, where we have many transmitters, many receivers developing a picture of the ocean in much the same way meteorological instruments developed pictures of the atmosphere.

Never before have we been able to look at the ocean in a three-dimensional form like this all at once. And I think it's because of that, because of the satellite that sees it from the surface, and acoustics, which see it from the interior, which are going to give us a new, better understanding of the oceans around us.

I started out by saying if there ever was a time when it was exciting to be an oceanographer, now is the time. And there's one other reason that I think it's exciting. And that is the world is a different place than it was five years ago. And we now, I believe, have the opportunity to focus our resources and our attention and our energy on learning something about the planet we live in instead of protecting ourselves or defending ourselves from nuclear catastrophe. Thank you very much.

[APPLAUSE]

OGILVIE: We're going to get the speakers back up here afterwards to take questions.

It's one of the interesting ironies of studying the oceans that NASA has been one of the most effective advocates of doing oceanography. And of course, they didn't do it because they were really interested in the oceans. They saw it as a very good excuse for getting more money for satellites and such programs. But some of the satellite pictures have given us tremendous information that we never could have gotten any other way.

Well, we're doing very well on time, I've got to say, remarkably so. But I think we will push on, even though we're a few minutes ahead. We are going to have a question and answer period at the end, when we will ask the four speakers to come up. And they can challenge each other or the audience can challenge them or simply ask questions.

So now, it's my pleasure to introduce Professor Carl Wunsch of the MIT Earth, Atmospheric and Planetary Sciences Department, who is-- well, I guess he's probably worked with some of those buckets in the past. But he's long since passed that stage and is using some of the most sophisticated technology we have. And so his topic is the effects of the ocean on global climate. Carl.

WUNSCH: Now, the ocean has a familiarity for most people to some extent, but we live on the upper edges. Most of us know it from being at the beach, or perhaps from having been on a ship. But it is an extraordinarily large, complicated, opaque fluid system that involves physics, chemistry, and biology. And its import for our everyday life is essentially unknown to most people, including most scientists.

And what I would like to do today is to try to convey to you some of the elements of this subject. And as you'll see in the next few minutes, I'm going to range all over the place. And at some point, you may wonder, what does this have to do with the ocean? And I'm going to try to tell you this.

My first slide is a famous one that many of you will have seen. It shows what Bob Spindel just alluded to, the rise in carbon dioxide as measured in the atmosphere since about 1958. That kind of sinusoidal oscillation you see there is what some people have referred to as the breathing of the biosphere, the annual cycle and the plants. But the main point is that carbon dioxide in the atmosphere is rising exponentially. It has been rising exponentially ever since the Industrial Revolution.

And understanding that there were, perhaps, going to be some interesting consequences of this was first recognized a hundred years ago. It's only in the last 20 or 30 years that people have come, however, to recognize that the consequences of such a rise in carbon dioxide and other greenhouse gases are potentially but not necessarily catastrophic.

You've seen this just a few minutes ago. Bob showed you that. Just look at this. It's the global rise in apparent temperature of the atmosphere as estimated by meteorological devices over roughly the last hundred years.

Whether this rise is connected to the greenhouse effect is not known. And whether we are seeing a greenhouse effect or whether we're seeing something else is-- the answer to that question is very much tied up in the ocean as I'm now going to try to show you.

This is a computation. It's from a set of models of the atmosphere carried out some years ago, in which an attempt was made to calculate how much the global atmospheric temperature would rise if you doubled the carbon dioxide content of the atmosphere.

The carbon dioxide content of the atmosphere will have doubled over the value it had before the Industrial Revolution in about the year 2030 if nothing is done to change the rates of emission, which come from burning fossil fuels primarily.

The point I would like to make is you see four curves on there. And the details of this are not really very important. The point I would like to make is that the predicted rise in global temperature at one extreme here is getting up close to 3 degrees by the year 2010, 2020. You predict in one model that there would be a 3 degree Celsius rise in temperature in the global atmosphere about 40 years from now. Or you predict the rise that's less than a degree.

Now from the point of view of those of us who live in the Earth's atmosphere, the difference between a 1 degree rise and a 3 degree rise, although it may sound like not very much, is gigantic. Because the consequences for temperature extremes, changes in rainfall patterns, the occurrences of droughts, shifts in agricultural belts, are enormously amplified if you have a 3-degree change than if you have less than a 1-degree range.

The oceanographer's problem is the difference between these two curves-- these four curves, comes solely from making a slightly different model of the ocean. And so all of this uncertainty, if you like, is shown in these graphs about what is going to happen comes from the question of, how does the ocean behave? And it's this kind of question that leads me into trying to explain to you a little bit about how this system works.

Now, this is a slightly technical slide. I apologize for it. But it's simply to allow me to make a particular point. I want to try to give you a little bit of the sense of what the ocean does to our climate.

These are curves of the amount of heat that is being carried from the equator toward the poles by the atmosphere in the ocean. Most of you will recognize that most of the heat comes in from the sun and the tropics. It's carried toward the poles where it's radiated back to space. Not many people recognize, including many meteorologists until quite recently, that at latitudes like where we live, 40 North, the ocean is carrying about half the heat polar, from equator to pole. At lower latitudes, the ocean is actually carrying a good deal more than the atmosphere. And it's that balance of heat in which you carry the input of radiation from the tropics toward the poles that makes the Earth habitable in places like Boston, or most of the places where people live.

You start to wonder, what would happen to our climate should the amount of heat carried by the ocean change for any reason? And so now my question is, is there any evidence that the amount of heat that the ocean has carried to make up our present-day climate, has that ever changed?

Now, this is a picture of a time in which we believe that the amount of heat and other properties carried by the ocean's circulation was radically different than it is today. In fact, this is a picture of the Northern Hemisphere, North America, about 18,000 years ago.

Now, depending upon your point of view, 18,000 years ago is a very long time ago of no concern to us. On the other hand, these are modern times, 18,000 years ago. The Earth was inhabited by people just like ourselves we're told. And clearly, the climate of Boston, not to speak of much of the rest of the Northern Hemisphere, was radically different than it is today.

Clearly a change like this was not caused by human intervention. If there was anything related to a greenhouse effect, which we'll come back to in just a minute, it was not because people were burning fossil fuels or doing anything else. The point of this is that we know from the historical record that the Earth's climate has been radically different in the past. And the evidence is that the ocean has played a major role in producing situations like this in which you have a mile of ice sitting over Boston not very long ago.

Now, here's another slightly technical slide, but it's one of the most interesting results of the past 10 years of trying to understand climate. I have to give you a little bit of technical detail.

The time scale at the bottom here is time. And it goes from the present 0 on the left over to 160,000 years ago. So that's my time scale. And there are three graphs on here.

The middle one is a very important one. It's an estimate of the atmospheric temperature over that period of time, between now, which is there, and 160,000 years ago, which is over there.

The two other graphs on here are-- the top one and the bottom one-- are of greenhouse gases. Carbon dioxide on the bottom-- the stuff we're putting into the atmosphere at a great rate-- and methane, which is another very important greenhouse gas. I should tell you that the way these curves are gotten is by drilling into the ice caps and measuring the concentration of gases trapped in the ice caps as the ice is compressed. The snow is compressed into ice.

And one can date it and one can, in fact, make temperature estimates of many other things. This is a fascinating curve because you'll see here that there was a time about 18,000 years ago in which the atmospheric temperature at the pole was about 8 or 9 degrees colder than it is today.

Well, this is very nice. It corresponds with the height of the last glaciation, the picture I just showed you a few minutes ago. So what we see is that 18,000 years ago, the Earth was much colder. And we see that the methane and carbon dioxide content of the atmosphere was much lower. If you like, a greenhouse or an anti-greenhouse.

Before I go on, it's worth pointing out that the Earth today is just about as warm as it has ever been in the last 160,000 years. We're just about at that extreme, a little above it. The carbon dioxide content of the atmosphere is increasing. And of course, one of the questions is, what is going to happen?

Let's look at this a little more closely. It's rather interesting that at a time when the Earth was very cold-- this period, and earlier glacial periods like this one-- that the greenhouse gas concentration in the atmosphere was much lower than it is today.

Where was that carbon? The amount of carbon that is taken out of the atmosphere and going from present conditions back to the last glacial period is billions and billions of tons of carbon that are missing, not found in the atmosphere. Where was it?

Well, we can think of only two conceivable places to put it. One is to put it into the biosphere, forests. Although, of course, much of the land was covered with ice. And so you actually have a good deal less room to put it into at least the terrestrial biosphere. Or, you could put it into the ocean. And I think there is a model consensus that this carbon was in the ocean.

But now, we start to ask some other questions. If this carbon got put into the ocean, did that cause the ice age, or was the ice age because of the removal of the carbon? Well, we don't know, actually.

On the other hand, what is quite clear from these curves is there's a very close correspondence to the concentration of greenhouse gases in the atmosphere and our climate. And of course, that the climate has been very different in the past. And it has been very different without any human intervention, whatever.

Now, before I move on, I've marked here a little peak in here. It shows up most clearly in the methane. There's a bit of jargon here called the Younger Dryas. This was a period in which as we were deglaciating, as the great Laurentide Ice Sheet was melting, the earth suddenly reglaciated again. It turned around, the ice cap grew again.

And it's interesting to ask, how fast did such a change take place? So what we're going to see in the next picture is an exploded view of some of the data that goes into making up those curves. And let's just look at this one.

Well, let's look at this one right here. It's probably clearest. The time scale here is no longer 160,000 years. It's 20 years. The people who look at these curves say that the major climate shifts that have gone on in the Earth in the past have not taken place over hundreds or thousands of years. But that features like the Younger Dryas period in which the Earth went from deglacial conditions back to glacial conditions for about 1,000 years, and then deglaciated again, those changes took place in 20 years. So what we are being told by records like this is that the Earth's climate is capable of shifting in a major way over period of decades.

There was even a paper in *Nature* about two weeks ago suggesting that the shift took place in three years. This is kind of interesting. It's perhaps a little bit worrying. But it's very difficult to escape the conclusion that something in this system is capable of shifting the climate state on time scales that are much shorter than a human lifetime.

Now, how does this happen? Well, the only element in the system that we can think of that is capable of shifting climate massively to this extent on time scales of decades is the ocean. Now, how might this work?

Here's a cartoon. And I emphasize that it is a cartoon of how this works. This is about as technical as I will get.

Think of this as looking from Europe toward North America, across the Atlantic Ocean with the sea surface here, the seafloor here. And schematically, what the ocean does is the following.

It's very cold up here at high latitudes, particularly in the wintertime. And it's so cold there and such a strong wind that the water gets heavy and it sinks. Since water is sinking, it has to be replaced by water from further South. Otherwise, sea level would fall. And that sucks water up from the South. That water is warmer. It's being heated up by the sun down here. And that heat is taken out by the atmosphere here as part of this process.

At the same time, the water that is moving northward, taking up heat, is also taking up carbon dioxide and methane and other greenhouse gases. And it's richer in carbon dioxide at the time that it sinks than it was down here. And so a lot of the carbon that we have been putting into the atmosphere is being sequestered in the ocean.

In fact, if you can remember the first graph I showed you, the rising CO2 in the atmosphere. Only about half of the carbon we believe that has been emitted by burning of fossil fuel and so forth appears in the atmosphere. Much of the remaining half we believe is being buried in the ocean.

Now, here's where it gets kind of interesting. That means that the greenhouse effect is being delayed, we believe, in a number of ways. One is there's much less carbon dioxide going into the atmosphere because some of it is going into the ocean. A lot of the heat, the excess heat that is being picked up here, is probably being buried in the deep ocean.

Now, we get into the biology a little bit. There isn't really time to do it here in any detail. The water that sinks eventually has to return to the surface. And that water that returns to the surface is rich in nutrients. It's the stuff that the phytoplankton and the other bugs and the things that fix carbon by photosynthesis at the surface live on. So what might happen if you changed the ocean?

Now, here's another cartoon. And I emphasize, it is a cartoon. I'm telling you a might happen. The meteorologists tell us that if we warm the atmosphere by a greenhouse effect, we're going to warm it more at the poles than we are at low latitudes. So what might happen to the ocean?

Well, if the atmosphere is warmer up here than it is now, the water that now sinks isn't going to be as cold. It will not be as heavy. So the water will not sink as far and it will not sink as rapidly. So the heat that enters here and the carbon that enters here will not be pushed deep into the ocean at the same rate it is today.

The possibilities are severalfold. One is that more carbon will stay in the atmosphere, that less heat will be tucked into the deep ocean safely out of the way. And will, therefore, stay in the atmosphere. And finally, the amount of nutrient-rich water, which feeds the biology and helps fix carbon, will also be reduced.

Now, could this happen? I'm not saying that it will happen. We believe that this is perfectly possible.

Now, let me remind you a little bit of what the current climate looks like. This is the global temperature of the Earth as seen in the mean and in the two seasons. For those of you who can see the lower panel, this is the Northern Hemisphere summer. You see the very intense high temperatures in the centers of the continents in the Northern Hemisphere, the extreme negatives in the Southern Hemisphere, and the comparatively mild temperature changes that we see over the ocean. This is the effect of the transport of heat from the equator toward the pole that maintains this pattern and that maintains the climate as we see it today.

It's a little dark. This is the global biology. This is merely to point out that the global biology, the nutrient-rich places, the places where we have intense biological productivity in the ocean today are a consequence of the ocean circulation. Anything that changes the ocean circulation is going to change not only the temperature of the ocean, but also the biological characteristics of the ocean.

This is to show you, for anybody who's wondering what the ocean looks like in cross-section, here's the sea surface of the Atlantic Ocean. United States here. The mouth of the Mediterranean here. The ocean is warm on top. It is very cold at the bottom. It's this medium that we're talking about. It's the northward flow of this warm water here that keeps Europe warm, keeps Boston comparatively habitable. It's the southward flow of cold water here that is part of that great conveyor belt, as some people like to talk about.

Now, here's a perhaps outrageous picture. Tell you what this is. This has nothing directly to do with the ocean. Why do I show you this? This is the calculation of the orbit of an asteroid over 2 and 1/2 million years by my colleague, Jack Wisdom.

Now, the behavior of an asteroid circling the sun is far, far simpler than the behavior of the climate system. Many, many orders of magnitude simpler. Much more easy to understand. Now, why do I show you this in the middle of a talk about the ocean?

Well, this is one of the elements, for those of you who care, the so-called "eccentricity of the orbit." In this calculation, what one finds is that this asteroid happily goes around the sun for, let us say-- look in this area. For 500,000 years, and it keeps its eccentricity, its orbit fixed, essentially, for half a million years. And anybody looking at this might say, aha, this is really very boring. That thing just goes round and round and round. And we've measured for 500,000 years. And nothing has happened and nothing is ever going to happen.

But if you're a little bit patient and have a big enough computer, you find that once in a while, that eccentricity jumps to a very large value. And then it jumps back again. And then it's stable for a bit, and then it jumps again.

Now, of course, this behavior has become familiar in the last few years. This is classical chaotic behavior of an orbit. And people, like Wisdom, have now applied this sort of thing to the solar system. A very interesting set of questions, but that's another talk for somebody else.

The point I'd like to make is we believe our climate system, and in particular the ocean, does have some characteristics of this behavior. That simply because our climate appears to be stable for long periods of time, if you think of it as behaving like an asteroid, it is no guarantee that it will be stable in the future.

In particular, again a slightly technical picture. Look at the upper left-hand picture and the upper right-hand picture. This is also looking westward across the ocean, top to bottom. This is in the Southern Hemisphere now. So the Antarctic is here and the equator is here, in a model calculation of the ocean in which one has a nice, simple, steady ocean circulation that is going around and around like that. And around and around like that down below.

In the space of four years-- four years, now mind you-- this model, which is a global model, shifts the entire circulation of this ocean basin from a pattern that looks like this to a pattern that looks completely different. In which this shift from here to here is unforced by any outside intervention. That is to say, we think that the ocean and, therefore, the climate-- because our climate is in large part determined by the ocean circulation-- is capable of this kind of behavior.

Now, I don't want to leave you with the impression that we know that this can happen, but the presence of ice ages suggest that it has happened in the past.

Oops, a little too dark. I guess it's mainly to remind me to tell you that the ocean is a gigantic reservoir of carbon dioxide. And if you reversed the ocean circulation, as the model in the previous figure suggested could happen, the ocean is potentially a vast new source of carbon to the atmosphere.

Remember all the carbon that was missing from the atmosphere during the last ice age? We think it was sequestered in the ocean through a change in the circulation.

There's still an awful lot of carbon in the ocean. So much carbon that you might actually make a greenhouse atmosphere. Sorry, you might actually make a Venus-like atmosphere should it be possible to release it. I don't think that's possible, but there is so much carbon there, the possibility of a drastic change in the ocean circulation.

And now, one, I would remind you could take place in a matter of years is it were at least worth thinking about. Now I'm going to switch topics slightly. This comes back to something else that Bob Spindel alluded to.

We know the ocean controls our climate in a number of ways on shorter time scales. There was-- if I can focus it-- what is called an El Nino-- can't quite focus.

This is the surface temperature of the Pacific Ocean. Most of the time, the surface here is very cold. Normal conditions. And intermittently, on about an every five to seven-year time scale, there's an enormous sloshing of this warm water over here that covers the Eastern Pacific. It has all the effects that Bob mentioned.

You change the desert conditions that are normally here into ones of torrential rains. You get droughts in Australia and Brazil. You get droughts in the [INAUDIBLE]. You get torrential rains and changes in the North American climate. It has enormous economic consequences.

Well, this is a serious picture. It shows you the soybean futures prices in the period of 1955 to 1985. And it shows you the strength of this phenomenon in the Pacific Ocean. And in the early 1970s, there was a so-called "El Nino phenomenon." And you see the Peruvian anchovy fishery collapsed. That's a measure of the strength of this thing. And the price of soybeans shot way up.

Now, some people have interpreted this curve to mean that the price of soybeans affects the climate of the Pacific Ocean. But if you prefer that explanation, I will leave it to you.

There are enormous economic consequences of which this is simply a schematic of some of the things that go on. There are people who now very carefully watch the ocean climate.

I want to end here, now rather quickly, with a couple of minor summaries. Just because, as I say, I've tried to condense into 30 minutes what we spend several years teaching students. The elements of the ocean in climate interaction are that it stores heat and moves it around. It stores moisture and moves it around. It's a source of the rainfall that is so important to our climate. It moves the nutrients and oxygen supply of plants and animals. There's a very complicated biological response. It's a place where things like carbon and other pollutants are being stored. And we have potential sea level changes.

I wanted to end this, and then I'm going to show you a short videotape clip, just by way of alluding to some of the rather interesting and important issues that oceanographers face.

You've heard from both previous speakers that the problem of observing the ocean is a very difficult one. Technically, I hope I've convinced you that perhaps it's worth worrying about.

It is sufficiently complicated and expensive that there's a certain amount of delusion in the world about what the ocean does to our climate. And these are what I call pleasant and comforting myths. I must say, I first made this slide when I was trying to show it to policymakers in Washington, to convince them that things were not well.

The first is that the ocean circulation is assumed to be steady. I hope I've convinced you that it is not that we're going to solve this problem by getting big enough computers. There are people who believe that quite sincerely.

That we observe the ocean in just about the same way we observe the atmosphere. Well, you've seen how hard is to measure it.

We know that we can predict it. Well, since we think it may be chaotic, we're not sure that we can predict it.

And then finally-- and this was the dig to the policymakers-- that we are doing enough to assure that by the year 2000, that our uncertainty about this will have largely disappeared.

Now, I showed you cartoons. What I would like to do as an antidote to that is just give you a little bit of the feeling of what the real ocean looks like, in part to complement the observational problem that the previous speakers mentioned.

Now, what I'm going to show you, just about two minutes of it, is from a computer simulation of the ocean. It's a global scale model. Models of the ocean circulation outstripped the largest supercomputers that people have even envisioned. So the model you're about to see-- and I'm going to show you a fragment of it in the Indian Ocean, simply to give you a feeling for the complexity of this system. This model we know is much too simple.

This is the temperature in the ocean. You're seeing years go by to speed it up. The point I would like to make for you is that for the people who are interested in fluids, the ocean is a turbulent fluid filled with very complicated elements. As was mentioned previously, it's about 4,000 meters deep. It is constantly changing.

If you focus over here on the Western side of the Indian Ocean, some of you will be able to see the monsoonal reversal of the flow. You see this extremely intense flow over here in the Western Pacific. You see a bit of it, some of it leaking through into the Indian Ocean. You see these turbulent jets moving across the equator. We're going down in depth.

You can also look down in here. This is the Antarctic Circumpolar Current coming through here. To close the loop, the observational problem for people trying to understand this system is daunting. It is one of the most challenging engineering problems known to me. You're dealing with a system of high pressure. It's corrosive. It's much more difficult than working in space. The time scale on which things change is slow compared to normal scientific cycle times of one or two years, but is fast compared to a human lifetime. And we have immense problems of finding ways to observe, understand, and as you see to model this fluid.

You can see, by the way, the topography. You see-- here's Australia and the islands to the North of it-- how crudely they are represented. But calculations similar to this represent some of the largest numerical calculations ever undertaken anywhere in the world. And they remain too large for the computers that we have today. And much of the pressure in this country to develop modern computer architectures arises from problems of understanding the ocean. Just as I think it is driving much of the engineering required to work in such a hostile-- but I hope you now see-- intensely important environment to us. Well, thank you.

[APPLAUSE]

OGILVIE: Well, thank you very much, Carl.

During most of the first century of ocean engineering, we really just worried about what was happening on the surface. And so ocean engineers learned a lot about ocean waves and how they affect the vehicles and platforms and so on that we deal with.

As we go into this next century, we had to think on an entirely different scale. So some of these things-- for example, that Carl Wunsch was just showing you, these flows. Well, it turns out that the basic unit of flow rate that oceanographers use, it's something called Sverdrup. It's 10 to the 6th cubic meters per second.

Now, you think a cubic meter of water. That's about a ton of water. And then you have to think in terms of flows at 10 to the 6th of these. It's a different world and a different level of thinking about things. Some of these ideas about carbon dioxide-- the carbon in particular, you're measuring it in gigatons.

And when you look at how much is in the ocean, you find out you have to measure it in tens of thousands of gigatons. They're big numbers. And I'm still having trouble absorbing the importance of those numbers.

Well, we're still doing very well on time. It reminds me once when I was at a conference in Japan, and they asked me to be the chairman of the last session on Friday afternoon. And I said, why should I get that one? And they said, you always end a meeting on time. And they even gave me some weapons and devices to make sure it happened.

Our speakers this morning have been extraordinarily cooperative. I haven't even had to remind them. Actually, we're a little early. When Bill Koch finishes talking, we're going to ask all four speakers to come up here. And so actually, I asked him, please. Let's stay within schedule and that will give us a little more time for questions. And there will be a special event at the end of the program. And we will still be able to get you out to lunch at the Johnson Athletic Center on time.

So now, it's my pleasure to introduce Dr. Bill Koch, who is actually a graduate of chemical engineering, but we forgive him for that.

[APPLAUSE]

You want this thing?

KOCH: No. I'll just use the--

OGILVIE: Okay.

KOCH: Thank you very much. I spent 13 years at MIT as a student. And it took me while to get through. And I never thought I'd give a talk in Kresge, so this is quite a unique experience for me. I'm quite honored by it.

As you know, we put together an America's Cup team 18 months before the start of the America's Cup. The America's Cup is the oldest sporting trophy in history. It's 100, I guess, and 41 years old now. It's only been won and lost 28 times. And less than 25 people have won it.

When we entered the America's Cup, we entered two years behind our biggest competition, which were the Japanese and the Italians. They had a two-year head start on us.

We also took a completely different approach than anybody else had ever done to the America's Cup. We took a management approach. We said it was a management problem first, a technological problem second. And then thirdly, just finally a sailboat race.

We had a system in which there were no stars on our team at all. The team itself for the boat was the star. That contrast to all of our competitors. Team Dennis Conner, which was our formidable opponent here, that describes it. The Italians hired Paul Cayard, an American sailor, at a salary of $1.7 million to be his star.

We also said that we were going to take a scientific approach to the America's Cup, which had never been done before. We determined that boat speed is a science, but sailing is an art. You've got to combine those two.

Most other yacht designers, or most yacht designers are artists first who do, in fact, create very beautiful yachts. But they describe them as it looks fast, it feels fast. What we cared about was what was fast.

We also had tremendous other odds against us. We had to race the very best sailors, professional sailors in the world. And yet, we were a team of amateurs. That's like going in the ring against Mike Tyson.

We had to race against Dennis Conner, the best sailor in the world, in his hometown. And then we had to build an organization completely from scratch in less than a year to upwards of 288 people. We had to develop a whole new set of technology completely from scratch. And then we built the infrastructure and the facilities necessary to carry this out. Namely, to get a compound built in San Diego.

And our biggest problem there was getting permits to put up two flag poles. One to fly the American flag and the other to fly the-- our America Cubed flag. It seems our country is bogged down in permitting.

But anyway, they also-- Las Vegas odd-makers gave us 100 to 1 odds against winning. I think I made the biggest mistake in not betting on myself.

One of the reasons they did that was at the head of the syndicate was a nerd from MIT who had only learned to sail eight years ago and was from Kansas. So in fact, our competitors out there, Raul Gardini, who incidentally was the only smart one in the America's Cup. He did not use his own money. He used his wife's family's money to finance his campaign. But he, unfortunately, now is close to being in jail in Italy.

But anyway, when we got by Dennis Conner, which was a very difficult feat in and of itself, the 22 out of 27 newspaper experts or media experts said that we would lose to the Italians on average of 4 to 2. The America's Cup is the best 4 out of 7 races.

Instead, we won by 4 to 1. And the one race we lost was because we made 28 mistakes, not because the Italians were brilliant or faster than we were. In fact, one of our coaches, who is one of the best match racers in the world, said that what we did was-- actually, it was a route, a complete route.

We set a number of records in addition to that. We were the first team in modern history ever to win the America's Cup on its first attempt. Ted Turner, it took him, I think two to three attempts to win it.

We were the first team ever to have a woman on our team. We were the first team ever have two blacks. And we were the first team ever to have a man on our boat who had never seen a sailboat before he joined our team.

Well, before I show you or tell you about some of the secrets on how we were able to come this far in less than a year and beat the very best in the world with a group of amateurs, I would like to show you a videotape that shows you that sailing in the America's Cup is not a sissy sport. Excuse me for a second, I've got to set this up.

[VIDEO PLAYBACK]

I should tell you that these boats that you will see are spectacular. They're 75-feet long, about 16-feet wide. They weighed 33,000 pounds, of which 80% of that is in the keel. They require 16 crew members, all of whom have to work in unison.

Even on the simplest maneuver, you've got to-- if one person makes a mistake, he could wreck the boat for you. In fact, we had a saying, no one person can win the race for you, but one person could lose it for you.

The sail that you're looking at there has 5,500 square feet.

During the course of a race, we'd carry 25 sails, or have 25 sails. We might carry a dozen, but we'd change it at least 25 times during the course of a race.

If you look closely, you'll see a man in the mast up there. That's a new sail material that we invented, the silver sail called Cuban cloth. It's made of liquid crystal carbon fiber and a high-density polymer. These were some of our tender support vessels that we carried.

Watch this closely. You'll see a $750,000 mistake. And then, turn the sound up, please.

-[INAUDIBLE].

-You got the right one, baby. Uh-huh.

-As the America's Cup Defender Series continues, Dennis Conner and America Cubed approaching each other. Tom Whidden and Dennis have Stars and Stripes on port tack. Dave Dellenbaugh on A3 on starboard, as both boats begin to jibe.

A3 looks to have the commanding position. Conner coming very, very close, has to be careful. Stars and Stripes smacks right into the stern of A3. Right away up goes the protest flags on both boats. We'll take another look from onboard A3.

The judge has put up a green flag. No foul.

In the Defender Series, Stars and Stripes against Kanza. Conner will have to tack on Kanza's stern. Kanza has taken the lead, and will be first to round the weather mark. Buddy tacks quickly over to port and has the inside overlap with Dennis Conner in Stars and Stripes going back to starboard.

And it looks like she'll try to sneak inside, but Kanza is rounding and holding firm. Conner is still coming on. And they look like they're on a collision course again.

Melges holds firm. Dennis Conner hits Kanza as they go around the mark. And the blue boat caroms into the mark. She'll have to reroute. Incredibly again, the judges put up a green flag.

In the pre-start, both boats have sailed into the spectator fleet. It looks like Dennis is going to try to squeeze in between. And look at that, he hits Bill Packer's boat. Bill of the New York Yacht Club and a member of the defense committee.

-Dennis getting down on the downside steering wheel to get a better view of his competition.

-That is some fast boat. Almost like a rocket ship.

-Dennis talking about A3, the boat.

-I'm telling you, he's just so fast. There's nothing I can do.

[MUSIC PLAYING]

KOCH: This was a spy boat chasing another spy boat off. That's how we transported the boats.

It was good luck if I got hit on the head. And it was good luck for Buddy Melges to get hit on the head that way.

When we were in San Diego, we spent something like close to 300 days on the water. During that time, I saw probably something like 10,000 to 20,000 dolphins, 30 whales. In fact, we even hit a whale during one practice session. And we saw a shark about the same size as the boat. You didn't want to fall overboard.

I'll tell you a little bit about our regime. We would start our day every morning at 6:30 with 2 hours of intense workouts, both aerobic and weight training.

Here we are carrying our sails on board. We'd follow that by a crew meeting. And then after that, we'd take an hour to get our boats ready to leave the dock.

We made something like 75 sandwiches during the whole course of our campaign. Then we'd sail-- well, we had a rule that the boat left the dock at a certain point in time no matter who was late.

And here I am running to catch the boat. And there's Buddy Melges waving goodbye to me. You can turn the sound up a little, please.

That's our bow man again. But anyway, we'd leave the dock at 10:00 in the morning. We'd sail all day long, take 20 minutes off for lunch, bring the boat back at about 4:00 to 6:00 in the afternoon. Take an hour putting it away, have a crew debriefing session, and then go home at night. Or have technical meetings, and then go home at night and get up the next morning and do it all over again. In fact, we did that seven days a week.

We gave our crew our four days for Thanksgiving. And I think three days for Christmas. We sailed on the 4th of July and we sailed on New Year's Day.

During the course of the America's Cup, or during the course of our tryouts, we had 400 people try out for applicants-- or 500. We narrowed that down to 160 that we gave actual tryouts to. And then we rated each one person from a category of 1 to 10 in 3 categories. The first was attitude, the second was teamwork, and the third was ability. And they had to have a 9 or 10 in attitude and teamwork to get on the boat. And it didn't matter if they had only 2 or 3 in ability.

That's Buddy Melges and me fighting over who's going to steer. I won't tell you who won.

That's the tradition. When you win, you get thrown in.

[END PLAYBACK]

[APPLAUSE]

I would like to tell you our two secrets on winning. We discovered that what you needed to win in the America's Cup Race, or any race for that matter, is-- first of all, a fast boat. And then secondly, is a crew that makes no mistakes. And the secret to getting a fast boat is to having the best science available.

One of the interesting things that I went through during this whole process was I had to negotiate with the MIT bureaucracy in order to get the use of Jerry Milgram and his staff at MIT, which very fortunately the bureaucracy was very kind and let us make generous use of Jerry and his team. And as a result, we came up with some of the best science in the shortest period of time that ever has occurred in sailing history, we believe.

We had something like 50 different scientists on our staff, all the way from the Department of MIT, all the way to a department at Stanford University. We covered something like 15 different disciplines, from structural engineering, meteorology, chemical engineering, mechanical engineering, and even yacht design. I'd like to go through some of that technology.

I should also tell you on our staff or in our program were a number of other MIT alumni. Besides Jerry, Harry Lee was on our team. Bill [INAUDIBLE], who's an MIT professor. Harry Lee was an MIT Professor. Bill [INAUDIBLE], Jim Draper, and then I think there's about a half a dozen other MIT alumni that were there. So this definitely was, you might say, an MIT effort. Can we turn on the slides, please?

But we had a very interesting technical challenge. We had to design the boats for a very peculiar race course that involved going upwind, downwind, upwind again through a complicated Z, and then back downwind. And then upwind and then downwind again for a downwind finish. It was a sail-maker's dream because you had to have different sails for each leg of the race.

In addition to that, we had very variable wind conditions in San Diego. 80% of the time the wind varied between 4 knots and 16 knots. And we had to develop a probability model to find out-- so we designed a boat that would have the highest chances of winning.

Complicating this was the fact that in San Diego, there's the worst of all possible worlds for sailing. There's light air and huge seas. The huge seas come in from the Pacific swell, so you get a very strange chop there.

In addition to that, we had an El Nino year that you've heard talk about. And we went back and did a study on all the El Nino years in San Diego to see whether that made the air heavier or lighter. That is, faster or slower than what was our statistical average.

We found out half the time, the weather was more stormy and heavier air. The other half the time, it was less.

We also had a difficult time in measuring the wind speed on the race course. We had to actually send some boats out there and actually measure it.

The only historical data we had was at the San Diego Airport. And we found that there was about a 2 or 3 knot difference between what happened at the airport and what happened out on the race course.

Furthermore, during the course of the race, the bottom curve shows the true wind speed as a function of time. It would start off in very light air, pick up to about 10 knots, and then die down in the afternoon. Also, during the course of the race, the wind would shift as much as 50 to 75 degrees, which means that if you were behind by 500 yards, if you got a 50-degree wind shift, you could all of a sudden be ahead by 500 yards if the boats were going in opposite directions.

Our biggest problem was time. Since we had less than a year to get ready, and we had about-- then we had about six months to compete in the finals. We had to design all of our technology and do all this and stuff in a very short period of time.

We did not have time to go through the traditional thing of building a boat, testing it, seeing how it performed, and then coming back and redesigning it and building a new boat. Our design cycle first, just to start off with, took abou-- I think nine months from designing the boat to actually constructing it, building it, and getting it ready.

We reduced that cycle down to, I think something like just less than 2 and 1/2 months towards the end of the campaign. But we had to concentrate most of our things on developing the scientific tools, which we did. That's the tools that we were able to use to look at a design, predict how fast the boat would be from that. And then, with a high level of accuracy.

I've listed some of the other things that we've had to do here. Some of the other technical things. Each one of them could require an hour or two hours lecture on them, but I'll just highlight them for you.

We evaluated 120 different hull designs, narrowed that down to 40, in which we tested them in a tank, a 200-yard tank, water tank, in which we built 26-foot models, towed them in the tank 109 times per test. We tested each boat twice. We figured that we've towed models through the tank at least 1,500 miles.

We tested another 140 different keel configurations through the wind tunnel. And then from that, we reduced it to about six that we tested actually on the water. We had to design an incredibly light structure for the hull and the skin of these boats because all the weight was in the keel and you wanted the skin to be light as possible. I would not sail in one of these boats above 20 knots because they'll crack and break and fall apart.

I've already told you about the sail. We came up with this new sail material, which we call Cuban fiber. We were nicknamed the Cubans primarily because we had a name America Cubed. But we got back at the people because we formed our own yacht Club called the Bay of Pigs Yacht Club.

But anyway, we came up with this new material that was composed of, as I said, liquid crystal carbon fibers and a high-density polymer. We designed and developed that in less than a year as well. And that material was something like one third the weight of Kevlar, which is the normal material that's used in sales. Which also you make bulletproof vests out. And yet, it was five times as strong.

One of our biggest problems out there was kelp, which is the seaweed that grows-- or a form of sea life that grows at the rate of about 6 feet per day. And if it gets caught around your keel, it could actually slow you down, both imperceptibly and completely. We once tacked into a kelp bed and it went to a dead stop.

Our technology there, we had a large problem first in identifying whether we had kelp on the keel. And then secondly, was getting it off. We developed a fiber optic system to see if it was there. And then we developed a knife that was embedded into the bulb that we would pull up by a stick and it would cut the kelp off.

But the rudder was a different problem because if strands of kelp got around that, you couldn't use a knife on it because it was a removable appendage. So we went to something very simple-- very high tech, but very simple. A very long 10-foot pole with a 10-foot rope on the end, which we'd put over and just push the kelp off.

Maintenance to us was a tremendous problem. In fact, we used all kinds of techniques-- ultrasound, infrared photography-- to make sure that the skin was attached properly to the core of the boat. We found out that the best technique was just tapping it with a little hammer and listening to the sound.

Reconnaissance is a very interesting story that I won't have time to tell you about. That's a nice word for spying. There's some interesting stories there.

And then, coaching. We developed a unique coaching system for the America's Cup in which we would videotape every race, every practice. And every night, we would review the videotapes, correct any mistake that was made. No ego was spared, including mine. Especially mine.

And in fact, we had a rule. That if you weren't making mistakes, you weren't improving. Any mistake to us was a good mistake as long as you learn from it and as long as you didn't sink the boat.

But anyway, one thing that we're very proud of is that our coaches and our technology have been selected by the US Olympic team for the next Olympics. I'd like to go to the next slide to show you where all this lead.

One of the great innovations that Jerry and his crew did at MIT was to come up with what we call a sailing dynamometer. Or that's a sail force boat. That's a half-sized model of an America's Cup boat. Inside of it was built a frame. And to that frame was attached all the sheets, the shrouds, the mast, anything having to do with the sails. And then that was attached to the hull of the boat with six strain gauges.

We were able to take that out and sail it around the San Diego Harbor, and then developed and measure precisely the side forces on the boat and the forward forces on the both that the wind exerted on the sails. And from that, we were able to develop a computer model that was able to predict within a tenth of a percent of accuracy how fast the boats would be and was a remarkable improvement in it.

Jerry also developed some other things that were interesting. He was able to break the hull resistance down into six different components. Each component had its own function. Its own independent variables and its own function. And therefore, you could optimize the boat for any particular wind and wave speed you wanted.

We could design a boat for 8 and 1/2 knots. We could design one for 9 knots, 10 knots, et cetera.

This is what a typical profile of a typical boat looked like. As I said, the mast was 110 feet high, weighed something like 33,000 pounds, 75 feet long.

This is what the under-body of the boat looked like. We're actually undressing the boat for you. These boats were dressed in skirts, and then we had to put panties around the keel in order to prevent the skin divers from being able to measure what they were.

This is what the keel looks like. It looked like a fat atomic bomb with winglets on it. And the shape and location and place of those winglets was extremely important.

This is where all the technology resulted in. Our first boat, which we had to buy from the French in order that we could catch up with all of our competitors, which is the 0 axis here. What this is, is time faster around the race course as a function of the boats we built. We built four boats.

Our first boat, Jayhawk, we designed without any of our tank test data or any of our tools. It was 3 and 1/2 minutes faster around the race course than the original French boat. Our second boat, Defiant, was about 5 minutes faster. That came a little bit later. That had about 20% of our tools.

And then finally, America Cubed and her sister ship, Kanza, came out very late in the game. And yet, with all of our scientific tools-- and this was a result of all of our tank testing, all of our tools. She was 6 and 1/2 minutes faster than the first America's Cup boat built of this class.

Considering that the race took 200 minutes, this was an improvement around the race course of 6 and 1/2 minutes, or 3 and 1/2%. Beating another boat in the America's Cup by 6 minutes is equivalent to about 100 to nothing score in a Super Bowl match.

Here's a graph of how we compared to Stars and Stripes. That is, Dennis Conner. We found that we were above 7 knots. We were faster than he was in all conditions. But below 7 knots, he was a little bit faster than us. Which pointed out a weakness to us that we had to cure for the America's Cup.

And in fact, when the Defender Finals were over, we took our boat, put it on the compound. Immediately took off its keel, took off its rudder. Put a new keel rudder, bulb, winglets, new mast on. We sent a lot of the yachting establishment into apoplexy because they said you have a fast boat, why change it? If it ain't broke, why fix it?

Well, we said we have a weakness. And our tools are good enough to be able to test this. And they said, well, but you haven't tested any of your ideas on the water. We said we don't have to because our-- but I would like to show you the results of that.

Here's a curve of how fast we were and our differential speed as a function of true wind against the Italians. The 0 is the America's Cup boat that we had in the Defender Finals against Dennis.

As you could see, we made substantial improvements below 10 knots, as much as-- over a half a minute around the race course at a very low sacrifice at the higher wind speeds. And yet, we were faster than the Italians under all conditions.

This next graph shows how we compared with all the other America's Cup boats that were in there. Versus the Swedes, we were 4 minutes faster around the race course than the Swedes. A little bit faster than the Italians, New Zealands, et cetera.

This next graph shows a comparison of what our boat was like versus the Italian boat. We're quite proud of our boat because it was completely different than any of the others.

Paul Cayard, the head of the Italian syndicate, gave us a great compliment when he said that if America Cubed is right, the rest of us are all wrong. Also, Dennis Conner gave us a great compliment in that he said even his grandmother could win in that boat.

But if you look at it, America Cubed is the white lines. We were narrower, a little bit deeper, a little bit longer than the Italians. And that's what our science told us. Our science told us that we had to go to a different type of structure, a different boat.

Our philosophy was that the yacht designers were to come up with the good ideas, but the tank tests and the scientists would make the final decisions.

This is a slide that I'm not very proud of. It shows how much money we spent, $68.5 million on this. But of that, $25 million was for research and development.

Our original budget, unfortunately, was $15 million with a $5 million contingency. I hope you all are much better at your budgets than we were.

This is a very interesting chart. This is knots of boat speed versus expenditure by each syndicate versus millions of dollars per knot. As you could see, the total amount of money was spent was $498 million. The Italians spent $238 million. Now you could probably see why Raul might go to jail.

The Japanese spent $85 million. We were the fastest boat with 9.3 knots. I would like to show you this next chart, which compares-- a bar chart comparing millions spent per knot as a function of each of the things.

The Italians were the least efficient, followed by the Japanese, and then by us. The New Zealanders, the French, and the Spain were more efficient than we were. However, we won.

Here's a very interesting curve I'd like to show you. This is a curve of the millions spent versus boat speed in knots of all the syndicates. As you could see, it follows a general curve.

To get up to 9.235 knots, you had to spend about $30 million. To get from there to the winning speed of 9.3, you had to spend an additional-- about another $40 million. Remarkable. Can we turn the slides off, please?

I'd like to tell you a couple of short stories, and then I'll just try to speed along, Francis. But the one thing that we found that was very important to us was teamwork, focus, and commitment.

Teamwork. At MIT, I learned how to think scientifically. And I still remember a course, the name of it, 1021, taught by Professor [INAUDIBLE], that taught us how to think qualitatively instead of quantitatively. A very profound course.

But on the other side of the campus, I learned about teamwork. There, I should tell you when I first came to MIT, which is in 1958, I played freshman basketball. The varsity basketball team that year only won one game.

MIT then went out and recruited from Methuen High School, which as you all know was a dying mill town in Northern Massachusetts, a new coach by the name of Jack Barry. And it took him a year to deal with-- learn how to find his way to his office, learn the players, learn the MIT method, and the bureaucracy.

That year, when I was a sophomore, we only won one game still. Then, he reorganized the team. He did something very interesting. He gave us only one play to learn. He said we, at MIT, weren't smart enough to handle more than one play. He also drilled us over and over on that play. And then he organized the team around everybody's individual weaknesses, so we'd make no mistakes.

That year, our junior year, we won half our games. Then our senior year, we had the longest winning streak and the least points scored against us of any team in the entire nation, including the Big 10. We had the best basketball team I think MIT ever had.

We had only one player who could have made any other college team. The rest of us, including me, wouldn't have even lasted 5 minutes in a Big 10 freshman college tryout. And that was my twin brother. It wasn't fun sitting on the bench behind him, I'll tell you.

But anyway, what did Jack do? Jack did something, was that he instilled in each one of us the ideas that we weren't nerds, that we could win if we wanted to. And that we could win if we played together as a team. That's a very profound lesson.

The other thing I should tell you about is what we would call commitment. As I told you our work schedule, 12 hours a day, 7 days a week for a year.

We had one incident right after the America's Cup was going to occur on a Saturday morning. On a Thursday morning, I walked into the crew meeting. The guy who was in charge of the crew scheduling said, well, we're not going to have a workout tomorrow morning. And I said why? And he said, well, because we have-- there's going to be the America's Cup Ball tonight. That's the highlight of the season. We all want to go to it. You've kept us away from all the beautiful girls in California. It's been a long dry spell for us. All these swimsuit models are coming down. Christie Brinkley is coming down. All these beautiful girls. We want to have a great time.

I looked at him and I said, guys. Dennis Conner says you've got to be committed to the commitment if you want to win. His crew says you've got to be committed for being committed to the commitment.

But I said, we're here for only one reason. And that's to win. And to win the America's Cup, no other. And if you guys are here to go to a party, fine. Go to the party. But those of you all who want to sail with me on Saturday morning on the America's Cup, you will be here promptly at 6:30 in the morning tomorrow morning, not hung over, not overtired, et cetera. All ready for a good day.

I said, however, I've got to go to that party. And the reason I've got to go is because I made a deal with the America's Cup organizing committee that I would go. I would shake hands, stand in the receiving line for just only an hour. Arrive at 8:00, leave at 9:00, and then be back at bed by 10 o'clock.

But then I relented, felt that I was being a little hard on the crew. And I said, if you guys win the America's Cup, what I'll do is give you a party anywhere you want in the entire world.

Well, after the America's Cup was over, we were pouring champagne all over each other. The commodore of the Bay of Pigs Yacht Club came up to me and said, Bill, we've decided where we're going to have our party. And I said, what party?

He promptly reminded me. I dropped this huge magnum of champagne, thinking it was going to be in Tahiti, or Japan, or something. And he said, no, we're going to have it in Hawaii. I relieved a great heave of relief.

We chartered an L-1011, flew 350 people, all the crew members, the janitor, everybody-- their wives, girlfriends, and children-- to Hawaii for 3 days of the best time of our lives. That was another one of our philosophy, everybody was equally important on our team, from the janitor all the way up to the skipper.

The one last thing I'll tell you about on teamwork-- last story-- is that in the Defender Finals, we beat Dennis fairly well in the first race. We beat him again in the second. Then, in the third. Then, in the fourth. Then, Dennis came out and got his conditions. He won the next race. He came out again. We had some squabbling onboard. He won the next race.

Then, he came out again on the third day, we had a lot of squabbling. He won the third race. The score was then four to three. I went home that night very upset, thinking we were clowns. We were idiots.

Here, we had spent $68 million. Dennis had spent $12.

I should also tell you during the course of this America's Cup campaign, I got tremendous heat from the press, and from some of the crew members, and from all the professional sailors being so presumptuous that they thought that Bill Koch could sail on the boat having only eight years experience.

I developed three answers for that questions. And I'll tell you what they are. Two are facetious and one is very serious.

The first is I said, I'm good enough to be on the boat because I've won two world championships in the maxis against the very same players. Although, I'm not the best sailor in the world and never will be.

Secondly, I said if I'm putting up the bulk of the funds, I'll do what I damn well please. And thirdly, I said if I'm on board, I could see what's going on, called hands-on management. That reminds me of a little story I'd like to tell you about a Mexican bandit who came in to Texas, robbed a bank, then went back into Mexico.

They sent a Texas Ranger after him. He captured him not too far from his own town, handcuffed him to a tree, and then went into town to find someone who could speak Spanish because he couldn't. He found the local mayor, who was a very distinguished-looking man with gray hair. He could speak both languages. Impeccable reputation. Brought him out and said, would you translate for me? He said yes. What's the bandit's name? Jose. Would you ask Jose where he hit the money?

Jose isn't going to tell you where he hid the money. Then, the ranger pulls out a pistol, puts it to the bandit's head, in his ear and says, now ask Jose where he hid the money?

Jose whispers in a very meek voice, I hid the money in the town well. The mayor then looks up very seriously with a long face to the ranger and says, Jose says he's not afraid to die.

So being on the boat, I could figure out what was going on. And what was going on was that we weren't acting as a team. The helmsman, Buddy Melges, was acting as if-- acting as tactician, skipper, and helmsman all at one. And bow man and mast man as well. The navigator was yelling at everybody. One of the trimmers was pouting and yelling at everybody else. It was a chaotic mess.

So finally, I decided the next morning to have a come to Jesus session with the crew. If you all ever been from the Midwest where I'm from to a revival meeting, you'll know what I mean.

Well, anyway, I got the guys in and said, guys. Red Auerbach said to the Celtics once, all you players are good enough to score 35 points any game, any night of the week. Any time. However, if you do it, we're going to lose. Why? No one's blocking shots. No one's setting up plays, et cetera. So he said, Bill Russell, you're going to block shots and rebound. Cousy, you're going to set up plays. I'm revealing my age with these names of these players. And then he said, if we win, everybody will be a star. If we lose, then no one will be a star. The stars trickle down to everybody if you win. And I said, that's what we're going to do.

Buddy, you're going to drive the boat as fast as possible. By, you're going to tell us where we are on the course. David Dellenbaugh, you're going to be the tactician. No one could override you except for me, the skipper. And if you guys don't like it, fine. I'll find some other guys out there.

Well, we went out on the race course. The score was four to three. Very tough time. It was so tense that some of our guys, including Vince Morrison, our Director of Operations and Technology, who incidentally doesn't have a degree. And yet, he was able to manage all these high-tech people if you could imagine that-- a terrific guy. But anyway, he with another guy jumped into the San Diego waters as we were going off from the highest point they could find. But our crew was so tense and the after guard was so pouting that you could cut it with a knife. They were pouting worse than my 6-year-old son does when I tell him he can't stay up late.

Anyway, we got out on the race course. We promptly lost. The score was four to four. So then I decided that night that a come to Jesus session wouldn't work. Try another approach. So I invited them all over to my house, pulled off a bottle of Montrachet wine, cheap French wine at $60 a bottle that a good friend of mine had sent me, gave it to them all. We sat around looking at each other watching the beautiful sunset over Point Loma in San Diego.

By Balridge finally spoke up after we stared at each other for 10 minutes and said, we should all be friends after this is over. I said, yes, that would be nice. We stared at each other for another 10 minutes. Then finally, Buddy Melges spoke up.

I should tell you a little bit about Buddy if you don't know him. He's 61 years old. He was our oldest crew member. He has won an Olympic gold medal, a bronze medal in the Olympics, 40 world championships, and is probably considered one of the best sailors in the world. And he's a fine, wonderful human being. He said, Bill, I guess I misunderstood what you were saying. I thought you told me I couldn't talk on a sailboat. He said, I can't do anything. I can't sail without talking.

But what you were saying was that we all have to depend on one another and each one do our jobs. And therefore, let's get together, guys. Let's rely on one another and each one do his own job. Got up, gave each one of us a hug.

We went out the next day, blew Dennis away in three straight races. Then, blew the Italians away from four to one.

People ask me, is spending $68 million worth it on the America's Cup? I would say spending that kind of money on America's Cup is obscene, absurd, and wasteful. And had I known it, I wouldn't have done it.

People ask me, is it worthwhile? And I say, sure, it is because we won. But I could say what we did show. And that what I'm most proud of is that we showed that ordinary Americans taking a scientific approach with the right focus, the right sense of teamwork, can go out and accomplish anything.

You could go out, not only compete with the very best in the world, but you could also win. Francis, if I could show one more video-- do I have 3 minutes? Thank you.

Can you turn the sound up on this, please?

[VIDEO PLAYBACK]

[MUSIC PLAYING]

[APPLAUSE]

-[INAUDIBLE]?

-You should ask my son that question. Whether he'll let me do it or not.

-Will you let him do it, Wyatt?

-No.

[MUSIC PLAYING]

[END PLAYBACK]

[APPLAUSE]

KOCH: Thank you very much.

OGILVIE: Does anybody have any questions?

Our department's been involved in America's Cup, actually, for a long time. Not many people know that when Australia took the cup away from the United States, the captain of the Australian boat was a graduate of Course 13. But he didn't do it the way Bill Koch did.

I would like to ask the four speakers, please, to come up. And we have places at the table.

Do any of you up here on the platform have something you want to say? Sylvia Earle.

EARLE: I'd like to ask Bill Koch when he's going to start designing submersibles, please?

[APPLAUSE]

KOCH: We'll talk about that. Incidentally, we did our America's Cup program without any government money.

[APPLAUSE]

OGILVIE: The lady out there.

AUDIENCE: I want to know where the boat is now, and why you're not going to do it again? It was wonderful.

KOCH: Well, I really haven't decided not to do it again. Although, you heard what my son said.

My biggest cost was not the money, but was time away from him. The boats are right now in Nevada in a warehouse. They're there because the temperature-- or the humidity is very low there. And additionally, they could avoid the California tax man.

OGILVIE: Yes.

AUDIENCE: My question is about genetic engineering and the possibility of producing superior plankton, photosynthetic plankton that might soak up more of the CO_2 in the ocean. Would someone respond to that, please?

OGILVIE: I think the panel is discussing who that question is directed to.

SPINDEL: It sounds like a good idea.

OGILVIE: Sylvia.

EARLE: Nature does a very good job, if we sort of clear the deck and allow things to operate effectively. What our real problem is, I think is that we are interfering with some of the very efficient systems that have evolved over a long period of time that it's going to be difficult I think for us to improve on that. Other than to try to, essentially, stop the interference. And we're doing a considerable amount of that. And that's the part that I think worries many of us. And that is the changing chemistry of the sea with unknown consequences.

But it's a nice idea. Maybe it's got some possibilities. But I think nature's doing a good job if we can get out of the way a bit.

AUDIENCE: Yes. My question is, I don't understand how the carbon is contained within the oceans or released. Is it CO_2 dissolving into the water and being released? Or is it a chemical reaction? Or is it a biological action where the, say, corals are absorbing it?

WUNSCH: It's dissolved in the water. It's essentially carbonic acid. And it can be released back to the atmosphere, depending upon the partial pressure of atmosphere and ocean. But it's mainly dissolved in the water. There's an enormous amount of carbon also buried in the rocks on the seafloor. But that is not available, except on much longer time scales.

AUDIENCE: Is that temperature affected, does the water temperature accelerate or decelerate that action?

WUNSCH: Yes, it does. It is temperature-dependent.

OGILVIE: Please.

AUDIENCE: My question is for Albert. You call--

OGILVIE: Can you speak up, please?

AUDIENCE: I'd like to point out that the tunnel [INAUDIBLE] has been completed.

OGILVIE: We can't hear you.

AUDIENCE: Hello?

[INTERPOSING VOICES]

OGILVIE: Use this one.

AUDIENCE: If the engineering required to complete the tunnel between England and France is in effect. And we have this enormous garbage disposal problem in New York and other cities and radioactive waste. And the ocean is huge and 4 to 5 miles deep in some of the valleys. Why isn't it possible to construct a tunnel-like approach to garbage disposal units at the bottom of the ocean under 4 or 5 miles of water?

WUNSCH: You could. It's a question of the cost. Who would want to pay for that?

AUDIENCE: [INAUDIBLE] now.

WUNSCH: The cost of the Channel Tunnel is in the billions of dollars. That's one tunnel.

AUDIENCE: [INAUDIBLE].

OGILVIE: And its volume is not all that big, so it would not hold a lot of garbage.

KOCH: And in one of my other lives, I produce electricity using alternative energy. And one of the things, such as geothermal steam or wood chips. And we've looked at a lot of garbage plants.

The problem with the garbage collection in the United States is it's controlled by the mafia. And that's a very practical reason on why we do not build or there are not many garbage generation plants in the United States, whereas there's a lot in Europe.

EARLE: A good thing to do with it.

KOCH: It's an excellent thing to do.

[APPLAUSE]

OGILVIE: Next question.

AUDIENCE: Yeah, I'd like to ask the panelists, or especially Carl, how you feel about the sort of political discourse that has taken over on the global warming issue, is there seems to be in the media and environmental groups the sort of de facto recognition that this is happening without a good level of scientific discourse on the topic. I find your discussion very interesting, but how do you really feel about that? I mean, are people just being a little bit too paranoid here that man's about to go under, turn the plant upside down? Or is real science getting into this discussion, or is it all just political extremism?

WUNSCH: Well, it's a very complicated, as you must be aware. The point of view that I would take personally is the kind of record that I showed you, or tried to show you, suggests that we are going to have climate change. Whether there is a global warming induced by carbon dioxide or not.

And I think that one needs to displace the discussion a little bit from the narrow focus on, will there be global warming due to carbon dioxide? Whatever the answer to that is much of the human population in the natural environment is now vulnerable to climate change of any sort. And much of the discussion, I think, has been much too narrowly focused on, are we seeing global warming? Are we not seeing global warming? And ought to be directed more to the question of, what are we going to do to ameliorate or adapt to the inevitable environmental changes that are taking place? Some of which are man-induced, including I would say, far more important probably than global warming per se, is simply the increase in human population, which is here with us. Its effects are quite clear. And there can be very little argument about the environmental impact of that.

But the issue that change will take place, I think is a settled one. Change has always taken place. And it would be the most astonishing surprise of all scientific time to suddenly discover that despite the fact that the climate changed in the past, that is never going to change in the future. There's absolutely no evidence for that, whatever.

OGILVIE: Yes. Next question.

AUDIENCE: Referring to your carbon dioxide, methane, and temperature plots. First of all, I can see how you measured the carbon dioxide and methane. But how did you measure what the temperature was in the polar ice cap some number of years ago? And then, it seems strange that the temperature came up to approximately the current levels before civilization started. So all the past history we're looking at is, how can the climate change in order to give us an ice age? And none of it is how the climate change in the other direction. Because we're at the top end of the scale now before we got started.

WUNSCH: I'm not completely sure I completely heard the question. I think it was a question about, how do you determine the temperature? Is that right?

AUDIENCE: Yeah.

WUNSCH: It's done using the fact that there are two isotopes of oxygen, oxygen 18 and oxygen 16. And the partition of these two isotopes in the ocean and in the ice and in the atmosphere is a function of the global temperature. And so one measures the ratio in the trapped air and can convert it into an equivalent temperature.

There is some uncertainty, but it does seem, in general, quite a reliable method.

AUDIENCE: Just based on the different solubility due to the mass.

WUNSCH: Well, it's a fractionation effect having to do with the evaporation rate. And the amount taken up in ice as opposed to water. And the amount in atmospheric water vapor.

The second question, I think had to do with whether we are at the top. It's not clear that we're at a time when the most carbon dioxide has ever been in the atmosphere. There is a lot of carbon in the earth, in the rocks in particular, and in the deep ocean, which could become present in the atmosphere were it released.

And way back in geological time, in the early days of the Earth's history, there is some evidence that there was far more carbon in the atmosphere than anything we see today.

OGILVIE: I would like to suggest that no more people get in the lines. You're being very orderly, which I appreciate. You probably have changed since the days when you were students. But let's have the next question.

We have about 10 more minutes for questions.

AUDIENCE: Well, I'd like to celebrate the 100 years of ocean engineering. It was about one third of that time, 33 years ago, that I first came into Kresge and heard Doc Edgerton talk about his exploits here.

Now, I made it through in 5 years, where it took Bill 13. So MIT is about intelligence. And we might gather something about intelligence there. But the fact is he learned a lot more than I did while he was here. So there must be a balance of intelligence and overall learning.

My question is for Sylvia, really. We might be a little smarter than the sea creatures, the dolphins, and the whales. Although, when you look at the America's Cup celebration and the victory, and how we celebrated and how the dolphins celebrated, I really think they did it better than we did.

You've spent a lot of time swimming around the ocean as I have. And I wonder if I in addition to building the scientific instruments and getting the government grants and everything, if it makes sense to spend more time swimming around after the whales and the dolphins and some of the creatures that have been there a lot longer than we have? Even though they might not be quite as intelligent, can't we just ask them how the ocean is and how the currents are, and how the temperatures, and what's going to happen in the next 100 years? Shouldn't we spend more time talking with the intelligent creatures in the ocean?

EARLE: Well, we certainly have a great deal to learn from looking at what they do. And I think that's one of the great areas that is overlooked by so many who study the oceans. And that is just the nature of the impact of life on the sea itself. That too many, present company definitely excluded, look at the ocean as water, period. And not as water filled with life. And thus, very different than simply an indifferent medium.

We have an enormous amount to learn about the whole history of life by looking at creatures in the sea. But as engineers, a lot of people are kind of inspecting the fine tuning that has been developed over many millennia on the part of the likes of tuna and whales and dolphins. And even box fish, with their peculiar form of thruster power using their pectoral fins. And any fish that has solved a particular problem for a particular environment. Mammals, the ocean-going ones as well.

But clearly, more work needs to be done. Plenty of action out there for all who are so inspired.

AUDIENCE: Thank you.

OGILVIE: I'm sticking with the line over on my left because it's longer. Yes.

AUDIENCE: What do you see as the most important values and uses of the oceanographic data that you're developing?

OGILVIE: I'm not sure I understood that.

EARLE: The value of the knowledge that's being acquired?

AUDIENCE: Yes.

EARLE: I'll take one small crack, but I leave it open. I think the greatest problem that we face with respect to plotting our future has to do with the magnitude of our ignorance. That we need every scrap of information that we can muster about how Earth systems, dominated by the oceans of course, how they really function. And armed with greater knowledge than we currently have, we have a much better hope of getting it right.

I'm very worried that not enough people even care to ask the right questions. But beyond that, we are profoundly ignorant of much that governs every breath we take of every day that we live. And it's very difficult to be sensible about planning the future when we know so little.

So what are we going to do with the information, the data? Well, I hope we digest it, synthesize it, and act on it, and get more of it, because we certainly need it.

AUDIENCE: Thank you.

[APPLAUSE]

KOCH: I'd like to add a comment to that, if I could, Francis. I think the most economic thing that could come out of studying the oceans is the predicting of the weather. There's a lot of money invested on weather predictions. We invested a fortune on weather predictions. And airports in every place around the country are always constantly looking at the weather. And I think the more we understand about that, that's a direct economic value from that.

EARLE: It's fundamental.

KOCH: Yes.

OGILVIE: That was a statement, I take it. Not a question.

EARLE: That was Bill.

AUDIENCE: That was him, not me. I have a question about the current El Nino, which I understand is particularly long and drawn out, even though not the most intense in a while. Do you see anything unusual about this? Is this portentous? And do you have any 6 to 12-month forecasts on it?

WUNSCH: I don't make any forecast, except that things will be different next year.

[APPLAUSE]

No, I don't think that there's anything portentous about it. The interval of time over which people have been able to observe El Nino instrumentally-- that is, scientifically-- is really very short. And we really don't know very much about what is typical, what is atypical, what would represent a profound change in the ocean. There's no evidence that there's anything very different about what is going on now except that it is somewhat different from the most intensely-studied episodes over the last 12 or 15 years.

This is an example, you see, of part of the scientific problem. El Nino is a change in the whole ocean and atmosphere that takes place at somewhat random intervals from 5 to 12 years. And it takes a very long time to build up enough information and understanding that you can start to say we are seeing trends in the system. It really is changing from what it was 100 years ago, or even from what it was 25 or 30 years ago. So it's different, but not unusual, I would say.

KOCH: Excuse me, but we tried to predict the effects of El Nino on us in the America's Cup because there was an El Nino coming in. We hired the best experts we could find and we used three different supercomputer models to predict the effects of El Nino, and they were all wrong.

OGILVIE: Thank you. Yes, please.

AUDIENCE: Bill, you didn't mention the mistake that caused you to lose the mast on your boat. And it seems to me like it might have been a running back stay. And if so, wasn't that your job to trim when you turned the helm over to Buddy?

KOCH: No, that mast went down on Dennis Conner's boat, not on my boat.

AUDIENCE: Thank you, sir.

KOCH: We did lose a mast. And I've broken several. And I have one to remind me at my home on the Cape Cod that's standing there as my flagpole to remind me not to make that mistake again.

AUDIENCE: I have a question for Bill Koch. Given that you mentioned how relatively fragile your boats were, and that a wind over 20 knots you didn't care to sail in it. Do you see this class as being-- as a boat as being boat of the future in the cups? Or do you think you might call for something that could, say, take a wind of 30 or 35 knots, which certainly occurs fairly frequently in squalls?

KOCH: Well, I think the design of these boats are stupid. Not the design, I should say. The rule that governs them is stupid. I think the boats cost $5 million. They're fragile. They break. And they have no use and no afterlife.

And I've been advocating going to a smaller, less expensive boat. And I've created a lot of controversy in the America's Cup by doing that.

But I think by shrinking the boat from 75 feet to 55 feet, you would greatly reduce the cost. But unfortunately, you design the boats for the conditions that you have. And in San Diego, 80% of the time the wind is in that bracket. So if you design it to handle 35 knots, you'd be adding a lot of unnecessary weight and other stuff to it.

What they did in San Diego, if the wind got above 20 something, they canceled the race. Because they didn't want to have anybody killed out there, which is smart.

AUDIENCE: Thank you.

OGILVIE: Last question. Yes.

AUDIENCE: Thank you. Captain Bill, my name's Howard Fawcett, Course 13, '52. Sometimes amateur sailor. I followed your program with rapt attention. I was tremendously impressed. And I must admit some pride as a fellow alumnus undertook this job. I got to ask you one question. It seems to me that everybody made great to-do about the fact that you hadn't been sailing very long.

In my mind, you undertook something along the line that was even more difficult than mastering sailing. You took on the media.

KOCH: I took on who?

OGILVIE: The media.

KOCH: The media, yeah.

AUDIENCE: The media. It seems to me you succeeded. Can you tell us how you did that?

KOCH: Very poorly. I found that dealing with the media was a very difficult thing. And if you got a good press article, you tend to believe it. But if you got a bad press article, it made you mad. And that would upset your performance. So during the America's Cup and before it, I would ignore the media. I would not read any newspapers or watch any television. I really didn't care what the media said about us. All I care about was how we performed. That's how we dealt with the pressure internally.

Externally, what I finally ended up doing, rather than trying to be the media spokesman myself, was to hire someone who was a real professional in that, who grew up in that, and who convinced me not to be so blunt and to try to smile at them and answer their hostile questions in a very pleasant, friendly way.

AUDIENCE: Your son?

KOCH: What?

AUDIENCE: Was that your son?

KOCH: That should be him, yes.

OGILVIE: Well, with that, I would like to thank all of our panelists once more. But don't go away. I think this is the end of the question period, question and answer period. So thank you all very much.

[APPLAUSE]

Can you get Paul Gray up here? We have one more event. And I would like to ask Paul Gray, please, to come up to the platform. I could give you this one.

KOCH: Paul, I'd like to make two presentations to MIT. One in recognition of the technology that you all taught us and helped us in the America's Cubed. And that's a full-scale model-- not a full scale, but a scaled down, fully rigged model of the America Cubed, the winning boat that MIT designed for us.

[APPLAUSE]

There's one another presentation I'd like to make to MIT. And particularly to the athletic department where I learned the essence of teamwork. And that is a half-scale model made by the same jewelers who made the original America's Cup. It's made out of silver. I won't tell you how much it cost, but a bunch. And this is going to be-- we're giving it to MIT to give to that student who best represents attitude and teamwork.

[APPLAUSE]

PRESENTER: Sure. Delighted.

PAUL GRAY: Bill, I perceive that I am here as a representative of the MIT bureaucracy. And I'm pleased to be here in that capacity on this occasion. And to receive on behalf of the Institute, all of my colleagues in the Institution, this model which will take its place in Hart Nautical Museum, the museum of Course 13. And this trophy as well, which will be put to use at MIT as a perpetual trophy to honor some of those qualities that you spoke of so movingly here this morning.

We all heard you speak about the importance in this effort of management, of technology, of teamwork. And you spoke at one point-- said that this effort illustrated that ordinary Americans who had commitment and focus and teamwork could do a great thing. And that certainly was evident from what you've shown us. But I would suggest as well that what you demonstrated this morning is that one extraordinary American who brought to this task enormous leadership, leadership not constrained by eight years of experience in sailing, made all the difference. Thanks very much.

[APPLAUSE]

PRESENTER: I would like to suggest a standing ovation for Bill Koch. He's a wonderful alumnus.

[APPLAUSE]