DR. CICERONE: THANK YOU, DR. SPINRAD AND TO THE ORGANIZERS OF THIS CONFERENCE FOR THE IDEA OF PUTTING IT TOGETHER, IN THE FIRST PLACE, AND FOR INVITING ALL OF US TO PARTICIPATE. IT'S A REAL TREAT TO BE HERE TO SEE SO MANY PEOPLE WHOSE WORK I RESPECT SO MUCH, TO RENEW SOME OLD ACQUAINTANCES, AND TO MAKE SOME NEW ONES; AND IT'S A REAL TREAT ALSO TO HAVE LOUISE KEELING HERE AND TWO OF HER SONS COMMEMORATING THE 50TH ANNIVERSARY OF THE CO2 RECORD. SEEING THE SLIDES THAT WERE JUST SHOWN BROUGHT BACK A FLOOD OF MEMORIES, NOT THE LEAST OF WHICH IS THAT WHEN MY WIFE HAD AN OFFER TO JOIN THE FACULTY AT UC, SAN DIEGO, IN THE '70S AND WE MOVED THERE, I RECEIVED A GREAT DEAL OF HELP FROM DAVE KEELING AND RAY WEISS AND ED GOLDBERG AND MIKE MULLEN AND OTHERS IN TRYING TO SET UP, BUT THERE WASN'T ENOUGH ROOM FOR AN OFFICE FOR ME. SO I WAS ABLE TO SHARE AN OFFICE THAT NORRIS RAKESTRAW HAD, WHO WAS HELPING DAVE KEELING. I THINK WITHOUT DAVE'S HELP, I WOULDN'T HAVE HAD THAT OFFICE. SO THAT WAS NICE TO SEE.

KEN, THANK YOU FOR REMINDING ME OF RAKESTRAW.

LET ME GO TO THE SLIDE. THIS IS AN OUTLINE OF WHAT I'M GOING TO TRY TO COVER. YOU CAN SEE THAT THIS IS A LIST OF TOPICS MOSTLY BY NOUNS. THERE'S ANOTHER WAY I COULD DESCRIBE THE MESSAGE THAT I WANT TO BRING ABOUT TODAY, IT'S KIND OF WHAT SCIENTISTS HAVE BEEN DOING, AND THEN HOW WE MOVE INTO THE FUTURE WHERE SCIENTISTS ARE GOING TO BE AS NECESSARY AS ALWAYS BUT NOT SUFFICIENT. SO, IN A WAY, WE LOOK AT THESE TOPICS AND WE SEE THAT ESPECIALLY IN THE LAST 50 YEARS SCIENTISTS HAVE BEEN DETECTING CHANGES AND MEASURING AND QUANTIFYING THEM. THEY'VE BEEN REVIEWING AND ASSESSING THE QUALITY OF THE WORK AND THE MEANING. THEY'VE BEEN ATTRIBUTING THE CHANGES TO NATURAL AND HUMAN-CAUSED EVENTS. THEY'VE BEEN PREDICTING. THEY'VE BEEN COMMUNICATING.

THE FINAL TWO ALTERNATIVE DESCRIPTIONS HERE WOULD BE THAT: WHAT DO WE DO TO DEAL WITH WHAT'S HAPPENING? HOW DO WE LIMIT CLIMATE CHANGE AND ITS IMPACT?

SO AS I GO THROUGH, YOU CAN KEEP THOSE OTHER VERBS IN MIND.

IT'S, I THINK, A LOT OF FUN TO START WITH ONE OF THE EARLIEST PAPERS OF DAVE KEELING FROM 1960. THIS IS AVAILABLE THROUGH SCRIPPS' WEBSITE. THE GRAPH SHOWS SOME OF THE VERY EARLIEST CARBON DIOXIDE-IN-AIR MEASUREMENTS EXPRESSED IN THE WAY DAVE ALWAYS DID, AS A DRY AIR MOLE FRACTION, PARTS PER MILLION CARBON DIOXIDE, SHOWING THE EARLIEST MEASUREMENTS HAPPENED TO BE A VERY LOW, PROBABLY A SPRING/SUMMER MEASUREMENT, WELL BELOW 310 PARTS PER MILLION, AND THEN THE ESTABLISHED SEASONAL CYCLES WHICH HE FOUND WHICH HE DETECTED TO SOMEWHAT
EVERYONE'S SURPRISE, AND YOU WILL SEE THAT THE FIRST MAUNA LOA MEASUREMENTS ARE FROM EARLY 1958.

WELL, AS I RECALL, THERE WAS ABOUT ONE MORE YEAR OF DATA ADDED TO THIS GRAPH WHEN ROGER REVELLE SHOWED IT TO THEN UNDERGRADUATE AL GORE AT HARVARD; AND THAT WHEN AL GORE WAS ELECTED TO THE U.S. HOUSE IN THE 1970S, HE HAD A HEARING, AND I WAS PRIVILEGED TO BE ONE OF THE WITNESSES, AND ONE OF HIS FIRST QUESTIONS WAS: WHAT HAS HAPPENED TO THOSE EARLY MEASUREMENTS THAT ROGER REVELLE SHOWED ME FROM DR. KEELING THAT WENT THROUGH ABOUT 1962?

NOW, AL GORE KNEW THE ANSWER, BUT HE WANTED THAT RECORD TO BE UPDATED AS PART OF THOSE HOUSE HEARINGS, AND HE DID THE SAME THING THROUGHOUT THE '80S IN THE SENATE AND SO FORTH.

SO THIS GRAPH, EVEN BEFORE THE FAMOUS KEELING CURVE, THIS EARLY KEELING CURVE BECAME IMPORTANT IN ABOUT 1962 OR '63, WHEN ROGER REVELLE SHOWED IT TO THE STUDENT AL GORE.

WELL, THIS IS, OF COURSE, THE IMPORTANT GRAPH THAT MANY OF US USE SO OFTEN. THERE WAS THE STORY IN THE EARLY '90S THAT IT WAS THE ONLY SCIENTIFIC GRAPH THAT HAD EVER SEEN THE LIGHT OF DAY IN THE WHITE HOUSE.

(LAUGHTER).

IT MIGHT HAVE BEEN TRUE, I DON'T KNOW. BUT THERE ARE MANY WAYS TO LOOK AT THIS GRAPH, WHICH IS OBVIOUSLY A MORE OR LESS CONTINUOUS RECORD OF CARBON DIOXIDE AT MAUNA LOA; AND ALSO IN RED FOR THE LOWER PART OF THE CURVE, THE SOUTH POLE, ANTARCTICA, THE EARLY PART OF THE CURVE, IN FACT, THIS ENTIRE CURVE IS FROM SCRIPPS' WORK, ALTHOUGH, AS YOU KNOW, THE NOAA INDEPENDENT EFFORTS HAVE BEEN EXTREMELY VALUABLE OVER THE LAST 30 YEARS OR SO.

THERE ARE MANY WAYS TO LOOK AT THIS GRAPH. FIRST OF ALL, THERE IS THE UNDERLYING POSITIVE TRENDS.

THIS IS SUCH AN ENORMOUS INCREASE IN A GAS WHICH ISN'T ALL THAT TRACE IN THE ATMOSPHERE. THAT IS A LOT OF TONNAGE OF GAS. YOU CAN SEE THE NUMBERS AND YOU HAVE HEARD THE NUMBERS VERY OFTEN. THE ROUGH BULK OF THAT CARBON DIOXIDE INCREASE IS VERY ROUGHLY EQUAL TO THE CARBON DIOXIDE EMITTED BY BURNING OF FOSSIL FUELS OVER THE SAME TIME. AS YOU KNOW, THERE'S ABOUT A FACTOR OF TWO DIFFERENCE, AND WE WILL HEAR A LOT MORE ABOUT THAT AIRBORNE FRACTION AS THIS MEETING GOES ALONG.

THERE IS EVIDENCE OF HUMAN ACTIVITY; PARTLY BY THE MAGNITUDE, PARTLY BY THE TIMING, CERTAINLY THE GEOGRAPHICAL PATTERNS OF THE CARBON DIOXIDE INCREASE WHICH HAVE BEEN MEASURED IN SO MANY OTHER PLACES, AND THEN IN ISOTOPIC DATA, AND IN THE AMOUNTS IN THE OCEAN AND SO FORTH. SO THERE IS DEFINITELY EVIDENCE OF HUMAN IMPACT.

THERE IS ALSO THE KIND OF STORY THAT SOME OF YOU ARE JUST BEGINNING TO SPEAK ABOUT ON THE
Panel, and that is the human story of the difficulty that was involved in achieving this kind of a record, the meticulous commitment to perfection, the mercury manometer on the wall that could only be viewed with a spyglass, the very careful taping of the glass flasks with adhesive tape in Dave's group. Everyone was sitting around on the floor putting the adhesive tape around the glass flasks, just like they were professional athletes' ankles. It was really fun to watch. Then, of course, NOAA's involvements. There are so many stories involved in this graph. And then, of course, science that comes out about the Earth's carbon cycle, some of which will be discussed here later in the meeting, also.

However, some of the new things that happened that probably no one expected are exemplified in this graph, which is the trace now of carbon dioxide amounts measured, but with dates on them as early as, in this case, 450,000 years ago, showing a wiggling trace of carbon dioxide being -- there's a little pointer here -- being low, low, low, and low. At four times in history, you can see the lows. Those are, roughly speaking, the ice ages at 20,000 years ago -- I can't read the numbers, but you can see them -- when the previous ice ages occurred. There is a very strong correlation between large ice ages and low amounts of carbon dioxide going back through the last four ice ages, and high amounts of carbon dioxide in the interglacial warm periods in between the ice ages. But the range of carbon dioxide over these huge swings in geologic history, that is, when the Earth's conditions changed so much, that swings are between about 180 parts per million and 280 parts per million, never as high as has been observed in the Keeling and NOAA record.

Now, some of you who saw Al Gore's movie saw this kind of a graph where the right-hand side, this red branch, puts on the geological record -- and by the way, these measurements are of carbon dioxide extracted from dated ice cores, ice cores which were drilled and obtained by Danish, French, Swiss, and Russian scientists, and towards the end of the record, some American scientists in particular places that were very controlled and uniform, in Greenland and in Antarctica. And the dated ice cores could then be either crushed or melted, in some cases, to extract the carbon dioxide in the dated ice, and that's how the historical record was created through direct measurements. But if you then superimpose on this 450,000-year record the modern record of carbon dioxide, which you just saw in the previous graph, it looks like this. And those of you who saw Al Gore's movie, that was one of the most entertaining parts of the movie, that to try to reach to the top of the graph, they had to bring out a stage jack and have
THE CEILING TO TOUCH IT, JUST TO EMPHASIZE DRAMATICALLY HOW RAPID AND HOW LARGE THE CO2 INCREASE HAS BEEN OUT OF THE RANGE OF THE FOUR PREVIOUS INTERGLACIAL WARM TIMES OF 280 PARTS PER MILLION UP TO ABOUT 380 NOW.

WELL, WHERE IS IT ALL COMING FROM? THIS IS ONE RENDITION OF A TIME HISTORY OF GLOBAL CARBON DIOXIDE EMISSIONS FROM FOSSIL FUEL BURNING, WITH A SMALL AMOUNT FROM CEMENT PRODUCTION AND, OF COURSE, JUST DIRECT GAS FLARING, NATIONAL GAS BURNING AT WELLS, SHOWING A GROWTH, A VERY, VERY, VERY RAPID GROWTH IN THE PAST 100 YEARS OF GLOBAL CARBON DIOXIDE EMISSIONS UP TO A FIGURE IN THESE UNITS OF ABOUT 7 BILLION TONS OF CARBON IN THE FORM OF CARBON DIOXIDE.

NOW, AS YOU NOTICE, AS WE GO ALONG, SOMETIMES THESE TONNAGES ARE EXPRESSED AS CARBON DIOXIDE TOGETHER AND SOMETIMES AS CARBON. BUT THE CURRENT FIGURE IS ABOUT 7 BILLION TONS OF CARBON IN THE FORM OF CARBON DIOXIDE EMITTED ANNUALLY BY THE WORLD'S FOSSIL FUEL BURNING, A NUMBER THAT'S GROWING. AND WITH THAT KIND OF A GROWTH CURVE, ONE CAN REALIZE THAT THE FUTURE IS GOING TO BE DIFFICULT TO COPE WITH IN TERMS OF LIMITING THESE EMISSIONS.

YOU CAN ALSO GLEAN FROM THIS KIND OF A GRAPH AN ESTIMATE OF THE TONNAGE INVOLVED, THE MASS, THE WEIGHT, THE BULK OF THE AMOUNT OF CARBON BEING RELEASED INTO THE AIR EACH YEAR, AND OF COURSE, SOME OF IT GOES INTO THE OCEAN, SO THAT PEOPLE WHO WANT TO TALK ABOUT CARBON CAPTURE AND SEQUESTRATION HAVE TO BE PREPARED FOR EXTREMELY LARGE BULK AMOUNTS.

WELL, ANOTHER WAY TO GET A FEELING FOR WHERE IT IS ALL COMING FROM IS TO LOOK AT SOME UNITED STATES DATA. THESE ARE UNITED STATES CARBON DIOXIDE EMISSIONS FROM ENERGY CONSUMPTION BY SOURCE; NAMELY, BURNING OF PETROLEUM, BURNING OF NATURAL GAS, BURNING OF COAL. SO YOU SEE IT IS ALMOST ALL FROM FOSSIL FUELS, WHERE NOW THE UNITS ARE BILLIONS OF TONS OF CARBON DIOXIDE TOTAL WEIGHT. SO THE U.S. MASS IS 7 BILLION TONS, BUT IT IS NOW CARBON DIOXIDE, NOT JUST CARBON IN THIS GRAPH. AND YOU CAN SEE THAT HYDROELECTRICITY, FOR EXAMPLE, THE BURNING OF ANNUAL BIOMASS AT LEAST, GIVES YOU NO NET CARBON EXCHANGE AND SO FORTH. SO THAT'S BY SOURCE.

BY USAGE -- AND THERE ARE VERY MANY WAYS TO LOOK AT THESE DATA -- THE SAME FIGURE ADDS UP TO THE SAME AMOUNT, BUT IT IS NOW U.S. CARBON DIOXIDE EMISSIONS FROM ENERGY CONSUMPTION BY USAGE, SO LIGHT-DUTY VEHICLES -- THAT'S CARS AND TRUCKS -- BURNING PETROLEUM PRODUCTS, GASOLINE, FREIGHT AND SHIPMENT, AIRCRAFT, ELECTRICITY GENERATION, INDUSTRIAL USAGE OF ALL KINDS, AND SO FORTH. SO IT JUST GIVES YOU A FEELING OF WHERE THE DEMAND IS.
LET ME NOW SWITCH TO CLIMATE, AND THERE ISN'T ENOUGH TIME TODAY TO GO INTO THE THEORY OF THE GREENHOUSE EFFECT, BUT WE HAVE A SITUATION WHERE THE DATA PRETTY WELL MATCH THE THEORY AS WELL AS WE CAN DO THE CALCULATIONS. LOOKED AT FROM A DISTANCE, OUR PLANET LOOKS KIND OF LIKE THIS CARTOON, ITS ENERGY BUDGET TO A VERY, VERY GOOD APPROXIMATION AS GIVEN BY THESE FEW NUMBERS: 342 WATTS PER SQUARE METER OF SUNLIGHT FALLING ON THE EARTH'S ATMOSPHERIC SYSTEM AVERAGED OVER DAY AND NIGHT, THE WHOLE PLANET, 342 WATTS PER SQUARE METER. ABOUT 105 WATTS PER SQUARE METER IS DIRECTLY REFLECTED RIGHT BACK TO SPACE IN THE FORM OF VISIBLE LIGHT, THE WAY IT CAME IN, FROM THE TOPS OF WHITE- AND LIGHT-COLORED SURFACES, LIKE THE SHINY PARTS OF THE OCEAN AT CERTAIN ANGLES, CERTAINLY SNOW AND ICE, LIGHT-COLORED LAND. THE NET DIFFERENCE, THOUGH, 342 MINUS 105, IS 237 WATTS PER SQUARE METER; AND THAT AMOUNT IS RADIATED BACK TO SPACE IN THE FORM OF PLANETARY INFRARED RADIATION. IN FACT, IF IT WEREN'T ROUGHLY BALANCED, THE PLANET WOULD EITHER BE HEATING UP OR COOLING DOWN VERY, VERY FAST; AND WE KNOW THAT IT IS NOT. THESE MEASUREMENTS HAVE NOW BEEN MADE WITH SOME PRECISION. AND AS CLIMATE CHANGES, THESE NUMBERS WILL STAY ABOUT THE SAME.

WHAT WILL NOT STAY THE SAME, THOUGH, IS THE ENERGY BALANCE IN THE LOWER LAYERS OF THE ATMOSPHERE, AND WE KNOW THAT THESE NUMBERS CAN BE CALCULATED RATHER ACCURATELY FROM LABORATORY SPECTROSCOPY DATA AND ALSO BY DOING A CALCULATION FOR WHAT SHOULD BE THE PLANET'S TEMPERATURE FOR DIFFERENT CLIMATES. I DON'T HAVE TIME TODAY, BUT IN THE ABSENCE OF A SIGNIFICANT ATMOSPHERE WITH GREENHOUSE GASSES SUCH AS CARBON DIOXIDE, OZONE, AND WATER VAPOR, FOR EXAMPLE, IN NATURE -- IN THE ABSENCE OF THOSE GASSES AND IN THE ABSENCE OF A THICK ATMOSPHERE, ONE CAN CALCULATE THE TEMPERATURE OF THE PLANET'S SURFACE VERY ACCURATELY; BUT IN THE PRESENCE OF THOSE GASSES, WE CANNOT. WE UNDERESTIMATE THE TEMPERATURE FOR EARTH AND VENUS. THAT IS ONE KIND OF EVIDENCE OF THE GREENHOUSE EFFECT, THE REALITY IN NATURE.

NOW, THE PROBLEM WE HAVE, OF COURSE, IS THAT BECAUSE OF THE CARBON DIOXIDE INCREASE AND ITS PROPERTIES IN THE INFRARED, AS WELL AS OTHER GREENHOUSE GASSES SUCH AS NITROUS OXIDE BUILDING UP -- AND THIS SET OF DATA IS FROM THE AGAGE NETWORK, FROM THEIR WEBSITE, WHERE RAY WEISS IS THE PERSON WHO HAS DONE THE MEASUREMENTS; ALSO FROM SCRIPPS. THERE ARE OTHER SETS OF DATA, INCLUDING NOAA DATA, OF COURSE, SHOWING INCREASES IN OTHER GREENHOUSE GASSES LIKE NITROUS OXIDE, WHERE THE SOURCES OF THIS EMISSION ARE PROBABLY MORE COMPLICATED THAN CARBON DIOXIDE. IN THE CASE OF CARBON DIOXIDE, NEARLY ALL OF THE EMISSIONS FROM HUMAN ACTIVITIES IS DUE TO
EITHER FOSSIL FUEL BURNING OR AGRICULTURAL PURPOSES
SUCH AS THE CLEARING OF FOREST LANDS FOR AGRICULTURE.
IN THE CASE OF NITROUS OXIDE, IT'S CLEAR THAT THERE
ARE HUMAN ACTIVITIES THAT ARE CAUSING THIS BUILD-UP,
BUT IT IS NOT QUITE AS QUANTITATIVE WHICH ONE IS
WHICH, IN MY OPINION.

WELL, ANOTHER ACHIEVEMENT OF SCIENTISTS IN
QUANTIFYING AND CALCULATING AND MAKING SENSE OUT OF
ALL THIS WAS THE SET OF CALCULATIONS THAT'S BEEN
GOING ON NOW FOR OVER 20 YEARS TO TRY TO QUANTIFY THE
STRENGTH OF THE IMPACT OF EACH OF THESE GREENHOUSE
GASSES AND THE WAY THEY'RE INCREASING. SO THE HEIGHT
OF THESE BAR GRAPHS REPRESENTS THE PERTURBATION TO
THE ENERGY BALANCE IN THE LOWER PART OF THE
ATMOSPHERE DUE TO THE INCREASE IN CO2 OVER THE LAST
HUNDRED YEARS, AND THAT'S AN IMPACT OF ABOUT
1.6 WATTS PER SQUARE METER. REMEMBER THAT THE ENTIRE

IMPACT OF SUNLIGHT IS 237 WATTS PER SQUARE METER. SO
ADDING UP THESE GREENHOUSE GAS IMPACTS -- AND THESE
CALCULATIONS WERE FROM NOAA -- IS OVER 1 PERCENT. SO
IT'S EQUIVALENT TO HAVING THE SUN BECOMING MORE THAN
1 PERCENT BRIGHTER IN THE COURSE OF ABOUT
1 AND A HALF HUMAN LIFETIMES, WHICH NO ONE HAS EVER
SAID THAT THAT WAS PLAUSIBLE; THAT IS, THE SUN IS NOT
GETTING THAT MUCH HOTTER. NO ONE HAS ANY PLAUSIBLE
SUGGESTION THAT IT COULD.

I LOOKED BACK AT OUR FIRST CALCULATIONS ON
RADIATIVE FORCING THAT BOB DICKINSON AND I DID IN
1986; AND WHEN WE PROJECTED INTO THE FUTURE, WE HAD
BIGGER NUMBERS FOR METHANE, AND WE HAD MUCH LARGER
NUMBERS FOR CHLOROFLUOROCARBON. LATER IN THE MEETING
SUSAN SOLOMON, I THINK, WILL SPEAK ON HOW THIS
CHLOROFLUOROCARBON BAR WAS LIMITED THAT LEN BARRIE
JUST REFERRED TO, ALSO.

IN THE CASE OF METHANE, WE SAW A GRAPH FROM
LEN BARRIE JUST A MINUTE AGO SHOWING THAT AFTER A
VERY, VERY RAPID RISE IN WORLDWIDE CONCENTRATIONS,
METHANE AMOUNTS HAVE LEVELLED OFF IN THE LAST 7 TO
10 YEARS. WE'RE NOT SURE WHY. BUT WHEN BOB AND I
DID THESE PROJECTIONS, WE THOUGHT METHANE WOULD
CONTINUE TO RISE. CFC'S HAVEN'T Risen AS MUCH. IN
FACT, THERE WAS A LITTLE NOTICED PAPER PUBLISHED IN
1990 OR '91 BY ANDY LACIS AND MICHAEL PLAGOR AND JIM
HANSEN WHICH SHOWED SOMETHING EXTREMELY STUNNING: IF
THE GROWTH IN THE WORLDWIDE CHLOROFLUOROCARBON
INDUSTRY HAD CONTINUED AT THE RATE THAT IT HAD
ACTUALLY ACHIEVED IN THE 1960S AND '70S, BY THE YEAR
1990, THE RADIATIVE FORCING DUE TO THE CFC'S WOULD
HAVE EXCEEDED CARBON DIOXIDE. AND THE FACT THAT THE
CFC GROWTH DID NOT CONTINUE AT THAT RATE IS SOMETHING
THAT WE CAN BE HAPPY ABOUT. THE MONTREAL PROTOCOL
DID NOT DIRECTLY RECOGNIZE THE GREENHOUSE EFFECT OF
THE CFC'S IN ITS PROVISIONS, BUT IT DID IN ITS
PREAMBLE.

OKAY, WHAT'S BEEN HAPPENING WITH ALL OF
Scientists have also been measuring things, and this particular graph shows temperatures recorded over land and oceans over the period of the instrumental record back to about 1880. This particular graph, although the credit isn't given very clearly, is from the NASA GISS Group, where the black dots represent annual averages, the red line connects them with 5-year running mean, and you see -- well, zero on this graph does not mean zero degrees on any scale; it's a reference temperature in this case by the average of the observations between 1951 and 1980, so zero means the average of 1951 to '80. Prior to that there was a significant run-up in temperature from about 1900 to about 1940, and then a decrease from about 1940 to 1975, and then a sharp monotonic increase since the late '70s to current. So that this last 30-year period is special in several respects: it's the fastest, most continuous increase in temperature. This is now a global average with urban heat island effects removed. So it's an unperturbed global average. The rate of the increase and the size of the increase is unprecedented, and it also exceeds the variability that anyone has been able to reproduce in a first principle's model of temperature.

The temperature increase is not uniform. Many of you know these data; that on a two-dimensional plot, you can see areas of false color imaging showing very high warmings observed over this 50-year period, 1955 to 2005, in the high latitude regions of the Arctic and Subarctic regions and down near the Antarctic Peninsula; areas over ocean, relatively small warming; the continents, intermediate in the temperate zone. There is now no place where temperatures are being measured of any geographical size to speak of where the temperatures are not increasing. This is another kind of evidence that the temperature anomaly of the last 30 to 40 years is not natural; that it is being caused by human influence in this case.

Another kind of data that, of course, is exceedingly important are sea level rise. This is a record of about 120 years data, 110 years data from traditional tide gauges and records from all over the world. Some of you know that the sea level rise has not been uniform in the different ocean basins; but when you do a global average, the rise is about 15 centimeters per century, which is 1 and a half millimeters per year.

You notice that there is a red part of this graph, the last dozen or 15 years, this is now that record shown from about 1992 through 2005 or so, of various physical oceanography-type remote sensing, TOPEX and Jason experiments, showing sea level rise...
MEASURED MUCH MORE GLOBALLY, WITH VERY, VERY PRECISE INSTRUMENTS, SHOWING A RATE OF SEA LEVEL RISE OF ABOUT DOUBLE OF WHICH HAD BEEN INFERRED FROM THE TIDE GAUGE, SO THAT THIS RATE OF SEA LEVEL RISE, WHILE IT CONNECTS WITH THE PREVIOUS RECORD AS WELL AS YOU CAN EYEBALL IT, THIS RECORD IS MORE PRECISE, IT IS MORE GEOGRAPHICALLY REPRESENTATIVE, AND IT'S TWICE AS FAST. NOW, AT THIS POINT NO ONE THAT I KNOW OF IS SPEAKING WITH ANY AUTHORITY THAT THIS IS ACTUALLY AN INCREASE IN THE RATE OF SEA LEVEL RISE OR WHETHER IT'S JUST A MORE PRECISE MEASUREMENT OVER A SHORTER PERIOD OF TIME, BUT IT DOES CAUSE SOME WORRY THAT THE INFERRED RATE OF SEA LEVEL RISE IS NOW DOUBLE WHAT IT WAS 15 YEARS AGO.

NOW, MANY OF YOU HAVE SEEN GRAPHS OR IMAGES LIKE THIS, LOOKING DOWN ON GREENLAND, AND SAY, WELL, IT SURE LOOKS LIKE THE EXTENT OF SNOW AND ICE OVER GREENLAND HAS DECREASED; AND YES, IT DOES. WHAT I WANT TO DO NOW IS TO SHOW JUST, AS AN EXAMPLE, THOUGH, OF HOW BEAUTIFULLY THIS KIND OF SCIENCE IS BEING DONE NOW WITH REALLY HIGH-TECH INSTRUMENTS.

ICE MASS LOSS AND THEN FURTHER COMPARE THAT WITH WHAT'S BEING DEDUCED FROM THE GRAVITATIONAL MEASUREMENT, AND YOU GET ABOUT THE SAME ANSWER TO WITHIN EXPERIMENTAL ERROR AT THIS POINT. SO, AS I SAY, THIS SCIENCE IS NOT BEING DONE IN A WAY THAT OUR GRANDFATHERS WOULD HAVE DONE IT, AND GRANDMOTHERS; IT IS BEING DONE MUCH, MUCH MORE PRECISELY WITH HIGH-TECH EXPERIMENTS.

AS I SAID EARLIER, THIS TEMPERATURE RECORD FROM GISS IN THIS CASE SHOWS SOMETHING SPECIAL WITHIN THE LAST 30 YEARS, WHICH WE HAVE NOW ATTRIBUTED, AND AS THE QUOTES FROM THE IPCC SEA REPORT SAY, MOSTLY IT'S VERY LIKELY DUE TO HUMAN ACTIVITIES.

THERE IS SOMETHING ELSE SPECIAL ABOUT THIS PAST 30-YEAR PERIOD; NAMELY, IT'S THE FIRST TIME IN HUMAN HISTORY THAT WE HAVE MEASURED THE OUTPUT OF THE SUN WITH ENOUGH PRECISION AND CONTINUITY TO BE ABLE TO SAY WHETHER THE SUN ITSELF CAUSED THIS WARMING. NOW, UP UNTIL JUST ABOUT A FEW YEARS AGO, MAYBE SIX OR EIGHT YEARS AGO, IT WAS TENABLE TO SAY THAT WE THINK THE SUN MAY HAVE CAUSED SOME OF THIS OR ALL OR MOST OF THE WARMING, AT LEAST SOME OF IT. IT ISN'T ANYMORE. THIS GRAPH IS FROM JUDITH LEAN AND CLAUS FROHLICH, WHERE THEY HAVE STRUNG TOGETHER SOME TOTAL SOLAR IRRADIANCE DATA, THAT IS THE SUNLIGHT REACHING THE EARTH AS THE SATELLITE ORBITS, AND THEY HAVE RECORDED ITS VARIATIONS. THEY HAVE CORRECTED THE DATA FOR WHAT IS CLEARLY DISCONTINUITY IN ONE INSTRUMENT, AND THIS IS THE RECORD THAT THEY GET. THE SUNLIGHT, FOR THOSE OF YOU ARE GOOD AT ARITHMETIC WILL KNOW THAT 342 MULTIPLIED BY THE GEOMETRICAL FACTOR OF 4 IS EXACTLY 1368. IT IS OFF BY ABOUT 1 WATT PER SQUARE METER. BUT THE POINT IS THE VARIATION IS ROUGHLY THAT OF A 11-YEAR SUN-SPOT CYCLE. THE PEAK-TO-PEAK AMPLITUDE IS 0.1 PERCENT.

NOW, I'VE ALREADY TOLD YOU THAT THE GREENHOUSE EFFECT DUE TO THE HUMAN-CAUSED GREENHOUSE GAS CONCENTRATION IS MORE THAN 1 PERCENT. SO THE HUMAN-CAUSED GREENHOUSE EFFECT IS AT LEAST 10 TIMES LARGER, IT'S SUSTAINED, AND IT'S GROWING COMPARED TO THIS VERY, VERY SMALL SOLAR OSCILLATION, WHICH HAS NOW BEEN MEASURED. SO IT IS UNTENABLE NOW TO SAY THAT SUN VARIATIONS ARE CAUSING THIS MOST RECENT WARMING.

WELL, WHERE DO WE GO FROM HERE?

DOUBLING IN 35 YEARS, THAT IS A 2-PERCENT-PER-YEAR GROWTH RATE. THAT SHOULDN'T CONFUSE ANYBODY. THAT'S EXACTLY WHAT HAS HAPPENED.

PROJECTING AHEAD TO THE FUTURE, WE SEE ANOTHER 50-PERCENT INCREASE IN ENERGY CONSUMPTION IN THE NEXT 20 YEARS OR SO, PERHAPS 25, BUT YOU WILL SEE A DIFFERENCE; THAT THE ENERGY CONSUMPTION IN THE LATTER PART OF THE 20TH CENTURY WAS DOMINATED BY MATURE MARKETS: THE UNITED STATES, CANADA, JAPAN, WESTERN EUROPE. IN THE FUTURE, MOST OF THIS GROWTH IS DUE TO DEVELOPING AND EMERGING ECONOMIES, AND YOU KNOW WHERE THEY ARE. THAT'S HOW THEY'RE GROWING.

WELL, WHERE IS IT HEADING? I WILL SHOW JUST ONE INDICATION. THE ONLY REASON I DON'T LIKE TO SHOW THIS NEXT GRAPH, IT CONTINUES TO USE GLOBAL AVERAGE SURFACE TEMPERATURE, WHICH IN TERMS OF EXPLAINING TO PEOPLE WHAT THE CONCERN IS, IT IS NOT VERY GOOD. BUT I WILL JUST FOCUS ON ONE OF THESE GRAPHS.

THIS IS FROM A UK GROUP PUBLISHED IN THE YEAR 2000 OF A MODEL, MATHEMATICAL MODEL, A FLUID DYNAMICAL MODEL OF THE EARTH'S ATMOSPHERE AND OCEAN, TAKING INTO ACCOUNT ALL FORCINGS. THIS IS THE TEMPERATURE RECORD WHICH THE MODELS COULD GENERATE, FAIRLY GOOD AGREEMENT, VERY GOOD AGREEMENT WITH WHAT WAS ACTUALLY OBSERVED OVER THE LAST 30 YEARS. AND PROJECTING INTO THE FUTURE WITH THAT KIND OF A FOSSIL FUEL SCENARIO, WITH ANY REASONABLE FOSSIL FUEL SCENARIO, ONE EXPECTS A MUCH LARGER WARMING IN THE REST OF THE CENTURY, OF COURSE. NOW, AS YOU KNOW, THERE ARE MANY MORE IMPORTANT FACTORS IN CLIMATE, SUCH AS PRECIPITATION, EXTREME EVENTS, AND SO FORTH, SO THE GLOBAL AVERAGE TEMPERATURE IS JUST THE EASIEST TO PREDICT. UNFORTUNATELY, IT IS NOT THE EASIEST TO IDENTIFY WITH.

WELL, WHERE DO WE GO FROM HERE? WHAT DO WE DO? A LOT OF THIS CONFERENCE IS FOCUSED ON HOW WE DEAL WITH THIS CHANGING CLIMATE; AND WE USE WORDS LIKE "MITIGATION" AND "ADAPTATION," OF COURSE. FIRST OF ALL, I WILL SHOW THIS. THIS IS AN UNREADABLE CHART, AND THAT'S PART OF MY MESSAGE. (LAUGHTER)

IT WAS GIVEN TO ME BY RESOURCES FOR THE FUTURE JUST A COUPLE OF WEEKS AGO. IT IS A LIST OF MARKET-BASED CLIMATE CHANGE LEGISLATION INTRODUCED IN THE CURRENT UNITED STATES CONGRESS. SO AS YOU CAN SEE, WITH ALL OF THOSE ADJECTIVES, THIS IS A LIMITED LIST. THESE ARE ONLY THE MARKET-BASED LEGISLATION INTRODUCED, WITH CATEGORIES GOING ACROSS: WHO IS REGULATED, WHAT ARE THEIR ALLOWANCE OR ALLOCATIONS, PRICE, STABILITY, OFFSET, TECHNOLOGY, COMPETITIVENESS, AND SO FORTH, WITH A LIST OF WHO IS SPONSORING THEM. SO THE MESSAGE HERE IS THAT TO DEAL WITH CLIMATE CHANGE, WHILE WE'RE GOING TO NEED PRIVATE PARTIES, BUSINESS LEADERSHIP, AND GOVERNMENT
INVOLVEMENT, IT'S NOT CLEAR AT ALL HOW WE'RE GOING TO DEAL WITH THESE THINGS. AND CONGRESS IS TRYING VERY HARD; BUT AS YOU KNOW, NONE OF THESE BILLS HAVE BEEN PASSED. VERY FEW BILLS HAVE BEEN PASSED THIS YEAR OF ANY KIND.

THIS IS A SOMEWHAT EASIER CHART TO READ IN THE SENSE THAT IT IS MORE LEGIBLE, BUT ALSO IT FOCUSES ON CARBON DIOXIDE EMISSIONS AND GIVES A COMPARISON OF THE IMPACTS OF VARIOUS PIECES OF LEGISLATION THAT HAVE BEEN INTRODUCED ON A HISTORICAL RECORD OF CARBON DIOXIDE EMISSIONS, AND A REASONABLE PROJECTION FORWARD, AS WELL AS THOSE FROM ELECTRICITY.

SO MY POINT HERE IS TO SAY THAT ALL THROUGH CONGRESS, THERE ARE MANY EFFORTS UNDERWAY TO TRY TO DEAL WITH CLIMATE CHANGE, FOCUSING MOSTLY ON CARBON DIOXIDE AND ENERGY. HOWEVER, MANY OF YOU KNOW THAT THAT IS NOT THE ONLY THING THAT WE HAVE TO FOCUS ON.

WELL, LET'S LOOK AT THE PICTURE FROM A BIT BIGGER DISTANCE, NOT JUST CONGRESS, BECAUSE AS I SAID BEFORE, THIS CHALLENGE OF DEALING WITH CLIMATE CHANGE IS NOT JUST FOR SCIENTISTS ANYMORE. SCIENTISTS WILL BE NECESSARY BUT NOT SUFFICIENT. BUSINESS LEADERSHIP, NGO'S, WHAT PRIVATE PARTIES DO, AND WHAT GOVERNMENTS DO ARE GOING TO BE VERY IMPORTANT. SO WHILE SCIENTISTS WILL CONTINUE TO DETECT AND MEASURE AND QUANTIFY AND ASSESS AND PREDICT AND COMMUNICATE, WE ALSO HAVE TO DEAL WITH THE ISSUES. AND WE HAVE TWO BASIC VERBS THAT HAVE CREPT INTO OUR VOCABULARY: "MITIGATE" AND "ADAPT." SO ONE DEFINITION OF "MITIGATION" IS TO REDUCE THE AMOUNT OF CLIMATE CHANGE OR TO SLOW IT; AND "ADAPTATION" IS TO REDUCE THE IMPACTS.

WELL, WE HAVE MANY EXAMPLES, AND SOME, I THINK, EXCELLENT PRESENTATIONS COMING UP ON DIFFERENT STRATEGIES AND TECHNIQUES FOR MITIGATION AND ADAPTATION. THE MITIGATION OPTIONS ARE BASICALLY EVERYTHING WE DO THAT INVOLVES ENERGY AND AGRICULTURE, AS WELL AS A LOT OF OTHER INDUSTRIAL PROCESSES. SOFT MITIGATION WOULD BE TARGETS SUCH AS ENERGY EFFICIENCY. WE HAVE SO MUCH TO GAIN BY ENERGY EFFICIENCY THAT YOU WOULD THINK THAT THERE'S MOTIVATION THAT EACH ONE OF US CAN IDENTIFY WITH.

ALL KINDS OF BENEFITS OF ENERGY EFFICIENCY, ALL THE WAY THROUGH TO OPTIONS WHICH ARE MUCH, MUCH LESS POPULAR, MUCH, MUCH LESS THOUGHT-OUT, AND MUCH, MUCH MORE HARD, I WOULD SAY -- "HARD" IN THE SENSE OF NOT MALLEABLE, THE GEOENGINEERING, FOR EXAMPLE. AND WE WILL HAVE SOME DISCUSSION, I THINK FRIDAY MORNING, ROB SOCOLOW TOLD ME, ON GEOENGINEERING.

WELL, WHERE DO WE GO ON MITIGATION AND ADAPTATION? THERE ARE MANY, MANY KINDS OF BUSINESS LEADERSHIP EMERGING AND MARKETS DEVELOPING, BUT I WANTED TO MENTION, AGAIN, WHAT CONGRESS IS DOING.

THERE'S TWO PARTICULARLY VERY SENIOR CONGRESSMAN,
DICKS FROM WASHINGTON AND OBEY FROM WISCONSIN, WHO
HAVE INTRODUCED A BILL WHICH IS PENDING APPROVAL --
THEM BOTH HAVE A GREAT DEAL OF INFLUENCE -- WHICH
WILL CREATE A NEW COMMISSION IN THE UNITED STATES TO
CREATE AND ALLOCATE A RESEARCH FUND IN THE FEDERAL
GOVERNMENT ABOUT MITIGATION AND ADAPTATION, AND ONE
OF THE REASONS WE'RE PAYING ATTENTION TO IT IS IT
NAMES ME TO CHAIR THE COMMISSION.

(LAUGHTER)

WE DIDN'T ASK FOR THIS, BUT I THINK IT IS A
GOOD IDEA.

THE COMMISSION WILL BE COMPRISED OF THE
ADMINISTRATOR OF EPA, THE DIRECTOR OF THE NATIONAL
SCIENCE FOUNDATION, THE ADMINISTRATOR OF NASA, THE
DIRECTOR OF THE USGS, THE UNDERSECRETARY FOR SCIENCE
OF THE DEPARTMENT OF ENERGY, THE ADMINISTRATOR --
THAT IS, CONRAD LAUTENBACKER -- OF NOAA, AND A FEW
OTHERS; AND I'M SUPPOSED TO CHAIR THE COMMISSION.
AND WHAT WE'RE SUPPOSED TO DO IS TO MAP OUT A WAY TO
SPEND A $50 MILLION ANNUAL FUND, WHICH THESE AGENCIES
WILL ADMINISTER, WHICH WILL DO RESEARCH ON MITIGATION
AND ADAPTATION, TO TRY TO FIGURE OUT WHAT IS A GOOD
IDEA AND WHAT'S FEASIBLE OR NOT.

SO IN THE WORLD AT LARGE WHAT WE SEE IS
CITIES AND STATES ARE ACTUALLY DOING THINGS IN
REGIONS, AND THE FEDERAL GOVERNMENT IS TRYING TO DEAL
WITH THE SITUATION BUT HASN'T YET COME UP WITH ITS
APPROACH, AND THERE ARE MANY, MANY OTHER PIECES OF
LEGISLATION WHICH ARE PENDING NOW BY VERY INFLUENTIAL
CONGRESSMEN AND WOMEN IN ADDITION TO THE DICKS AND
OBEY LEGISLATION; AND MANY OF THEM FOCUS ON
MITIGATION AND ADAPTATION. THERE IS A MOOD IN
CONGRESS THAT SAYS, LOOK, WE'RE CONVINCED, WE SEE
THINGS HAPPENING, WE THINK IT'S PROBABLY DUE TO
HUMANS, BUT WE WANT TO DO SOMETHING ABOUT IT AND NOT
JUST THE SCIENCE RESEARCH ANYMORE.

WELL, ON AN INTERNATIONAL LEVEL, LET'S ALSO
REMEMBER THAT AT HAND WE HAVE A GLOBAL SITUATION AT HAND

WITH THE EMERGING MARKET ECONOMIES GROWING MUCH
FASTER THAN THE REST OF US, AND THEIR FUTURE ENERGY
DEMAND IS GROWING MUCH FASTER THAN OURS WILL. SO
WHAT DO WE HAVE INTERNATIONALLY?

IN 1992, THE UN, UNITED NATIONS, FRAMEWORK
CONVENTION ON CLIMATE CHANGE WAS AGREED TO IN
RIO DE JANEIRO, AND IT WAS SIGNED BY PRESIDENT BUSH,
THE FIRST PRESIDENT BUSH, ALONG WITH ABOUT 150 OTHER
NATIONS, AND ARTICLE 2 STATES THE OBJECTIVE, TO WHICH
PEOPLE AGREE, AND I HAVE HIGHLIGHTED IN YELLOW,

LANGUAGE HERE THAT ONE OF THE GOALS IS TO STABILIZE
GREENHOUSE GAS CONCENTRATIONS IN THE ATMOSPHERE AT A
LEVEL THAT WOULD PREVENT DANGEROUS ANTHROPOGENIC
INTERFERENCE WITH THE CLIMATE SYSTEM. AND ONE OF THE
REASONS WHY WE DO NOT HAVE A SUCCESSFUL COMPREHENSIVE
INTERNATIONAL AGREEMENT YET IS THAT PEOPLE HAVEN'T
AGREED ON WHAT "DANGEROUS" MEANS.
In 2001 Inez Fung and I were on a committee together, requested by the White House, this President Bush, and I don't know if Inez caught on, but I didn't catch on until much later that the yellow question that is highlighted here out of a list of 14 questions, the yellow question was the loaded one. The question was: "Has science determined whether there is a 'safe' level of concentration of greenhouse gases?"

And like good scientists, we said a long-winded answer: on the one hand, this; on the other hand, this. If you're in a rich country and you can anticipate climate change, you can deal with it through technology, and you have capital and an educated population, a certain level of climate change might not be so dangerous. If you're in a poor country, without available technology, without capital to invest, without an educated population, and very little ability to anticipate the change and to restructure your industries and agriculture, you might be in danger earlier.

Well, apparently, that wasn't enough to answer the question. But there's another part of this question which is loaded. It says, "Has science determined whether there is a 'safe' level?" and how do we do that?

Well, there hasn't been very much work done on determining what is dangerous and what is not. I'm certainly not aware of all of it, but I'm aware of some of this work, and there isn't much. There are only a few scientists that are trying to come up with a scientifically-based definition, and they're focusing on things like irreversible changes. For example, a sea level change could well be irreversible in any reasonable time span. Loss of biodiversity is thought to be irreversible.

There is a great quote from the famous ecologist Aldo Leopold from about 1948, which I really love. He said, "The first rule for successful tinkering is to save all of the parts."

(Laughter)

And I think that has to apply to the biological world. So that might be involved.

And then, of course, the rate of disruption; if it's greater than the rate at which we can adapt might also be regarded as dangerous. But I want to close on this final question: who should define "dangerous"?

The question from the White House said: has science defined a dangerous level or a safe level?

I'm not so sure that this is a question just for scientists. In a representative democracy, we, I think, have to expect our elected leaders to participate in this definition; however, I think...
THEY, IN TURN, ARE GOING TO SAY THAT SCIENTISTS HAVE TO PROVIDE A BASIS. SO WE HAVE A GREAT CHALLENGE IN FRONT OF US.

LOOKING BACK ON THIS LAST 40 OR 50 YEARS, JUST LOOKING BACK 10 YEARS AGO TO WHEN THE MAUNA LOA OBSERVATORY HAD ITS 40TH ANNIVERSARY CELEBRATION, WHICH I ATTENDED AND REALLY ENJOYED, IT'S BEEN A VERY STRIKING DECADE, I THINK THE PACE OF WHAT WE HAVE TO DO, WHAT'S REQUIRED OF US AND OUR ROLE IN SOCIETY AS SCIENTISTS AND THE NECESSITY FOR US TO COLLABORATE WITH THE ENLIGHTENED BUSINESS COMMUNITY AND WITH GOVERNMENT LEADERS ALL AROUND THE WORLD IS GOING TO BE REALLY STUNNING IN ITS DRAMA IN THE NEXT DECADE OR TWO. SO I'M VERY HAPPY TO SEE SO MANY YOUNG PEOPLE HERE AT THE TABLE BECAUSE THE NEXT TEN YEARS IS REALLY GOING TO BE EXCITING AND EXTREMELY IMPORTANT FOR US ALL TO DO GOOD WORK AND TO BE ABLE TO COMMUNICATE.

SO I WILL STOP THERE AND THANK YOU AGAIN, RICK.