DR. FEELY: THANK YOU.

ALOHA.

IT WOULD BE REMISS OF ME IF I DIDN'T SAY A LITTLE BIT ABOUT DAVE KEELING'S ROLE ON THE OCEAN CARBON CYCLE. MANY OF US WHO HAVE BEEN INVOLVED WITH CHEMICAL OCEANOGRAPHY OVER THE PAST 30, 40 YEARS GOT MUCH OF OUR INSIGHT AND INTUITION BY INTERACTIONS WITH DAVE KEELING.

I WOULD LIKE TO POINT OUT THAT IN 1965 THE FIRST GLOBAL DATA SET FOR THE DIFFERENCE BETWEEN THE ATMOSPHERE AND THE OCEAN PCO2 WAS PUBLISHED IN THE "JOURNAL OF GEOPHYSICAL RESEARCH" BY DAVID KEELING. AND THE PERSON WHO HELPED DAVE MAKE THAT POSSIBLE BY DEVELOPING THAT TECHNIQUE FOR MEASURING CARBON IN THE OCEAN WAS TARO TAKAHASHI, WHO SPENT THE REST OF HIS CAREER, AS MOST OF YOU KNOW, IMPROVING AND REFINING THE GLOBAL CO2 CLIMATOLOGY FOR PCO2 IN THE OCEANS.

DAVE HAS BEEN A PERSONAL MENTOR TO ME. HE IS THE ONE WHO SUGGESTED TO ME THAT I SHOULD BE MAKING MEASUREMENTS OF CARBON IN THE EQUATORIAL OCEANS ON THE NOAA SURVEYS THERE, AND WE WORKED

0385

TOGETHER ON SOME OF THE FIRST MEASUREMENTS IN THE 1980S. AND HE ENCOURAGED ME TO CONTINUE THAT TO THIS DAY. SO I'M GREATLY APPRECIATIVE OF HIS MENTORSHIP AND HIS IMPACT ON MY CAREER.

IN THE LAST PART OF HIS CAREER, HE HELPED GUIDE NICKY GRUEBER AND NICK BATES IN THE ESTABLISHMENT OF THE TIME SERIES MEASUREMENTS AT HOT AND BACK (PHONETIC) IN THE OCEANS, AND PUBLISHED THE MOST RECENT DATA ON THOSE LONG-TERM OBSERVATIONS AT THESE OCEANOGRAPHIC SITES. HE HAS HAD A MAJOR ROLE TO PLAY IN DEVELOPING THE CARBON CYCLE IN THE OCEAN, AND I THINK IT IS IMPORTANT TO RECOGNIZE THAT.

TODAY WHAT I WOULD LIKE TO DO IS TO TALK ABOUT THE IMPACTS OF CLIMATE CHANGE ON THE OCEANS, AND WHAT I WILL DO IS TO GIVE AN OVERVIEW OF THAT.

AND THEN I WILL TURN IT OVER TO MY TWO COLLEAGUES, DR. SCOTT DONEY, FROM WOODS HOLE OCEANOGRAPHIC INSTITUTION, WHO IS A LEADER IN OUR COMMUNITY. HE DIRECTS AND IS IN CHARGE OF THE NATIONAL OCEAN CARBON AND BIOGEOCHEMISTRY PROGRAM WITHIN THE UNITED STATES. THIS IS A MULTIAGENCY EFFORT TO STUDY CARBON BIOGEOCHEMISTRY DYNAMICS IN THE OCEANS. HE IS ALSO A LEADER IN MODELING BIOGEOCHEMICAL PROCESSES IN THE OCEANS AND, IN PARTICULAR, THE IMPACTS OF CLIMATE CHANGE ON THOSE

0386

GEOCHEMICAL CYCLES, AND HE WILL TALK TO US ABOUT THE GLOBAL SCALES OF CHANGES THAT WE EXPECT TO SEE IN THE FUTURE.

OUR SECOND COLLEAGUE THAT WE WILL BE DISCUSSING TODAY IS DR. VICKI FABRY. SHE IS FROM CAL STATE, AT SAN MARCOS IN CALIFORNIA, AND SHE IS A LEADER IN UNDERSTANDING THE BIOLOGICAL IMPACTS OF OCEAN ACIDIFICATION, AND SHE IS THE CO-CHAIR OF THE U.S. GROUP THAT HAS BEEN DEVELOPING THE PLANS FOR

OCEAN ACIDIFICATION RESEARCH IN THIS COUNTRY. SO SHE PLAYS A VERY IMPORTANT ROLE. HER EXPERTISE IS IN BIOCALCIFICATION PROCESSES IN THE OCEANS, AND HER WORK IS FEATURED IN THIS MONTH'S ISSUE OF "NATIONAL GEOGRAPHIC" MAGAZINE, AND I ENCOURAGE ALL OF YOU TO LOOK AT THAT.

NOW, IF WE LOOK AT THE BOSTOCK RECORD, AND THIS WAS PRESENTED . . . WE SEE VERY CLOSE CORRESPONDENCE BETWEEN THE TEMPERATURE RECORD, GLOBAL TEMPERATURE RECORD, AND THE CO2 RECORD. AND THE PREDICTIONS THAT WE HAVE NOW IS THAT THE CO2 LEVEL IS NOW AT A VALUE OF ABOUT 383, GLOBALLY, MICROATMOSPHERES, WHICH IS A LITTLE MORE THAN 100 MICROATMOSPHERE ABOVE THE AMBIENT VARIABILITY IN THE PRE-INDUSTRIAL PERIOD, AND THERE HAS BEEN ABOUT A .8-DEGREE INCREASE IN GLOBAL TEMPERATURE.

0387

WE LOOK AT THE PROJECTIONS TO 2050, AND WE SEE AN INCREASE AS HIGH AS 550 MICROATMOSPHERES, AND AN INCREASE, CORRESPONDING INCREASE IN TEMPERATURE.

AS WE MOVE OUT TO THE END OF THE CENTURY, WE CAN SEE VALUES AND PROJECTIONS OUT TO ABOUT 800, AND, PERHAPS, A 1.4 TO 3.5 INCREASE IN GLOBAL TEMPERATURES.

THESE IMPACTS HAVE VERY SERIOUS CONSEQUENCES FOR THE GLOBAL OCEANS, AND THAT'S WHAT WE'LL TALK ABOUT TODAY. NOT ONLY IS THE IMPACTS ASSOCIATED WITH THE TEMPERATURE RISE, BUT ALSO THE VERY STRONG IMPACTS THAT WE HAVE BEEN OBSERVING FOR THE CARBON INCREASES IN THE OCEANS, AS WELL.

SOME OF THE IMPACTS THAT WE OBSERVED ARE:

INCREASES IN THE SURFACE TEMPERATURE OF THE WATERS. THIS PENETRATES DOWN TO DEPTHS AS DEEP AS 3,000 METERS SOME PLACES IN THE OCEANS.

INCREASE IN SEA LEVEL RISE, WHICH AFFECTS ECOSYSTEMS IN OUR COASTAL REGIME, AND SIGNIFICANT CHANGES THERE.

LOSS OF SEA ICE, AND VICKI WILL SHOW US A LITTLE BIT LATER TODAY THE LOSS OF SEA ICE HAS A VERY STRONG IMPLICATION ON OUR MARINE ECOSYSTEMS AT HIGH LATITUDES.

LOSS OF BIODIVERSITY.

0388

AND A VERY IMPORTANT SERIOUS IMPACT, A NEW ONE, OCEAN ACIDIFICATION, AND I WILL SPEND SOME DETAIL ON THAT.

FOR US THE SCIENTIFIC PROCESS IS VERY IMPORTANT IN HELPING THE DEVELOPMENT OF POLICY AND MITIGATION STRATEGIES. WE DO THIS FIRST BY PROCESS IDENTIFICATION, THAT'S WHAT WE'LL BE TALKING MOST ABOUT HERE. PARAMETERIZATION INTO MODELS, THAT'S WHAT SCOTT WILL TALK ABOUT, AND OBSERVATIONS THAT VERIFY THE MODELS. AND I THINK THIS IS THE AREA WHERE WE NEED THE MOST DEVELOPMENT IN THE FUTURE; THAT IS, WE NEED ENOUGH OBSERVATIONAL CAPABILITIES IN THE OCEANS TO CONSTRAIN THE MODELS. NOW, I WILL PAY A LOT OF ATTENTION TO THAT DURING THE COURSE OF THE

DISCUSSION.

HERE, FOR EXAMPLE, IS THE OCEAN HEAT CONTENT IN THE GLOBAL OCEANS FROM 1955 THROUGH 2005. THIS IS THE WORK OF LEVITUS, ET AL. AND WE SEE INTEGRATED HEAT CONTENT FROM 0 - 300 METERS IN RED, 0 - 700 METERS IN BLUE, AND 0 - 3,000 METERS IN GRAY. AND WE SEE A VERY SIGNIFICANT INCREASE IN THE GLOBAL HEAT CONTENT IN THE WORLD. THIS IS DUE NOT ONLY THROUGH ANTHROPOGENIC WARMING, BUT DECADAL VARIABILITY.

I THINK ONE OF THE MOST SIGNIFICANT

0389

FINDINGS OF THIS RESEARCH IS THAT 80 PERCENT OF THE EXCESS HEAT IN THE CLIMATE SYSTEM STILL RESIDES IN THE OCEANS. AND IT IS THIS INERTIA IN THE OCEANS THAT WILL DRIVE FURTHER HEATING OF THE GLOBAL ATMOSPHERE IF WE CONSTRAIN CO2 TO ITS PRESENT LEVEL. THIS WOULD BE AS MUCH AS A HALF DEGREE ADDITIONAL WARMING BY THE ADDITIONAL HEAT CONTENT IN THE OCEAN.

A SECOND IMPORTANT POINT TO MAKE ABOUT THIS IS BY MAKING THESE OBSERVATIONS IN THE OCEAN IN TERMS OF THE TOTAL HEAT CONTENT, WE HAVE BEEN ABLE TO BALANCE THE HEAT BUDGET DUE TO GLOBAL WARMING AND THEN COMPARE THAT WITH THE MODELS, AND THE MODELS AND OBSERVATIONS AGREE. SO WE NOW HAVE A BALANCED HEAT BUDGET RESULTING FROM GLOBAL WARMING ACTIVITIES. THIS IS WHY THE SCIENTIFIC COMMUNITY PLACES SO MUCH EMPHASIS ON HOW MUCH WE'VE REDUCED THE DEGREE OF UNCERTAINTIES IN THESE ESTIMATES OVER THE LAST FIVE YEARS.

A CONSEQUENCE OF THAT, AS WE'VE TALKED ABOUT EARLIER -- I WON'T GO INTO GREAT DETAIL -- IS SEA LEVEL ICE AGE CHANGES. RICHARD SOMERVILLE POINTED OUT THAT IT IS ABOUT 2.7 PERCENT PER DECADE. IN THE LAST YEAR, DURING THIS LAST SUMMER, WE'VE SEEN AN ENORMOUS CHANGE IN THE SEA ICE EXTENT, AND THIS IS ABOUT THE AREA OF THE SIZE OF THE STATE OF ALASKA,

0390

THIS IS ABOUT A 38-PERCENT DROP IN THE SEA ICE EXTENT. AND THAT HAS A SIGNIFICANT IMPACT ON THE ECOSYSTEMS IN THE ARCTIC REGION, BECAUSE IT'S THIS ICE EDGE LOCATION WHICH DRIVES MUCH OF THE CARBON FLUX FROM THE SURFACE OCEAN TO THE BENTHIC ENVIRONMENT. IT SHOWS THAT AS WE REMOVE THE ICE FROM THAT REGION, WE ALSO IMPACT THIS IMPORTANT ECOSYSTEM AND CARBON TRANSPORT, WHICH THEN PERMEATES UP INTO THE HIGHER TROPHIC LEVELS, SUCH AS SEALS AND POLAR BEARS AND EVEN WHALES.

HERE IS THE ESTIMATES FOR THE PROJECTIONS FOR GLOBAL TEMPERATURES, RANGING FROM ANYWHERE FROM 1.5 TO PERHAPS AS HIGH AS 3.5. THESE HAVE SERIOUS CONSEQUENCES FOR THE OCEANS AND THE ECOSYSTEMS, AND WE'LL HAVE MOST OF OUR DISCUSSIONS ABOUT THESE CONSEQUENCES. BUT ALSO THE CHANGES IN THE ICE STRUCTURE AND THE HEATING OF THE OCEANS BRING BACK VERY IMPORTANT CONSEQUENCES FOR CARBON FEEDBACKS AND FEEDBACKS TO THE CLIMATE SYSTEM.

SO WE'LL START WITH THE ATMOSPHERIC RECORD, AND THIS IS A REPRESENTATION OF GLOBAL VIEW. THIS IS THE ATMOSPHERIC OBSERVATIONAL NETWORK THAT'S MAINTAINED BY THE GLOBAL MONITORING DIVISION OF NOAA. AND I WANTED TO SHOW YOU THIS PRESENTATION FROM THE LABORATORY, WHICH I THINK IS QUITE STRIKING. HERE IS

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A MONTHLY INCREASE OF THE ATMOSPHERIC RECORD FROM THE SOUTH POLE TO THE NORTH POLE, AND WE CAN SEE THE BREATHING OF THE ATMOSPHERE WITH A RELEASE OF CARBON IN THE WINTERTIME AND UPTAKE IN THE SUMMERTIME. BUT THROUGHOUT THE ENTIRE DATA SET, WE CAN SEE THE GRADUAL INCREASE OF ABOUT ONE AND A HALF MICROATMOSPHERES PER YEAR. AND THAT'S THE CLEAREST EVIDENCE I KNOW THAT MAN'S INFLUENCE ON THE GLOBAL CARBON CYCLE IS INCREASING AT AN EVER-INCREASING RATE.

WHEN WE LOOK AT THE AIRBORNE FRACTION, WE CALCULATE THAT OUT, AND PIETER TANS DID A WONDERFUL JOB OF EXPLAINING THAT, ABOUT 45 PERCENT OF CO_2 EMISSIONS IS ACCUMULATED IN THE ATMOSPHERE; 25 PERCENT, OUR BEST ESTIMATE NOW, IS REMOVED BY THE OCEAN; AND ABOUT 30 PERCENT IN THE LAND BIOSPHERE. SO IT IS VERY IMPORTANT FOR US TO UNDERSTAND HOW THIS EFFICIENCY IS CHANGING OVER TIME AND WHAT THE IMPLICATIONS FOR THE AIRBORNE FRACTION ARE IN THE FUTURE.

SO FOR THE OCEANS THESE CHANGES ARE A FUNCTION OF CO_2 SOLUBILITY, WHICH IS A FUNCTION OF TEMPERATURE AND SALINITY, WHICH WE KNOW QUITE WELL; OCEAN CURRENTS AND STRATIFICATION, WHICH IS A LITTLE MORE DIFFICULT, IT'S MORE UNCERTAIN; CHANGES IN WIND

0392

SPEED; BIOLOGICAL ACTIVITY; AND NOW, ALSO, IMPACTS FROM OCEAN ACIDIFICATION.

SOME RECENT WORK THAT HAS BEEN DONE BY CANADELL AND COLLEAGUES HAS SHOWN THAT IN THE CASE OF THE EFFICIENCY OF THE OCEAN TO TAKE UP CO_2 FROM THE ATMOSPHERE, THE EFFICIENCY HAS DECREASED BY AS MUCH AS 16 PERCENT OVER THE LAST 50 YEARS. AND IT IS PARTICULARLY IMPORTANT TO UNDERSTAND WHY THIS IS HAPPENING. MUCH OF OUR UNDERSTANDING SO FAR COMES FROM MODELING EFFORTS, SUCH AS THE WORK OF LE QUERE, AND IT'S BEEN HER SUGGESTING FROM WORK IN THE SOUTHERN OCEAN THAT ABOUT 30-PERCENT DECREASE IN EFFICIENCY IN THE SOUTHERN OCEAN HAS OCCURRED IN THE LAST 20 YEARS. AND THIS NOTION IS IMPORTANT BECAUSE IT REMOVES ABOUT .7 PETAGRAMS OF CARBON PER YEAR, ANTHROPOGENIC CO_2. AND THIS DECLINE IN THE EFFICIENCY OF THE SOUTHERN OCEAN IS DUE TO THE STENGTHENING OF THE WINDS AROUND THE ANTARCTIC REGION, WHICH ENHANCES THE VENTILATION OF NATURAL CARBON-RICH WATERS, AND THIS STRENGTHENING OF WINDS IS PERHAPS DUE TO A GLOBAL WARMING PROCESS ASSOCIATED WITH THE FORMATION OF THE OZONE HOLE. THIS IS SOME NEW INFORMATION THAT HAS COME TO DATE.

THERE ARE OTHER CHANGES THAT HAVE BEEN

SHOWN OVER THE LAST DECADE OR SO. MY OWN WORK IN THE

0393

EQUATORIAL PACIFIC SAYS THAT THE EQUATORIAL PACIFIC IS INCREASING IN ITS SOURCE OF CARBON TO THE ATMOSPHERE OVER THE PAST TWO DECADES DUE TO LONGER CLIMATE VARIABILITY CHANGES SUCH AS THE PDO AND OTHER FACTORS. SO WHAT WE NEED TO HAVE IS A VERY STRONG OBSERVATIONAL COMPONENT THAT IS COMPLETE THROUGHOUT THE GLOBAL OCEAN SYSTEMS TO VERIFY THESE MODEL RESULTS.

RICK WINEACAUFF (PHONETIC) OF AML HAS BEEN INSTRUMENTAL IN DEVELOPING A WORLDWIDE OBSERVATIONAL CAPABILITY OF SEA SURFACE MEASUREMENTS THROUGHOUT THE GLOBAL OCEANS, BUT THERE ARE STILL GAPS IN OUR OBSERVATIONAL CAPABILITIES THAT PREVENT US FROM VERIFYING THESE NEW MODELING RESULTS. SO THIS, I THINK, IS AN ISSUE OF GREAT IMPORTANCE FOR THE FUTURE.

NOW I'M GOING TO TURN MY ATTENTION TO OCEAN ACIDIFICATION, AND I WANT TO GO THROUGH A LITTLE BIT OF THE CHEMISTRY SO EVERYONE CAN FOLLOW IT. WHAT WE DO KNOW FROM OBSERVATIONS OVER THE PAST 30 YEARS IS THAT THE CO2 CONCENTRATION AND THE PH OF THE SURFACE OCEANS HAVE BEEN CHANGING DRAMATICALLY, AND THERE HAS BEEN A .1 PH DROP OVER THE PAST 2 CENTURIES. THIS IS EQUIVALENT TO ABOUT A 30-PERCENT INCREASE IN THE OVERALL ACIDITY OF THE SURFACE OCEAN AND A

0394

CORRESPONDING DECREASE IN THE CARBONATE ION CONCENTRATION OF ABOUT 16 PERCENT.

THIS IS PARTICULARLY IMPORTANT TO ALL CALCIFYING ORGANISMS BECAUSE THEY USE CARBONATE ION TO FORM THE CALCIUM CARBONATE SHELLS, AND SO WITH A DECREASING CARBON ION CONCENTRATION, IT IS MORE DIFFICULT FOR THEM TO DEVELOP THEIR SHELLS AND SKELETONS, PARTICULARLY CORAL REEF SYSTEMS HERE THAT ARE VERY IMPORTANT TO OUR ECONOMICS. IT IS SUGGESTED THAT, FOR EXAMPLE, THE FISHING AND THE TOURIST INDUSTRY SUPPORT ABOUT 500 MILLION PEOPLE GLOBALLY IN TERMS OF JUST THE CORAL REEF SYSTEMS ALONE. IT IS ALSO IMPORTANT BECAUSE MANY SPECIES OF PHYTOPLANKTON AND ZOOPLANKTON FORM CALCIUM CARBONATE SHELLS, AND THEY'RE VERY UNIQUE IN THE FOOD CHAIN, SO WE'RE CONCERNED ABOUT THE IMPACT AND THE CHANGING COMPOSITION OF THE LOWER PART OF THE FOOD CHAIN AND THEIR IMPACTS IN OUR FISHERIES THAT WE DEPEND ON SO HIGHLY FOR FOOD.

THE REACTIONS ARE REALLY QUITE SIMPLE. CO2 REACTS AT THE SURFACE TO FORM CARBONIC ACID. WE KNOW THIS QUITE WELL. THE CARBONIC ACID NEARLY DISSOCIATES TO FORM HYDROGEN ION. THIS IS WHAT GIVES US OUR ACIDITY. HYDROGEN ION THEN REACTS WITH A CARBONATE ION TO FORM CARBONATE, BICARBONATE. THIS

0395

CARBONATE ION THEN IS DEPLETED OVER TIME, AND THE HYDROGEN ION IS INCREASED OVER TIME. SO THE NET REACTION, CO2 PLUS CARBONATE, FORMS TWO BICARBONATES.

SO WHAT WE SEE WHEN WE MODEL THIS THROUGH TIME IS THAT THE PH OF AVERAGE SEAWATER IS ABOUT 8.2. IT HAS DECREASED TO THE PRESENT TIME OF ABOUT 8.1. AND THE CARBONATE ION CONCENTRATION HAS DECREASED ABOUT 16 PERCENT. WHEN WE PROJECT THE CO2 SCENARIOS OUT TO THE END OF THE CENTURY, USING THE BUSINESS-AS-USUAL SCENARIO OF THE IPCC, WE SEE A CORRESPONDING PH DROP OF ANYWHERE FROM .3 TO .5 PH UNITS. THIS IS 150-TO-200-PERCENT INCREASE IN THE ACIDITY OF THE OCEANS OVER THIS TIME PERIOD, AND AS MUCH AS A 50-PERCENT LOSS IN THE CARBONATE ION CONCENTRATION. THIS IS UNPRECEDENTED THROUGH ALL OF GEOLOGICAL HISTORY, THESE KIND OF CHANGES THAT HAVE BEEN TAKING PLACE.

NOW, THE ORGANISMS ARE CONCERNED ABOUT THE SATURATION STATE OF SEAWATER, AND I HAVE TO EXPLAIN A LITTLE CHEMISTRY HERE. SATURATION STATE IS A FUNCTION OF THE CALCIUM ION CONCENTRATION, AGAIN THE CARBONATE ION CONCENTRATION, DIVIDED BY THE APPARENT SOLUBILITY PRODUCT. THIS APPARENT SOLUBILITY PRODUCT INCREASES WITH DECREASING TEMPERATURE AND INCREASE IN PRESSURE. SO THE SATURATION STATE IS LOWER DEEP IN

0396

THE WATER COLUMN WHERE THE WATERS ARE COLD, OR AT THE HIGH LATITUDES WHERE THE WATERS ARE ALSO COLD, AND THE SATURATION STATE IS HIGHEST NEAR THE EQUATOR.

WHEN THE SATURATION STATE IS ABOVE 1, AS THROUGHOUT MOST SURFACE SEAWATER RIGHT NOW, THE ORGANISMS CAN PRODUCE THEIR SHELLS. WHEN IT IS LESS THAN 1, DISSOLUTION TAKES PLACE, AND THEY CAN NO LONGER PRODUCE THEIR SHELLS. SO WE NEED TO KNOW EXPLICITLY WHAT IS OCCURRING IN THE OCEANS AND WHERE IT IS OCCURRING.

WE KNOW VERY CLEARLY FROM THE TIME SERIES WORK AT HOT AND BACK THAT THE CO2 CONCENTRATION IN THE OCEANS IS MIMICKING VERY WELL THE INCREASE IN CO2 IN THE ATMOSPHERE. YOU'LL SEE HERE FROM THE WONDERFUL WORK DAVE KARL AND HIS GROUP HAS DONE AT THE HOT STATIONS AND MONTHLY MEASUREMENTS OF PCO2 THAT WE CAN SEE THAT THERE IS A VERY GOOD CORRESPONDENCE BETWEEN THE RATE OF INCREASE OF PCO2 AT HOT AND THE ATMOSPHERIC THAT WE HAVE AT MAUNA LOA. THEREFORE, WE CAN THEN CALCULATE THE PH DROP OVER THIS TIME FRAME, AND THIS HAS BEEN DONE, AND THIS AMOUNTS TO ABOUT A .02 PH DROP PER DECADE OVER THESE TIME SCALES. SO WE HAVE VERY CLEAR EVIDENCE THAT THERE IS A CHANGE, A DECREASE IN PH, AND THIS IS TRUE NOT ONLY AT HOT BUT AT BACK AND ALL THE OTHER TIME SERIES MEASUREMENTS WE

0397

MAKE, AND A CORRESPONDING DECREASE IN THE CARBONATE ION. HERE IS CLEAR AND REFUTABLE EVIDENCE THAT WE ARE CHANGING THE OCEAN CHEMISTRY. PH IS A FUNDAMENTAL PARAMETER. IT AFFECTS THE CHEMISTRY OF MOST CHEMICAL SPECIES IN THE OCEAN, SO WE'RE AFFECTING THE BASIC CHEMISTRY OF THE OCEAN WITH THESE CHEMISTRY CHANGES DUE TO THE INTRODUCTION OF ATMOSPHERIC CO2.

FROM THE GLOBAL OCEAN SURVEY THAT WE COMPLETED AS A COOPERATIVE EFFORT WITH NOAA AND NSF AND NASA AND EIGHT OTHER COUNTRIES THROUGHOUT THE WORLD, WE COMPLETED A GLOBAL CO2 SURVEY, 72,000 SAMPLES, 99 CREWS, AND IT TOOK US FIVE YEARS TO COMPILE ALL THIS DATA; AND WHAT WE HAVE OBSERVED WAS, FROM OBSERVATIONS ALONE, AN INCREASE OF ANTHROPOGENIC CO2 AVERAGING ABOUT 60 MICROMOLES PER KILOGRAM IN SURFACE WATERS, BUT MOSTLY PENETRATING, OTHER THAN THE NORTH ATLANTIC, STILL ONLY TO DEPTHS OF ABOUT 1,500 METERS. SO MOST OF THE ANTHROPOGENIC CO2 IS THE SURFACE WATERS, WHERE IT IS GOING TO HAVE ITS MAJOR IMPACTS ON OUR BIOLOGICAL SYSTEMS.

AND FROM THAT WORK THAT CHRIS SABINE AND COLLEAGUES PUBLISHED IN 1994, WE GET 118 PLUS OR MINUS 19 PETAGRAMS OF CARBON IN THE SURFACE OCEANS; AND IT IS THIS DATA SET THAT WE HAVE UTILIZED TO SHOW

THAT THESE CHANGES IN ANTHROPOGENIC CO2 ARE CAUSING THE GLOBAL CHANGE IN ACIDIFICATION OF THE OCEANS. AS I SAID, MOST OF THE ANTHROPOGENIC CO2 RESIDES IN THE UPPER 10 PERCENT OF THE OCEANS RIGHT NOW, AND THESE ARE THE CHANGES THAT ARE AFFECTING OUR CHEMICAL CHANGES FOR THE MANY SPECIES THAT YOU HEAR ABOUT.

IN MY OWN WORK, I HAVE SHOWN WHERE THE CORROSIVE WATER, WHERE THE SATURATION STATE IS AT 1, AND BELOW THAT, IT WOULD BE CORROSIVE TO CALCIUM CARBONATE SPECIES, FOR BOTH ARAGONITE AND CALCITE; AND WHAT WE FIND IS THAT IN THE NORTH PACIFIC OCEAN IT IS VERY, VERY CLOSE TO THE SURFACE, IT IS WITHIN 200 METERS OF THE SURFACE OCEAN; WHEREAS, IN THE NORTH ATLANTIC IT IS STILL QUITE DEEP. THIS IS DUE TO THE LONG-TERM CIRCULATION OF THE OCEANS AND THE UPWELLING IN THE NORTH PACIFIC OF THE VERY DEEP WATERS BACK TO THE SURFACE. SO THE HIGH CORROSIVE WATERS ARE VERY, VERY CLOSE TO OUR SURFACE.

WE SHOULD BE VERY CONCERNED ABOUT THIS. THAT MEANS THAT CORROSIVE WATERS CAN BE UPWELLED ONTO OUR CONTINENTAL SHELVES THROUGHOUT MOST OF NORTH AMERICA ON THE WESTERN SIDE. THIS IS A VERY SERIOUS PROBLEM AND REPRESENTS A VERY IMPORTANT FINDING OF THESE RESULTS.

WE ACTUALLY CALCULATED THE RISE OF THIS

SATURATION CORROSIVE WATERS BASED ON THE GLOBAL CO2 SURVEY IN THE ATLANTIC AND THE PACIFIC, AND THE INDIAN OCEAN, I JUST SHOWED THE INDIAN OCEAN, AND IT RISES AS MUCH AS 200 METERS IN THE INDIAN OCEAN AND AS MUCH AS 100 METERS IN THE PACIFIC OCEAN. BUT YOU CAN SEE HERE UP AROUND ALASKA, THIS CORROSIVE WATER IS LESS THAN 200 METERS, WHICH MEANS IT WILL BE ON THE CONTINENTAL SHELF, AND WE JUST NEED TO LOOK FOR THAT.

SO HERE IS A MODEL PROJECTION WE HAVE OF WHAT THE CONDITIONS FOR GOOD PRECIPITATION OF CALCIUM CARBONATE SPECIES AROUND THE WORLD OCEANS, THIS IS FOCUSED ON ARAGONITE, THE PTEROPODS AND THE CORALS,

AND THE BLACK SPOTS HERE ARE THE LOCATIONS OF OUR CORAL REEF SYSTEMS. THE MAGENTA ARE THE DEEP-WATER CORAL SYSTEMS. AND HERE WERE THE CONDITIONS FOR THE PRE-INDUSTRIAL WORLD, WHERE WE HAD BASICALLY GOOD CONDITIONS FOR PRECIPITATION OF CALCIUM CARBONATE THROUGHOUT MOST OF THE WORLD, A LITTLE PROBLEMS IN THE HIGH AND THE LOW IN THE SOUTHERN LATITUDES. WE GO TO THE PRESENT DAY, AND WE HAVE LOST ALL OF THE VERY FAVORABLE CONDITIONS ALREADY, AND WE'RE NOW INTO REGIONS OF MARGINAL, SOME FAVORABLE CONDITIONS STILL IN THE TROPICS, BUT MOSTLY MARGINAL CONDITIONS.

USING THE BUSINESS-AS-USUAL SCENARIO OUT AT

0400

THE END OF THE CENTURY, WE PROJECT THAT ALL OF THE SOUTHERN OCEAN WILL BE CORROSIVE THROUGHOUT THE ENTIRE WATER COLUMN, PORTIONS OF THE NORTH PACIFIC, THE ARCTIC OCEAN, AND PRETTY CLOSE THAT THE NORTH ATLANTIC WILL BE CORROSIVE; AND THE ENTIRE WORLD OCEANS ARE NO LONGER FAVORABLE FOR PRECIPITATION OF CALCIUM CARBONATE. THIS IS A VERY SERIOUS PROBLEM FOR OUR MARINE ECOSYSTEMS.

SO WHAT I WANT YOU TO THINK ABOUT AS YOU HEAR THE NEXT TWO DISCUSSIONS IS TWO IMPORTANT QUESTIONS THAT WE NEED TO ASK OURSELVES AS A COMMUNITY:

THE FIRST IS WHAT LEVELS OF CO2 AND PH CHANGES SHOULD WE STRIVE TO AVOID IN THE OCEANS? IS A .2 PH CHANGE, WHICH HAS BEEN SUGGESTED BY SOME COUNTRIES, THE RIGHT PH CHANGE WE WANT TO AVOID? THAT'S AN IMPORTANT QUESTION THAT WE NEED TO ANSWER. A .2 PH CHANGE IN THE SURFACE OCEANS IS A PCO2 IN THE ATMOSPHERE OF ABOUT 500 PARTS PER BILLION.

WHAT MITIGATION AND ADAPTATION STRATEGIES CAN BE APPLIED TO REDUCE THE SEVERE IMPACTS IN THE OCEANS?

SO THESE ARE THE QUESTIONS I THINK WE NEED TO FOCUS ON HERE TODAY, AND I HOPE THAT YOU ASK THESE KINDS OF QUESTIONS TO OUR EXPERTS DURING THE PANEL AT

0401

THE END OF THE SESSION.

I WILL TURN THE MICROPHONE OVER TO SCOTT DONEY, WHO WILL TALK TO US ABOUT THE GLOBAL MODEL.

SCOTT.