REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average one hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden to Washington Headquarters Services. Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget. Paperwork Reduction Project (0704-0188). Washington, DC 20503.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY)	2. REPORT DATE	3. DATES COVERED (FROM - TO)
06 January 2010	06 January 2010	10/1/08 - 9/30/09

4. TITLE AND SUBTITLE

Climate, Science and Technology Symposium

5a. CONTRACT NUMBER

5b. GRANT NUMBER

N00014-09-1-0483

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

A.D.J.Haymet, Director, Scripps Institution of Oceanography, UCSD

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES)

The Regents of the University of California
Scripps Institution of Oceanography, UCSD
9500 Gilman Drive
La Jolla CA 92093-0210

8. PERFORMING ORGANIZATION REPORT NUMBER

2009-00894R1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
875 N. Randolph Street, Ste. 1238
Arlington VA 22203-1995

10. SPONSOR/MONITOR'S ACRONYM(S)

ONR

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT

approved for public release; distribution is unlimited

20100112025

13. SUPPLEMENTARY NOTES

14. ABSTRACT

In March 2009, distinguished scientists, national leaders, and friends gathered at the Roger Revelle Centennial Symposium, the scientific focus of Scripps Institution of Oceanography's celebration of Roger Revelle's 100th birthday. UC San Diego founder and former Scripps Director Roger Revelle was a world-renowned scientist and is considered one of the true pioneers of climate change research. Revelle revolutionized how we think about the ocean and climate, and how science and technology truly benefit society. As such, the Roger Revelle Centennial Symposium honored Revelle's continuing legacy, and highlighted the influence his work continues to exert upon the scientific community and society at large. We were honored with thoughtful and engaging presentations, and reflections from many globally distinguished scientists and policymakers who discussed the interrelationships of climate change, ocean and environmental health, national security, and energy independence, and the critical role science and technology can play in meeting today's global challenges. In today's conflicted world, it is important to remember Revelle's vision of the profound effect technology and scientific discovery can have upon all aspects of modern society.

15. SUBJECT TERMS

climate, science and technology, symposium, Roger Revelle

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF	18. NUMBER	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE	ABSTRACT	OF PAGES	Mary Tabaie
unclassified	unclassified	unclassified	none	18	19b. TELEPHONE NUMBER (Include area code) (858) 246-0359

SYMPOSIUM PRESENTATIONS AND COMMENTARY

Roger Revelle: On the Shoulders of Giants
Ed Frieman, *Director Emeritus, Scripps Institution of Oceanography*

Climate Change and Roles for Scientists
Ralph Cicerone, *President, National Academy of Sciences*
Commentary by* **Ray Weiss, *Distinguished Professor of Geophysics, Scripps Institution of Oceanography*

NOAA's Vision for Climate Products and Services
Richard Spinrad, *Assistant Administrator, National Oceanic and Atmospheric Administration*
** Commentary by* **Dan Cayan,** *Research Meteorologist, Scripps Institution of Oceanography*

Challenges in Widespread, Globally Scalable,
Carbon-Neutral Energy Production for Climate Stabilization
Nate Lewis, *George L. Argyros Professor of Chemistry, California Institute of Technology*
Commentary by* **B. Greg Mitchell, *Research Biologist, Scripps Institution of Oceanography*

Innocence and War: Past and Future
VADM Paul Gaffney USN (Ret.), *President, Monmouth University*
Commentary by* **John Orcutt, *Professor of Geophysics, Scripps Institution of Oceanography*

UC San Diego Approaching 50
Marye Anne Fox, *Chancellor, University of California, San Diego*

Human Capital and the Promise of Research Universities
Mark G. Yudof, *President, University of California*

On Roger Revelle
** Commentary by* **Walter Munk,** *Professor Emeritus, Scripps Institution of Oceanography*

Roger Revelle's Role in Developing Scripps' Fleet and the Fleet Today
** Commentary by* **Bruce Applegate,** *Director, Ship Operations, Scripps Institution of Oceanography*

Integrating Ocean Science and Policy: The Legacy of Roger Revelle
Mike Chrisman, *California Secretary for Natural Resources*

Scripps Research Today and Tomorrow
** Commentary by* **Tony Koslow,** *CalCOFI Director, Scripps Institution of Oceanography*

The Future of Science and Science for the Future
Ashok Khosla, *Chair, Development Alternatives; President, Club of Rome; President, IUCN*

Training a New Generation of Globally Active Scientists
** Commentary by* **Phil Hastings,** *Professor of Marine Biology,*
Curator of Marine Vertebrates, Scripps Institution of Oceanography

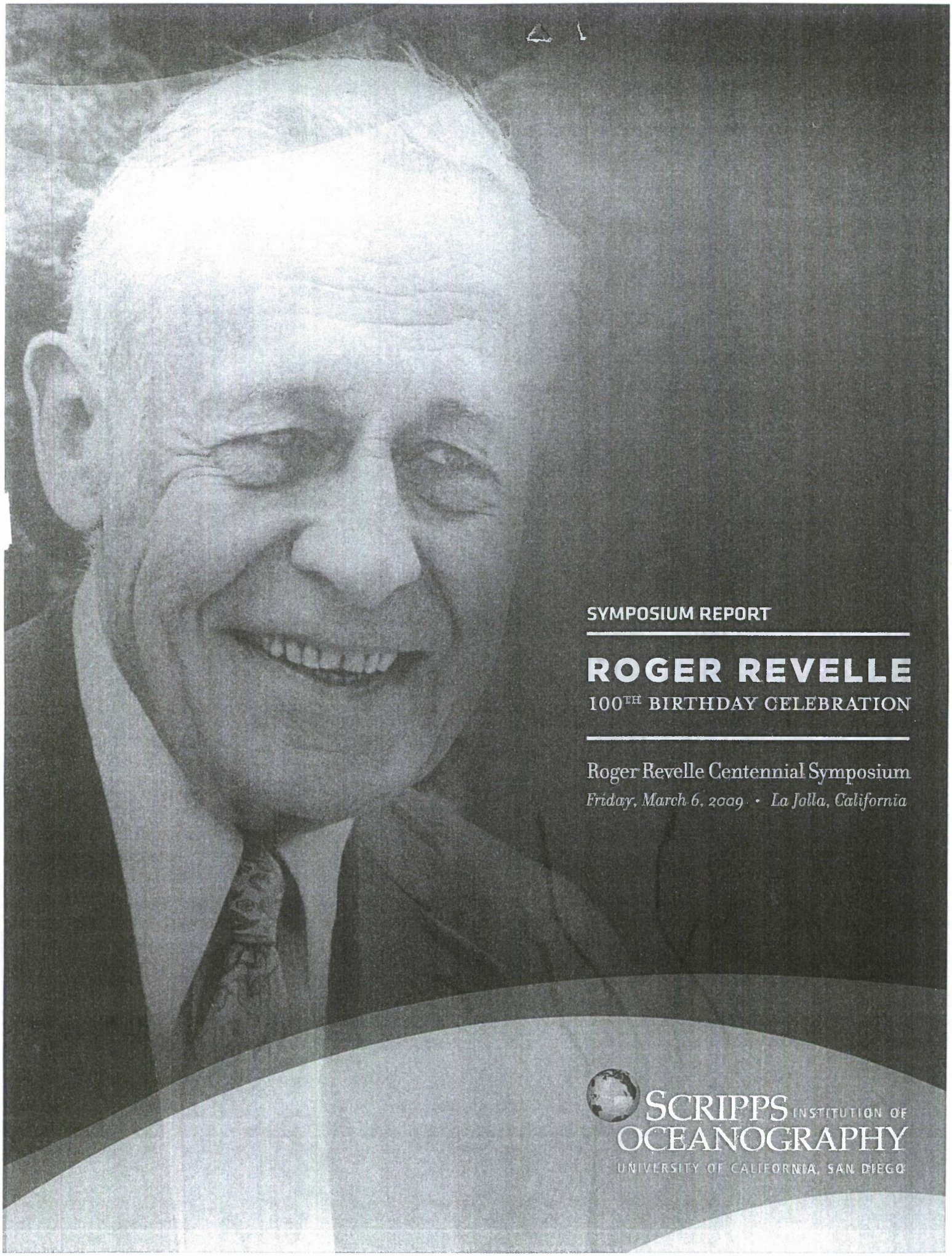
Project Surya
** Commentary by* **Ed Frieman,** *Director Emeritus, Scripps Institution of Oceanography*

In Memoriam: Ellen Revelle

What I Learned About Roger
** Commentary by* **Charlie Kennel,** *Director Emeritus, Scripps Institution of Oceanography*

Following the Symposium, there was a student lecture by former Vice President Al Gore, the recipient of the inaugural Roger Revelle Prize.

To view the Roger Revelle Centennial Symposium on UCSD-TV, visit ucsd.tv/revellesymposium



SYMPOSIUM REPORT

ROGER REVELLE

100TH BIRTHDAY CELEBRATION

Roger Revelle Centennial Symposium

Friday, March 6, 2009 · La Jolla, California

SCRIPPS INSTITUTION OF OCEANOGRAPHY

UNIVERSITY OF CALIFORNIA, SAN DIEGO

Three generations of Scripps Directors participated in the Roger Revelle 100th Birthday Celebration events. From left, Ed Frieman, Tony Haymet, and Charlie Kennel.

A MESSAGE FROM THE DIRECTOR

In March 2009, distinguished scientists, national leaders, and friends gathered at the Roger Revelle Centennial Symposium, the scientific focus of Scripps Institution of Oceanography's celebration of Roger Revelle's 100th birthday.

UC San Diego founder and former Scripps Director Roger Revelle was a world-renowned scientist and is considered one of the true pioneers of climate change research. Revelle revolutionized how we think about the ocean and climate, and how science and technology truly benefit society. As such, the Roger Revelle Centennial Symposium honored Revelle's continuing legacy, and highlighted the influence his work continues to exert upon the scientific community and society at large.

We were honored with thoughtful and engaging presentations, and reflections from many globally-distinguished scientists and policymakers who discussed the interrelationships of climate change, ocean and environmental health, national security, and energy independence, and the critical role science and technology can play in meeting today's global challenges.

In today's conflicted world, it is important to remember Revelle's vision of the profound effect technology and scientific discovery can have upon all aspects of modern society.

We thank our colleagues and leaders for being a part of this momentous celebration inspired by the late, legendary statesman of science, Roger Revelle.

Sincerely,

Tony Haymet

Tony Haymet
Director
Scripps Institution of Oceanography
UC San Diego

Roger Revelle: On the Shoulders of Giants

Ed Frieman, *Director Emeritus, Scripps Institution of Oceanography*

There is an intriguing book, known to its enthusiasts as OTSOG, "On the Shoulders of Giants," by the distinguished sociologist Robert K. Merton. It traces the history of this saying down through the ages to Bernard of Chartres in the twelfth century. It tells the story of dwarfs standing on the shoulders of giants and thereby seeing farther. While perhaps not dwarfs, we are standing on the shoulders of a giant who helped us to see farther by raising penetrating questions about the world and the human condition that we are struggling with to this day.

The Roger Revelle I got to know, for too short a number of years, was a complex man. In street language one would say he not only talked the talk but he walked the walk. On one side, he saw himself as an ocean explorer in a historical continuum with Prince Henry the Navigator of Portugal, who was active in the early 1400s. I was a bit surprised to learn that Prince Henry was somewhat like the Right Admiral Sir Joseph Porter, the Ruler of the King's Navy in *HMS Pinafore* who stuck to his desk and hardly ever went to sea. He was good at starting things, but not very good at finishing them.

So what did Roger start and leave for us to finish? It is a formidable and daunting list of challenges and observations. Global warming for one: he called himself the grandfather of the greenhouse effect and started David Keeling on measuring the buildup of CO_2 thereby enabling us to directly see man's influence on the environment. He spoke out publicly and forcefully on that issue many times. He founded a major front-ranked university, UC San Diego. He pushed for sustainable development couched in somewhat different words through studies of population, energy, and global food supplies. He influenced the future of oceanography through helping found the modern Office of Naval Research. He cared about the environment, nuclear weapons and arms control, and the world's poor and disadvantaged. And all the while, he had a special regard for young scientists and was delighted by their enquiring minds.

When I became director of Scripps in 1986, I quickly learned how much Scripps, twenty-odd years or more after Roger left, was shaped by his vision, insights, and drive. He had returned from Harvard and was teaching on the main campus, but spent time at Scripps walking around the halls and asking questions about what various researchers were doing. I approached him about returning to Scripps without disturbing his life. When he agreed, I selfishly moved him into the office next door.

He influenced the future of oceanography...

Some of the most important and deep discussions we had concerned philosophical and direct discussions on long-range strategy and policy issues.

One of the more difficult strategy issues facing Scripps around that time was what our response should be to the winding down of the Cold War. The Navy, which was a major supporter of Scripps' research, was abandoning blue water oceanography because the Soviet strategic missile submarine force was largely staying home. Further, the Navy's later shift to defense of the homeland – emphasizing coastal research – was not yet doctrine. We were seeing both sides of the equation, discussing science for policy and policy for science.

After much discussion, we agreed that taking advantage of this shift with a new focus on the environment and climate would be the most sensible strategy.

The conversation eventually converged on an atmospheric science initiative strongly linked to climate as probably holding the most promise. Roger also strongly recommended establishing our own policy group and linking the two programs.

The growing scientific consensus that the pace of climate change is exceeding the 2007 Intergovernmental Panel on Climate Change (IPCC) baseline, and that warming should be limited to 2°Celsius to avoid dangerous anthropogenic interference, has led to increased concern about avoiding tipping points where abrupt climate change kicks in. Often cited are the disappearance of the Greenland ice sheet, the dieback of the Amazon rain forest, changes in the Atlantic thermohaline circulation, and the reduction of the Hindu-Kush-Himalya-Tibetan glaciers that are the headwaters of the major Asian river systems. It has been suggested that fast-track climate mitigation strategies might help avoid the tipping points. Perhaps there is an OTSOG story here that is not yet complete.

Climate Change and Roles for Scientists

Ralph Cicerone, *President, National Academy of Sciences*
Summary of Remarks by **Ray Weiss**, *Distinguished Professor of Geophysics, Scripps Institution of Oceanography*

Roger Revelle played a pioneering role in establishing the scientific foundations for our current understanding of anthropogenic climate change, nationally, internationally, and at the National Academy of Sciences (NAS). He recognized the importance of understanding the global carbon cycle and mankind's impact on that cycle through the burning of fossil fuels.

In the 1950s, he famously brought David Keeling to Scripps Institution of Oceanography to implement one of the most important observational programs in the history of the earth sciences – the accurate measurement of the trend of atmospheric carbon dioxide that continues to this day. This work was the first to show the seasonal cycle of carbon dioxide that is driven by the photosynthesis and respiration of land plants at temperate latitudes, the globally increasing long-term trend driven by the combustion of fossil fuels, and the latitudinal gradient that results from most of this combustion occurring in the Northern Hemisphere.

At the NAS, Revelle played a major role in increasing national awareness and funding for a better understanding of climate and the global carbon cycle. In 1979, as a member of the Climate Research Board of the NAS, he helped create the report *Carbon Dioxide and Climate: A Scientific Assessment*. In 1983, he contributed to the much more extensive report, *Changing Climate*, in which he was the lead author of sections focusing on the large potential enhancement of global warming by methane liberated from clathrates in continental slope sediments as a result of global warming, and on the rise of sea-level associated with global warming.

The surface temperatures of solar system planets are controlled by the balance between the energy coming in from the sun, mainly in the form of absorbed visible light, and the energy radiated back to space, mainly in the form of invisible infrared light. For planets such as Mars, which has very little infrared absorbing atmosphere, this straightforward calculation gives a reasonably accurate answer. But for Earth, which has significant amounts of carbon dioxide, water, and other infrared-absorbing gases in its atmosphere, and Venus, which has massive amounts of carbon dioxide in its atmosphere, surface temperatures are significantly higher than the calculation predicts. This difference is the "greenhouse effect."

Current man-made emissions of carbon dioxide into the atmosphere total about 29 billion metric tons annually, a number that has increased dramatically in the century since Revelle's birth. As Keeling and Revelle at Scripps noted, roughly half of the emitted carbon dioxide remains in the atmosphere and accounts for the observed atmospheric increase. The balance is absorbed primarily by the oceans and land biota.

The United States emits about six billion metric tons of carbon dioxide into the global atmosphere annually, with petroleum and coal being the largest sources, and electricity production and transportation being the main drivers of these emissions. Globally, about 85% percent of the energy used by mankind is produced from the burning of fossil fuels. In addition to the climate effect – or radiative forcing – of carbon dioxide emissions, there is a host of other manmade emissions, principally of methane, nitrous oxide, and chlorofluorocarbons, which together add half again as much radiative forcing as carbon dioxide emissions.

This increase in radiative forcing has been manifested in a steep increase in global average temperature over the past 30 years, on the order of 0.5 or 0.6 degrees Celsius over this time period, with the greatest increases in high

Glass floats at the end of a mooring that measures levels of dissolved carbon dioxide in surface ocean waters during a deployment 250 km south of Pt. Conception.

latitudes, especially in the Arctic. Tide gauge records for the past century show a long-term rise in sea-level, with satellite measurements suggesting a recent increase in that rate to an average of 3.3 millimeters per year. Satellite measurements of the volume of ice in Greenland based on very sensitive gravity measurements, and on measurements of the elevation of the ice surface, provide strong evidence of significant net melting. Measurements of variations in solar intensity show changes of only 0.1% over the recent 30-year warming period, a factor about 10 times too small to explain the temperature observations, so that the greenhouse effect remains as the only credible explanation.

Projections of total global energy consumption into the future show continued large increases, with some stabilization of emissions from mature economies but large increases in the share attributed to transitional and emerging economies. In particular, recent projections show dramatic increases in coal-fired electric power production in China and India between now and 2030.

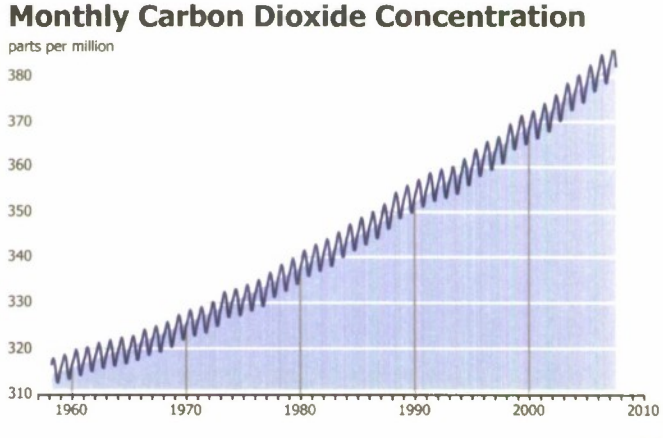
If we wanted to halt the present rise in atmospheric carbon dioxide, the current fluxes in and out of the atmosphere are such that we would have to reduce our current global man-made emissions by two thirds or three quarters of their present value. What rate of climate change is acceptable? This question is normally answered as either a rate that can be accommodated by human society and natural systems, or as a rate that avoids irreversible changes such as large losses of ice and large sea-level rises, or loss of biological species. One must either adapt or mitigate. Recent heat waves in Europe accompanied by large losses of life and projections of more extreme climate events by climate modelers cast doubt on our ability to adapt.

Mitigation, largely in the form of "geoengineering" approaches to counteract the effects of greenhouse gas emissions by means such as injecting reflective sulfate particles into the stratosphere, must be approached with caution. But even if the direct climate effects of increasing carbon dioxide could be offset by such methods, the continuing acidification of the ocean by the absorption of increased atmospheric carbon dioxide, and its significant effects on marine life including coral reefs, could not be offset without actually reducing atmospheric carbon dioxide. Research on geoengineering solutions should be rigorously peer reviewed and approached initially on small scales involving international participation.

The roles for scientists in climate change therefore ought to include the following components: discovering the problem and characterizing its fundamental phenomena; quantifying its likely future course; identifying and analyzing options; communicating with the public and its leaders; and educating a new generation about challenges associated with climate change.

To effectively perform these new roles, scientists will require greater scientific expertise from disciplinary experts, broader societal awareness, and the ability to communicate clearly to decision-makers and the general public. Revelle possessed these capabilities and applied them generously. As succeeding generations of scientists move forward, they can honor his contributions by emulating his career.

The Keeling Curve



NOAA's Vision for Climate Products and Services

Richard Spinrad, *Assistant Administrator for Oceanic & Atmospheric Research, National Oceanic and Atmospheric Administration*

More than fifty years ago, Roger Revelle wrote, "Human beings are now carrying out a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future."

In that spirit, NOAA is developing a vision for a National Climate Service. Just as Revelle focused his attention on tomorrow's climate outlook, NOAA today shares a vision of why the science community should care about climate change and how today's science leaders can further the understanding of its complicated implications. Research informs our understanding of the economic impacts of climate change, especially as related to marine transportation, fisheries, agriculture, and energy.

Climate change has implications for environmental stewardship. We need the capability to predict ecosystem impacts including ocean acidification. We also face the challenges of a changing climate in terms of NOAA's ability to manage responsibly place-based management regimes, such as the National Marine Sanctuaries System.

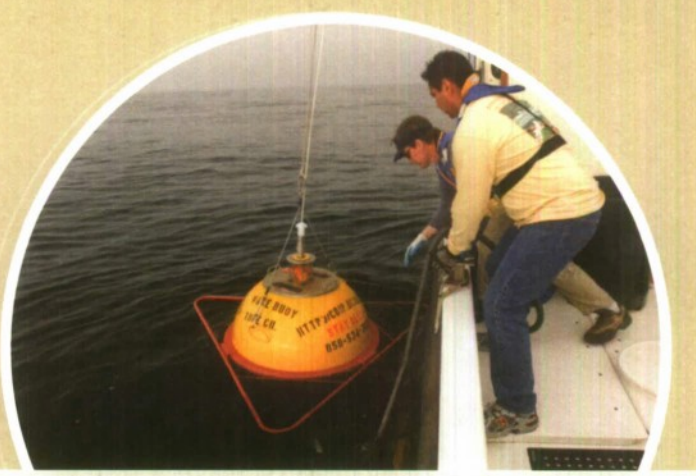
A changing climate will cause profound implications, requiring additional protection for lives and property. Increased impacts on coastal populations and infrastructure may be compounded when combined with predictions for more intense Atlantic hurricanes and sea-level rise.

There also are consequences for human health. These include the need to expand harmful algal bloom forecasts beyond the Gulf Coast of Florida; a deeper understanding of the changes on vector-borne diseases such as malaria, dengue, and avian flu; and the implications for air quality in our major cities are issues facing us right now.

National climate services are not just about research or operational capabilities, but also about policy implications, including assessments. It is important to maintain and expand observations, such as the Keeling Curve and California Cooperative Oceanic Fisheries Investigations. Today, NOAA's global climate change model projections for various emissions scenarios feed into important tools such as the assessment reports of the Intergovernmental Panel on Climate Change (IPCC). In addition, some upcoming tools will aid policy makers in evaluating and adopting climate change mitigation and adaptation strategies, including Carbon Tracker developed at NOAA's Earth System Research Laboratory, and the National Integrated Drought Information System.

The Coastal Data Information Program (CDIP), based at Scripps Institution of Oceanography, measures, models, and forecasts waves across the coastal U.S.

National climate services are not just about research or operational capabilities, but also about policy implications.



The benefits of climate products and services to the nation include enabling sound adaptation and mitigation strategies; improving preparation for and response to heat waves, drought, coastal inundation, and other phenomena; equipping policy makers and business leaders with the most accurate and credible information to guide their decisions; and stimulating private development of technologies and applications.

"Now our country must rise to a new challenge – dealing with the impacts of the changing climate. In my work on the Ocean Commissions, I heard firsthand from businesses and state and local governments about the need for better information and predictions about the impacts of climate change in communities all across this country. From concern about droughts and sea-level rise to changes in the chemistry of the ocean, there is a real hunger for more and better information. If confirmed, I will work to create a National Climate Service, which would be similar to the National Weather Service, within NOAA. NOAA is the best agency in the government to synthesize the scientific data on climate change and create products and services that can be used by the public to guide important decisions such as where to build a road or wind turbines. This idea has been studied by the agency, the National Academy of Sciences, and by members of this Committee. It is an idea whose time has come, and I would like to make it happen."

Dr. Jane Lubchenco
Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator
Senate Commerce Committee, February 12, 2009

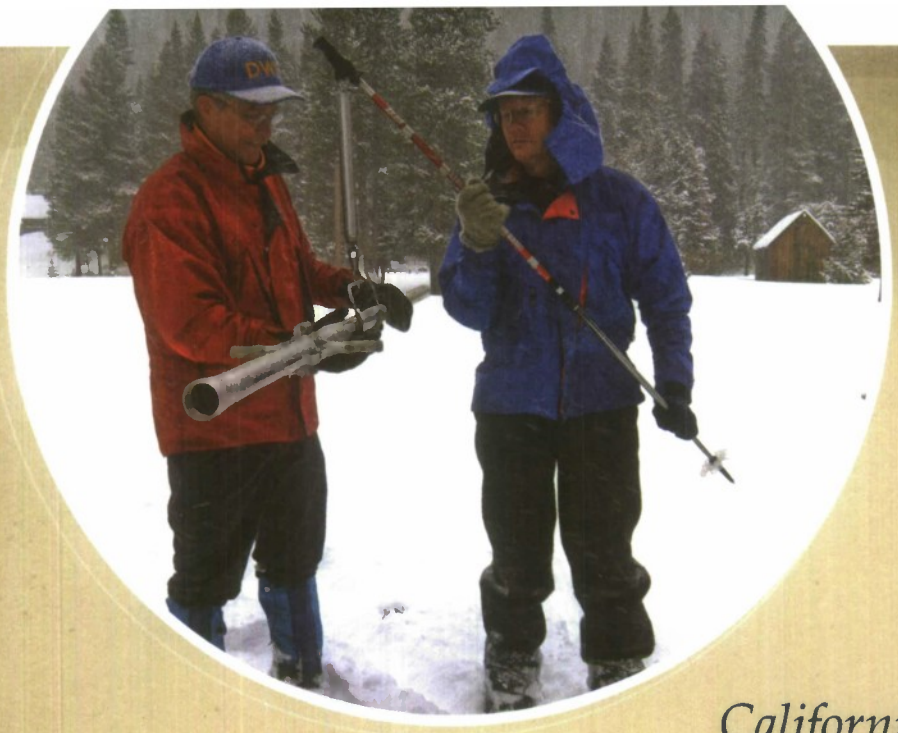
Understanding California's Vulnerability to Climate Change

Dan Cayan, *Research Meteorologist, Scripps Institution of Oceanography*

Sectors in California are becoming increasingly aware that the climate they must plan for is not the climate they have been accustomed to. A strong and growing set of evidence from the science community, keynoted by the latest Intergovernmental Panel on Climate Change (IPCC), indicates we are in the early ramp-up of climate warming and other changes.

Dr. Spinrad discussed California's vulnerability to the threats posed by sea-level rise and ocean warming due to its being a coastal state with the largest estuary along the U.S. west coast. And, since a large portion of our water supply is derived from mountain snowpacks, the effects of warming in reducing this natural storage reservoir may cascade through ecosystems, agriculture, our supply of electricity, and many other facets of the California economy. We can be quite certain that the climate will continue to change, likely at a pace that is even greater than we have been observing. Uncertainties in the climate system and uncertainties about how humans will deal with its changes underscore the need for a national climate service. But the unique set of physical features and social landscapes such as those in California will require that the climate service is distributed, rather than centralized, in order to function effectively.

Scripps has a long and continuing set of contributions to observing and understanding the climate, highlighted by the seminal work by David Keeling that demonstrated and quantified the anthropogenic increase in CO_2 in the global atmosphere. Climate researchers at Scripps are working with the California Energy Commission (CEC), Cal/EPA, the California Natural Resources Agency, and other state agencies to understand changes and possible future impacts of climate change on California's physical climate, associated ecosystems, and social-economic sectors. To help clarify gaps in knowledge that lurk in the changing climate of the next several decades, Scripps and some of its federal and state sponsors have established the California Applications Program and the California Climate Change Center, applied research programs aimed at the California climate variability and climate change issues. Scripps and its partners have targeted study areas that straddle parts of the climate-affected economic, social, and ecological sectors in the state, including water resources, wildfire, human health, and agriculture. It is also intended to learn more about how and why decision makers use climate information so that such activities can be more effective and that they might be transferred to other applications.



California has become a model for regional climate scenario assessments.

California Applications Program and California Climate Change Center

meteora.ucsd.edu/cap

California has become a model for regional climate scenario assessments, largely because California has been able to allocate the funding and assemble the expertise required to design and implement a comprehensive climate change science investigation, as instituted by Governor Schwarzenegger in his 2005 Executive Order S-3-05. The assessments have been distributed to state officials and to decision makers broadly across the state, and have provided important guidance to policy such as AB32, the California Global Warming Solutions Act of 2006. A crucial element of this process is the ongoing evaluation that was mandated in the Governor's call for a series of biennial assessments. The CEC PIER Program, Cal EPA, and the California Natural Resources Agency, among other state agencies through California's Climate Action Team, have organized the assessments, and have enlisted a set of experts from California's university, government, and NGO communities. Scripps Institution of Oceanography, through the California Climate Change Center, has played a lead role in developing the science that underpins these assessments, as well as some of the impact analysis. This process has already resulted in two scientific assessments, the first in 2006, and the latest in 2009.

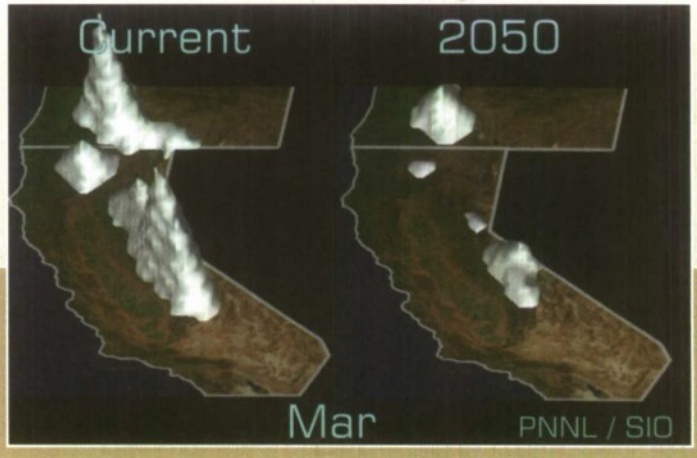
California Climate Change Scenario Assessments:

2006 ASSESSMENT

Our Changing Climate: Assessing the Risks to California
www.climatechange.ca.gov/publications/biennial_reports/index.html

2009 ASSESSMENT

DRAFT 2009 Climate Action Team Biennial Report to the Governor and Legislature, Posted April 1, 2009
www.climatechange.ca.gov/publications/cat



Challenges in Widespread, Globally Scalable, Carbon-Neutral Energy Production for Climate Stabilization

Nate Lewis, *George L. Argyros Professor of Chemistry, California Institute of Technology*

Dr. Lewis' presentation discussed various challenges in transitioning to a low-carbon energy system. The first is the availability of abundant, relatively inexpensive fossil energy.

His summary of consensus estimates of fossil energy supplies indicate that we have an abundant, relatively inexpensive global resource base if we choose to exploit it. Because of this, renewables will not, therefore, play a larger role in energy generation until they become more efficient or we change the way we think about using fossil fuels.

On the other hand, if we continue to use fossil energy at projected rates or at any comparable rate, there is no doubt that we will produce increased CO_2 levels in the atmosphere. Although we can not say for certain what effects this will bring, we can say that, unmitigated, the effects will last for a time scale comparable to modern human history. And we can say that in the past, the data shows a robust correlation between increased CO_2 concentrations and increased global temperatures. Hence we are taking a chance that we will drive our planet into a state that no human would have otherwise experienced, and in a fashion that is essentially irreversible on a human time scale. Hence the "game-changer" is whether we want to take the risk that such CO_2 emissions will be undesirable, or avoid that scenario by drastic reductions in emissions starting now.

Dr. Lewis then reviewed the options available at scale for emissions mitigation. Nuclear power is one, but providing the needed amounts of energy from nuclear power alone would require a staggering effort, involving construction of something like a nuclear power plant a day, every day, somewhere in the world, for the next 40 years. If we only built one per week, then 90% of the problem would still remain, even assuming drastic improvements in energy efficiency globally down to twice the level that it takes to eat per capita. Carbon capture and storage offers another globally scalable option, but the reservoirs can not leak at 0.1% per year for a time scale of around 1000 years to make it technically successful. No one knows now, or will know with only 10 years of data, whether this will work or not. Hence there is another risk to be taken if this route is pursued.

Finally, Dr. Lewis assessed the potential of the various renewable energy sources globally. By far the largest is solar energy, which provides more energy to the earth in one hour than all of the energy consumed on the planet in an entire year. But to make solar energy widely deployable and globally scalable, it has to be as cheap as paint or carpet, and additionally we have to find a way to store the energy to compensate for the intermittency of sunlight.

In all of these cases, R&D is needed to bridge the technology gaps between where we are today and what is needed to transition to a robust, globally scalable clean energy economy. The question is then whether we will do the needed R&D in time to mitigate the risk that will accompany increased CO_2 emissions that will otherwise result from fossil fuel consumption to provide energy to support economic prosperity and energy security for the world.

Energy, Water, and Land: Thinking Outside the Terrestrial Biomass Box

B. Greg Mitchell, *Research Biologist, Scripps Institution of Oceanography*

We must think beyond the horizon, as we shall arrive there and we had better be prepared; this was an over-arching message of Professor Nate Lewis as he conveyed the inspiring scientific, social, and political leadership underpinning of Roger Revelle's profound influence on us all.

Professor Lewis shared Roger Revelle's concern that the combination of population growth, energy use per capita, and dependence on fossil carbon energy will, collectively, lead to the acceleration of the impending threat posed by greenhouse gasses. Exploring options to provide needed growth in energy while also ensuring we pull in the reins on greenhouse gases was the focus of Prof. Lewis' tribute. Prof. Lewis challenged the symposium to consider options for energy solutions at a scale that can match the need. What is that scale? To meet growing global demand of energy and stave off massive warming, 10-30 terawatts of carbon-free energy will be required by 2050. What are the options? Many were reviewed, but the fact that 10 terawatts is equal to 10,000 new 1-gigawatt nuclear reactors is daunting - to say the least. Unfortunately, while society pursues many options, Prof. Lewis pointed out that most cannot scale up to solve the problem:

"Researching, developing, and commerciolizing corbon-free primory power technologies copoble of 10-30 terowotts by the mid-21st century could require efforts, perhops internotionol, pursued with the urgency of the Monhotton Project or the Apollo Spoce Progrom."

Ultimately, solar energy is sufficient to meet the need with a relatively small area of the earth's surface; the clarion call for solar voltaics was sounded – and should be heeded! Biomass is also a form of solar energy. However, using terrestrial biomass production rates and availability of land and fresh water, Prof. Lewis discounted biomass as a long-term solution. But should we completely discount biomass for the long-term? The requirement for more food, largely as feed for animals, continues to increase along with our energy needs. As pointed out by Prof. Lewis, terrestrial photosynthesis on arable land using fresh water falls far short of being a viable solution, but perhaps salt-tolerant algae might be an option. In the 1970s-1980s scientists at Scripps Institution of Oceanography were pioneers in the Department of Energy research programs on algal biofuels. Algae consume CO_2 during photosynthesis and yield 10-50 times more vegetable oils and protein than terrestrial crops considered by Prof. Lewis.

As Prof. Lewis stated in reference to Revelle: "Great scientists work on great problems, and have the vision to understand what those problems are before the rest of us do." There are many energy options, but for animal feed, photosynthesis is the only option. Might we then envision massive scale-up of algae on non-arable land using saline water to feed our animals the protein while achieving a sustainable "free biofuel lunch" using the residual bioenergy molecules? Together with colleagues at UCSD and regional companies, scientists at Scripps are emerging as the global leaders in research on utilizing algae for biofuel and mitigation of waste CO_2. This research is an example of over-the-horizon thinking that Professors Lewis and Revelle have encouraged us all to explore.

R/V *Roger Revelle* in the Antarctic

Innocence and War: Past and Future

VADM Paul Gaffney, USN (Ret.), *President, Monmouth University*

Roger Revelle, a globally distinguished naturalist and science administrator, enjoyed an unusual and productive relationship with the military, specifically with the Navy. He saw that science could help in his country's defense while, at the same time, military capabilities could contribute to science. That understanding is as true today as it was during World War II and the Cold War.

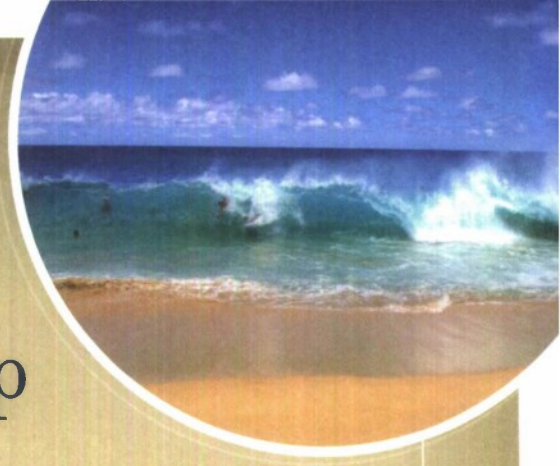
Revelle volunteered for Naval service before the U.S. entered WWII. He focused his talent on oceanographic and acoustic challenges. His contributions to anti-submarine and amphibious warfare were profound, as was the work he did with the early atomic energy "Bikini" experiments in the Pacific at the war's end. The most lasting of his science-military achievements was his role in helping start the Office of Naval Research, thereby institutionalizing the first federal support for basic and applied research in civilian universities – a practice that predates the National Science Foundation and continues today.

Building on the trust he nurtured over decades between civilian oceanographers and those naval entities that would both pay for and use civilian-based research, we can find contemporary opportunities to better understand a global phenomenon first described by Revelle in the 1960s: "climate change."

Roger Revelle, the internationalist, would clearly recognize that climate change, if its full prediction is realized, is likely to impact peoples in underdeveloped nations most harshly. They are least able to adapt to the "grinding" nature of climate change. Unrest is likely to result, migrations of increasingly desperate peoples will occur, flooding or lack of water will burden society, and disease will result. Revelle would point out that such effects lead to desperation, regional crises, and inevitable new pressures on U.S. military forces, the world's only globally-capable military today.

He also would be quick to remind us that that same globally-ranging military capability is well-suited to observe and measure climate change, especially in the oceans of our planet. In the 1990s, national security components (the Navy and the Intelligence Community) came together with civilian scientists to test this theory of cooperation. It was done without jeopardizing secrecy. It gave climate scientists whole new sets of data about the oceans and Arctic never available before.

As we reflect on Revelle's unique experience with one foot in civil science and the other foot in national security, we are urged to find new opportunities to unite the deep analytical skill and responsible theories from climate scientists with the substantial observational capabilities of the robust national security enterprise.



Revelle's Visionary Leadership

John Orcutt, *Professor of Geophysics, Scripps Institution of Oceanography*

As Paul Gaffney emphasized in his talk, Roger Revelle was a big thinker and paid little attention to the trappings of power or the perceived administrative obligations of a director.

Paul has emphasized the importance that Roger saw in collaborations between government and academia in solving major problems; at the time, this included the implications of nuclear weapons for the environment and the demands the ocean environment made on naval warfare.

Today, Roger would fully recognize the challenge of climate variability and change over the next several hundred years and the importance of Paul's appeal for a continuing relationship between government – including defense and intelligence – and academia to understand the scope of this problem and measure future efforts at mitigation. Climate and related instabilities will change the world enormously, often unpredictably, and rarely for the better.

Roger's Scripps is a unique institution in America and the world. Roger fully understood the importance of long-term stable estimates or measures of Earth's state and that the pursuit of such measurements placed enormous intellectual burdens on scientists in terms of persistence, instruments, sensors, and observations. The application of this culture to the growing modern problem of climate is essential and can draw the very best from the institution in the future.

Roger would have recognized at first glance the growing collaborations between Robert Gates' previous intelligence community, Robert Gates' present Department of Defense, and academia in addressing the coupled public policy challenges of climate, energy, and national security. Roger's knowledge of treaty negotiation would lead him to an instantaneous understanding of the importance of government and academic collaboration in the present administration's negotiation and verification of a new climate treaty to lead the U.S. and the world to a resolution of this tremendous, unprecedented challenge.

In his ability to single out the important, big picture, I suspect Revelle would find every possible way to set aside the comparative distractions of a state immersed in political, unfocused turmoil.

UC San Diego Approaching 50

Marye Anne Fox, *Chancellor, UC San Diego*

During the three-day celebration to honor the 100th birthday of Roger Revelle, many friends and colleagues noted his extraordinary scientific accomplishments: the groundbreaking research in climate and marine science that formed the basis on which we continue to discover new knowledge. Others cited Roger's extraordinary vision, hard work and determination as the founder of this great university, the University of California, San Diego. "It must be distinctive," he said, envisioning an institution with a strong and vital research focus.

Roger Revelle built UC San Diego from the ground up, starting with the recruitment of the world's top scholars, artists, innovators, and leaders to teach at the youngest University of California campus. He selected instructors who would create and advance art, technology, and science, instilling in their students a passion for innovation. An outstanding faculty is the foundation of any great institution, he said, and he was right.

In addition to identifying gifted faculty, Roger took the lead in the acquisition of land for the campus. He faced tough battles in convincing key decision makers that jet noise from the nearby Miramar military base would not be an insurmountable issue for the establishment of the new campus. In a recent presentation sponsored by the La Jolla Historical Society, former UC San Diego Chancellor and UC President Emeritus Dick Atkinson relayed a story that revealed Roger's clout and perseverance. During a particularly heated debate about the potential impact of military jet noise, Roger excused himself from the meeting, stepped outside, and placed a phone call to the head of the Miramar base. When he returned to the meeting, Revelle declared that the noise would no longer be an issue. That's the kind of man Roger Revelle was: a leader with vision and dedication whose efforts made it possible for UC San Diego to become one of the nation's most accomplished research universities.

As we approach our 50th anniversary, we are proud to take stock of our achievements in research, education, health care, and public service, and our high standing among the world's oldest and most prestigious institutions. Roger Revelle created the collaborative and interdisciplinary ethos of UC San Diego, and he initiated our tradition of excellence.

Because of Roger Revelle, UC San Diego is the world-class university it is today. His legacy remains strong today, 100 years after his birth, and nearly 50 years after the founding of this campus. We will forever be grateful for his contributions to science, and the impact he's had—and continues to have—on our students, our faculty, our community, and our world.

From left: UC President Mark Yudof, UC San Diego Chancellor Marye Anne Fox, and Scripps Director Tony Haymet.

Human Capital and the Promise of Research Universities

Mark G. Yudof, *President, University of California*

I have a deep regard for Roger Revelle and his tremendous contributions to our society. His vision – for what a research university could be and do – led directly to the success story that is UC San Diego. This campus is a shining example of how an academic institution can have a transformative impact on the economy and the innovation culture of the community around it.

UCSD was particularly fortunate to have wise leadership – in the form of Roger Revelle, Herb York, and others – in its founding years. It was also fortunate to get its start in the last great period of public investment in California, the 1960s.

An important question for today is whether, and how, we can sustain that transformative impact of public research universities in America. The declining investment in human capital, both in California and across America, is one of the biggest threats to our prosperity and competitiveness.

In California, over the last 20 years, the state's per-student investment in the education of UC students has fallen 40%, adjusting for inflation and enrollment growth. In 1970, 7% of the state budget went to the University of California; today, it is half that amount. A February report from the Information Technology and Innovation Foundation ranked the United States last, among 40 countries, in an assessment of the progress each country has made on innovation and competitiveness over the last decade. In California, we are still living off the investments made in the era of Roger Revelle, Governor Pat Brown, and UC President Clark Kerr.

Yet human capital is the core ingredient in our success as a society. Our greatest technology transfer at the University of California is our graduates, who go out into the world and apply their talent and intellect to the social, cultural, technological, and economic challenges constantly before us.

The faculty and alumni of UCSD have created at least 193 start-up companies, currently employing more than 17,000 people in California and generating more than $10 billion in annual sales. Companies that have come out of UC San Diego range from Qualcomm to biotech companies, pharmaceutical firms, surfboard makers, and even a chocolate manufacturer. The work of research universities accomplishes important things not only for the economy, but for the lives of everyday people. Scripps has an incredible impact on our understanding of climate change, environmental health, national security, and alternative energy sources.

The University of California is accountable for its use of public money and for telling the story of how we use that money to improve the lives of the public that supports us. Fortunately, there are elected officials who are already believers in the transformative value of research universities. President Obama, for one, believes that "the answers to our problems don't lie beyond our reach. They exist in our laboratories and universities... in the imaginations of our entrepreneurs and the pride of the hardest-working people on Earth."

The work of Revelle is testament to the extraordinary and lasting impact of the American research enterprise. Revelle probably could not have envisioned the tremendous transformation that would unfold from the humble beginnings of Scripps Institution of Oceanography. His reach exceeded his imaginings. It is my hope that this continues for all in higher education who are working to push outward the frontiers of discovery.

Walter Munk and Ellen Revelle at the Roger Revelle 100th Birthday Celebration in March 2009.

On Roger Revelle

Walter Munk, *Professor Emeritus, Scripps Institution of Oceanography*

There are two themes to Roger Revelle's professional life: the interaction of science with society, and, in science, the emphasis on observations.

His analytical skills were minor, as was typical of geologists of his era. He more than made up for this by a keen sense of reasoning, following the Conan Doyle tradition of eliminating one suspect after another.

He was rather bored with what some people consider the essence of administration: answering telephone calls and mail promptly (or at all), getting to meetings in time, etc. Admiral Gaffney told a delightful story of a Letter of Reprimand written to Lieutenant Junior Grade Revelle for not having returned in a timely fashion a book on Navy rules and regulations with a statement that he had read and understood them.

We have a photograph at the Institute of Geophysics and Planetary Physics (IGPP) of Roger talking to a "roughneck" about a core sample aboard the *CUSS I*. This was when we first learned to drill into the deep sea bottom. Roger is totally absorbed in his discussion with the sailor. In all his career, he was totally absorbed in whatever he was doing, often forgetting appointments with people who were (or thought they were) important.

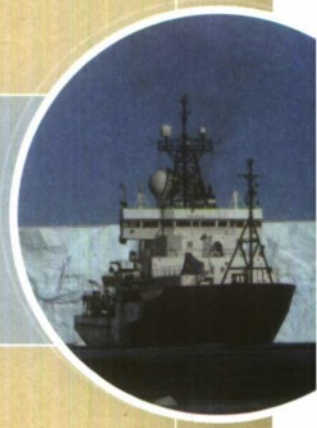
These habits (which Roger readily admitted) were responsible for delaying his appointment to the Scripps directorship by three years. And they contributed to U.C. President Kerr's decision not to appoint Roger to be the first Chancellor of UCSD. From my point of view his traits were part of what made Roger such a great leader and such a loyal friend. When I went to see the NOAA Administrator John Knauss (a former student of Roger's) at his Washington office to plead for permission for a certain acoustic transmission at sea, there was Roger sitting quietly. He was then near the end of his career, frail and managing his cane with hesitation. He had walked the endless corridors of the Department of Commerce to lend his silent support.

Roger Revelle, Willard Bascom, Gustaf Arrhenius, and Walter Munk on *CUSS I* during preliminary drilling for Project Mohole, December 1961.

Roger Revelle's Role in Developing Scripps' Fleet and the Fleet Today

Bruce Appelgate, *Director, Ship Operations, Scripps Institution of Oceanography*

Scripps operates one of the largest academic research fleets in the world, with four research vessels and the research platform FLIP. Our home port, the Chester W. Nimitz Marine Facility in Point Loma, along San Diego Bay, has evolved to be one of the nation's finest support centers for research vessels.



The vitality of the Scripps research fleet is one of Roger Revelle's enduring legacies. Scripps research ships, guided by the highly skilled crew and technicians who sail aboard them, today conduct significant and societally-relevant research on a global scale.

Roger Revelle understood the necessity of a capable oceanographic fleet, and the present strength of the Scripps fleet is a direct consequence of his philosophy and leadership. Roger relished expeditionary oceanography, and wrote, "I have often wondered why it is so pleasant to be on a small, oily, and uncomfortable ship, far from the nearest land." Despite such hardship, Roger's passion for going to sea fueled a remarkable string of discoveries that changed long-held assumptions about the deep ocean. Roger understood that better access to the deep ocean enabled new discoveries, and under Roger's leadership as director, the Scripps fleet grew to include eight research vessels.

In recognition of Roger's contributions to ocean science and service to his country (he led the Navy's Bureau of Ships and established the U.S. Office of Naval Research), one of America's most capable research vessels bears his name: R/V *Roger Revelle*, proudly operated by Scripps Institution of Oceanography.

R/V *Roger Revelle* has served as Scripps' flagship research vessel since delivery in 1996 from the Office of Naval Research. One of the most capable research vessels in the world, R/V *Roger Revelle* is 277-feet long, displaces 3,512 long tons, and carries a crew of 22 and scientific party of 37. A typical year for R/V *Roger Revelle* involves 300 days at sea, several crossings of major oceans, and port stops around the world.

Integrating Ocean Science and Policy: The Legacy of Roger Revelle

Mike Chrisman, *California Secretary for Natural Resources*

Roger Revelle was one of society's great ocean pioneers. He understood the challenges of thinking outside the box and taking risks to make progress. I am privileged to know first-hand that the scientific leadership at Scripps Institution of Oceanography has helped pave the way for marine research being conducted throughout California and throughout the world.

The State of California's relationship with Scripps dates back more than a century. In 1904, Governor George Pardee expressed his interest in the small marine research station that eventually became Scripps.

In the 1940s, the State of California partnered with Scripps and the federal government to establish the California Cooperative Oceanic Fisheries Investigations (CalCOFI) to help solve the issues associated with the sardine crash. Revelle stressed that a more comprehensive approach that considers multiple species and factors would be more beneficial than single species investigations.

California continues to fund innovative and practical projects including the Southern California Coastal Ocean Observing System (SCCOOS) and Scripps' Coastal Data Information Program (CDIP), which provides real-time wave data and predictions – a tremendous public service that plays a key role in on-the-water safety in California.

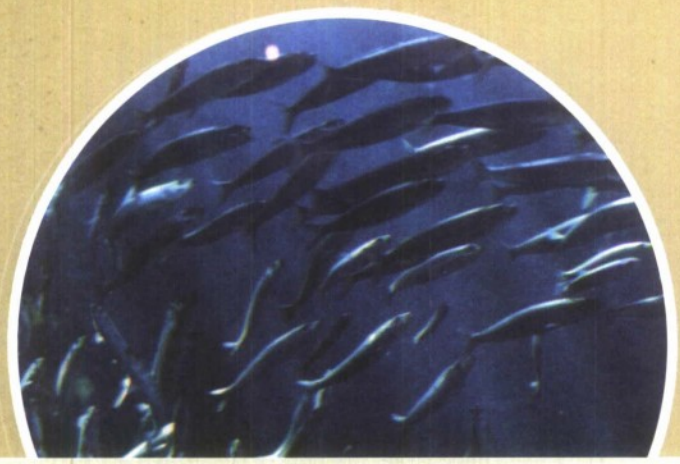
Indeed, the State of California and the leaders at Scripps agree that science should be the foundation of our ocean and coastal public policy. This is a philosophy that was cultivated by Roger Revelle.

Governor Schwarzenegger has made ocean protection and management a top priority from the beginning of his administration. In 2004 he released his 13-point Ocean Action Plan, the first comprehensive state plan in the nation to address key concerns raised by the U.S. Commission on Ocean Policy and the Pew Oceans Commission.

One action was passing the California Ocean Protection Act, which established the California Ocean Protection Council (OPC). The OPC has invested more than $30 million to support innovative projects for ocean and coastal protection and management.

Both the U.S. and the Pew Ocean commissions called for more regional approaches to ocean and coastal management. In order to enhance regional relationships, California is working with our neighbors in Oregon and Washington to ensure adequate protection and management of shared waters. In September 2006, Governor Schwarzenegger, Oregon Governor Ted Kulongoski (whose son is a Scripps graduate), and Washington Governor Chris Gregoire signed the West Coast Governors' Agreement on Ocean Health.

Governor George Pardee expressed his interest in the small marine research station that eventually became Scripps.



The California current runs off the coast of all three states and this plan will help the states address our ecosystem management concerns collaboratively, on a regional basis.

Under Governor Schwarzenegger's leadership, California is also a leader in the race to curb global warming and to protect California's economic and environmental resources. The Governor took bold action when he signed into law Assembly Bill 32, the California Global Warming Solutions Act of 2006. But adaptation and mitigation must complement each other in order to effectively tackle the challenges that a changing climate will bring, so in November 2008, Governor Schwarzenegger called for California's first statewide climate change adaptation, led by the Natural Resources Agency. Given the serious threat of sea-level rise and other climate impacts to California's water supply and coastal resources, the adaptation plan is the first comprehensive step in identifying the state's most at-risk areas.

The integration of science into our management actions is key and Revelle and Scripps have provided leadership by supplying robust scientific information to help manage our resources. Today, we build upon the relationship cultivated by Revelle, and I look forward to continuing this relationship long into the future.

In 1947, Roger Revelle said:

"The sardines cannot be treated as isolated organisms living in a vacuum... The investigation must be an integrated one in which proper weight is given not only to the currents and other aspects of the physical environment but also to the entire organic assemblage including the plants and animals which form the food chain of the sardines, their competitors for the food supply, and the predators, including man."

Scripps Research Today and Tomorrow

Tony Koslow, *CalCOFI Director, Scripps Institution of Oceanography*

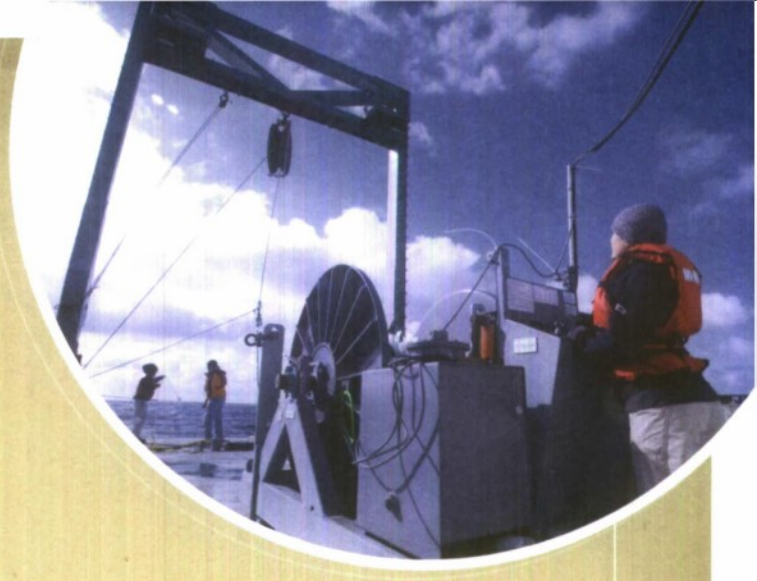
Roger Revelle was the father of climate research at Scripps Institution of Oceanography, and climate continues today as a focal point of the institution's research programs. From the outset, Revelle's vision and Scripps' climate research programs were characteristically broad and interdisciplinary, with scope ranging from the regional to the global, and combining consideration of the physical, chemical, biological, and human dimensions of the issues.

Several of the far-sighted programs that Revelle instituted, as well as his remarkable vision, continue to contribute to the science-based management of California's marine life to this day.

California's sardine fishery, once the largest fishery in the Western Hemisphere, collapsed in the decade following World War II. The cause of the collapse was unknown; in response, Revelle and others instituted the California Cooperative Oceanic Fisheries Investigations (CalCOFI) in 1949 to study sardine dynamics in relation to the species' physical and biological environment. This approach transformed fishery science from the study of species' population dynamics in isolation to the interdisciplinary science that today underlies ecosystem-based management. Sixty years on, the CalCOFI program continues to provide the scientific underpinning for the assessment of the sardine fishery (now recovered), among others.

CalCOFI data have also proven critical to ongoing climate research programs at Scripps and elsewhere, as the basis for understanding how the marine living resources off the coast of California respond to the dominant modes of climate variability in the North Pacific – the El Niño cycle, Pacific Decadal Oscillation, and North Pacific Gyre Oscillation – and to global climate warming. As California progresses toward implementing Marine Protected Areas along the coast of California, the CalCOFI data set provides an invaluable baseline to understanding how coastal populations respond to a new management regime.

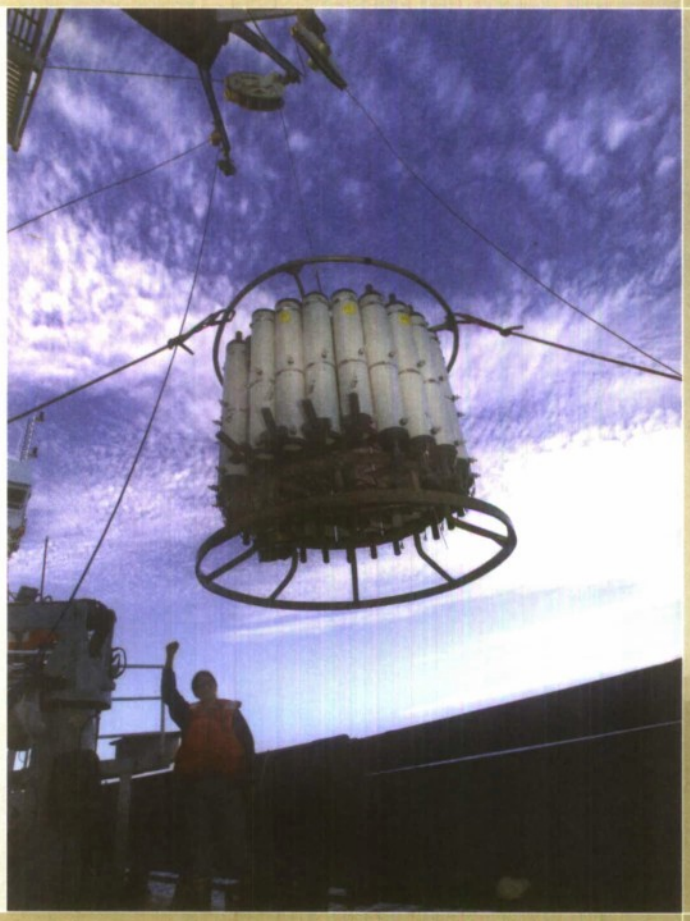
One of Revelle's greatest scientific contributions was toward understanding how seawater chemistry influences the interaction of CO_2 in the atmosphere and ocean: how CO_2 uptake by the ocean will be limited by increasing ocean acidification. Today, we find that acidification is a greater problem in the waters off the west coast of the U.S. than virtually anywhere in the world, because of the naturally low-pH, low-oxygen state of these waters. In response, Scripps recently proposed to establish a national center for the study of ocean acidification and to enhance its measurements of ocean pH and the carbon cycle in the waters off California as part of the CalCOFI



The CalCOFI data set provides an invaluable tool for understanding how coastal populations respond to a new management regime.

program. These proposals directly build on the Scripps legacy of Revelle and David Keeling, who Revelle brought to Scripps to measure the changing CO_2 levels in the atmosphere.

No one understood better than Revelle the need for science to address issues critical to human well-being. This legacy continues today in the California Applications Program (CAP) and Scripps' California Climate Change Center (CCCC). Climate change for California – and much of the southwestern U.S. – is predicted to lead to increasing drought, decreased snowpack, and increasingly restricted freshwater supplies for the region. Management of this issue – and other climate change issues – will depend on the best available scientific input. Climate studies at Scripps continue in the Revelle tradition to carry out the interdisciplinary observations, analysis, and modeling required to understand and predict the implications of climate change for California and its coastal waters.



Science for the Future and the Future of Science

Ashok Khosla, *Chair, Development Alternatives; President, Club of Rome; and President, IUCN*

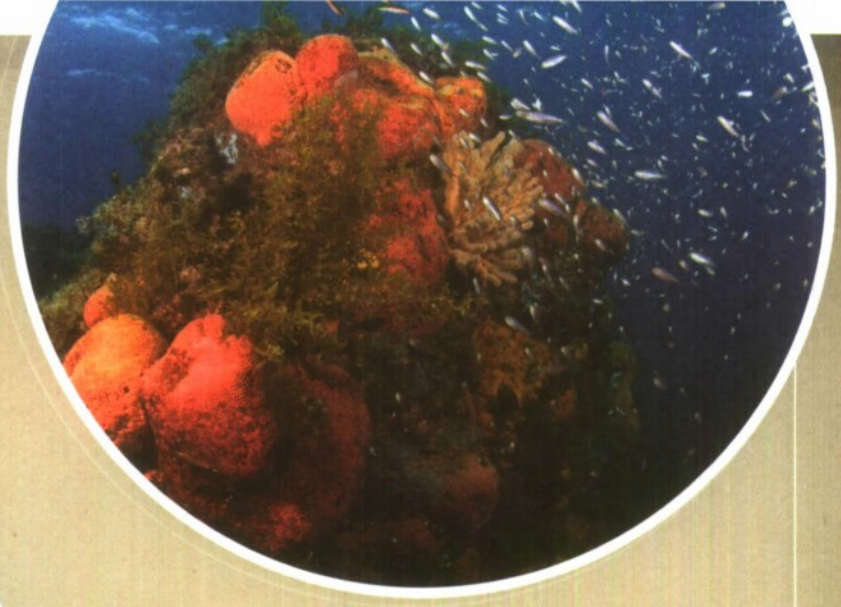
I first met Professor Roger Revelle at Harvard University in 1964, shortly after he arrived there to set up and head the Center for Population Studies. This was the beginning of a most fruitful intellectual collaboration and also a wonderful, lifelong friendship, not just with him but with his entire family.

Roger was then designing a new general studies course (Natural Sciences 118), the first in any university undergraduate program, in the emerging field of environment. Already in those early days of environmental concern, he had recognized the integral relationship between people, nature, and the quality of life – leading him to entitle the course "Population, Resources and the Environment" – some twenty years before the concepts and terminology of Sustainable Development were to enter the environmental discourse.

At the planetary level, Roger had discovered the rising concentrations of CO_2 in the atmosphere a decade earlier. More recently, as a special advisor to President Kennedy, he had seen and been deeply moved by the grinding human deprivation and massive degradation of soil and water resources in the Subcontinent. Poverty, growing populations, and threats to our life support systems were at the top of his mind – and the source of the feeling of outrage that was his spontaneous reaction to any injustice or unfairness. But Roger was not one to be daunted by problems, however big. His natural inclination was to search for root causes and find solutions that could work in the real world.

I had the privilege of helping Roger prepare the course and for several years, as one of his assistants, of teaching many of the students in smaller sections. Some of these students went on to become national and world leaders and have referred to the course as one of their life-changing experiences. The subjects Roger covered and the case studies he used constituted a remarkable intellectual tour de force, from earth sciences through biology and anthropology to social science and economics. Exploring the interplay among such a variety of issues – that were treated in conventional academics as separate and isolated – he was able to clearly and in understandable terms highlight the need for a systemic, strategic analysis of the implications of an exponentially-growing economy and population for a finite resource base – and, more importantly, vice versa.

Beyond resorting our knowledge structures and redesigning our analytical techniques to allow for such cross-sectoral studies, Roger's teaching method highlighted the fundamental role of empathy, curiosity, and quantification in good science. His case studies ranged from the lives of Bangladeshi farmers, Bombay slum dwellers, to Bostonian researchers and practitioners. They exemplified the importance of seeing the world from different perspectives in getting solutions that work and are widely acceptable. He encouraged students to formulate their own issues for study, and to demonstrate how numerical analysis and order-of-magnitude calculations could lead to useful insights and sensible decisions.



Roger's teaching method highlighted the fundamental role of empathy, curiosity, and quantification in good science.

Working with Roger was to learn to be critical of every assumption and conclusion, and to find out that empirical data, quantification, and systems analysis were the essence of good, practical science. To get useful conclusions on where our planet and civilization were headed, we must consider the whole rather than a few parts – and that this required understanding the root causes and relationships between seemingly disparate parameters. This in turn meant that good science involved lifelong learning and teaching, and had to be communicated in simple, widely-accessible terms.

When I returned to India after completing my doctorate (which was in experimental physics), Roger persuaded the then-Prime Minister, Mrs. Indira Gandhi, to appoint me as the head of the newly-constituted Office of Environment in the Government of India. For the following several years, he visited India many times and continued his mentoring, often making time for joint visits to ministers and policy makers to present initiatives that we considered to be important for better management of the nation's resources.

After 1982, when I set up Development Alternatives, a new type of organization to address social objectives through business and market oriented approaches, Roger's help in conceptualizing the mission and program of research was a major factor in making it one of the more successful "social enterprises" today. The innovation engine of Development Alternatives has succeeded in producing numerous technical and institutional solutions that have led to a direct and significant scale impact on the lives of the poor in India. His influence is obvious in our choice of mission, which is to create sustainable livelihoods and to regenerate the environmental resource base – the rivers, soils, and forests – on which the poor depend for their livelihoods and basic needs.

Today's economic and environmental crises show that the societal choices we have made in the past hundred-odd years are not likely to be sustainable. They result in too much inequity, resource destruction, and population growth. The alternative development pathways that my work in Development Alternatives, the Club of Rome, and the International Union for Conservation of Nature have led me to explore are a direct outcome of the thinking I was encouraged to pursue by Roger during the twenty-five years we worked together.

I am deeply grateful to him for that encouragement and opportunity.

Training a New Generation of Globally-Active Scientists

Phil Hastings, *Professor of Marine Biology, Curator of Marine Vertebrates, Scripps Institution of Oceanography*

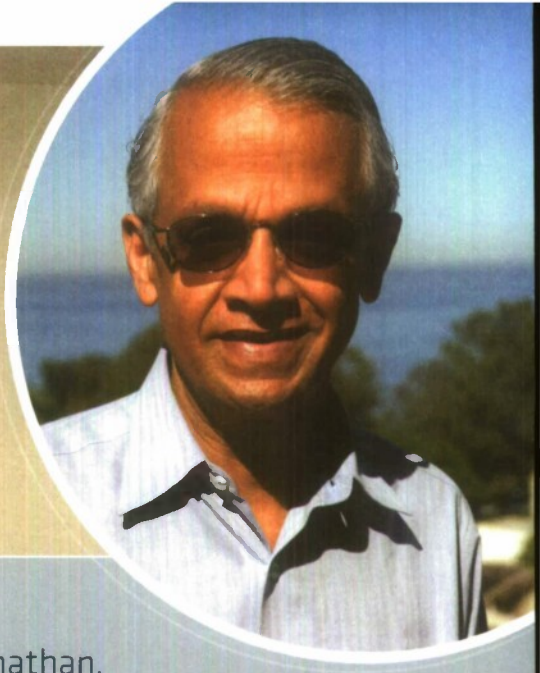
Among the many things that Ashok Khosla learned from his mentor Roger Revelle are that learning and teaching are life-long processes, that issues need to be confronted from a global perspective, that the root causes of societal problems need to be understood and illuminated, and that both quantification and communication are critical in leading to research that is both excellent and relevant.

Education and research at Scripps reflect these axioms and are nowhere more evident than in the Center for Marine Biodiversity and Conservation's (CMBC) Interdisciplinary Ph.D. Program in Global Change, Marine Ecosystems and Society. This program is founded upon excellence in studies of global change and the marine environment at Scripps, together with expertise from partners in a variety of other disciplines. By working to improve the conservation of marine biodiversity in the world's most diverse and threatened eco-regions through research, training, and global partnerships, the program's goal is to mobilize local capacity building and science-based management tools to achieve a sustainable future for the world's oceans.

Maintaining the integrity of ocean ecosystems and managing their use in the face of rapid and inevitable global change is one of the greatest challenges of this century, clearly articulated by Revelle over half a century ago. Changes in temperature, sea-level, and ocean chemistry will have enormous implications for marine biodiversity and ecosystem function, and for human exploitation of marine resources, human migration, and national security. Scientists and policy makers need to understand and quantify ongoing and potential perturbations to natural processes caused by global change and incorporate this knowledge into social policy.

Clearly, the science and conservation implications of global change demand interdisciplinary understanding, as well as the ability to work in interdisciplinary teams and to communicate effectively to a diverse array of audiences. The CMBC program seeks to address these needs by giving students the tools to understand the dimensions of global change issues affecting the oceans as well as sufficient knowledge of the intersecting fields to be effective in developing and communicating first-rate global change science and utilizing that science to design effective social policy.

This program builds on the recent National Science Foundation-funded Integrated Graduate Education and Research Training (IGERT) project at Scripps that addressed local human impacts on biodiversity. The new program shifts focus to the consequences of greenhouse gas emissions for Earth's marine ecosystems and the human economic and political systems that depend on them. Research will be centered in five thematic areas: 1) understanding the underlying causes of climate change, 2) predicting the magnitude and effects of sea-level rise, 3) elucidating the causes and effects of ocean acidification, 4) implementing agreements over the commons as they affect marine conservation, and 5) understanding and mitigating resistance to global change science and policy. Study of these thematic areas is very much in the tradition of relevant research that Revelle imparted to Ashok Khosla. They link physical and biological systems with analyses of their social and economic consequences. The goal is to train a new generation of leaders to develop wise conservation and management policies.



Scripps Climate and Atmospheric Science Professor V. Ramanathan

Project Surya

Ed Frieman, *Director Emeritus, Scripps Institution of Oceanography*

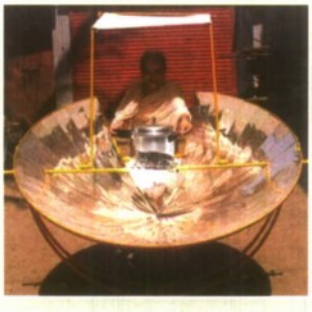
In 1990, Scripps Institution of Oceanography recruited "Ram" Ramanathan, considered to be a world leader in atmospheric sciences, thereby laying the groundwork for the institution's atmospheric thrust.

Ram is leading a program called Project Surya, which is Sanskrit for solar. It combines all the elements that Roger thought important and is also at the forefront of some of the major climate research and policy issues today.

About half the world's population cooks with fuels such as wood, dung, and charcoal, which release black carbon, methane, and ozone-producing gases. Exposure to these indoor pollutants in the poorest parts of India, China, and Africa lead to more than 1.6 million deaths each year of young women and children. Although it has long been known that CO_2 is not the only contributor to global warming, it has become clear recently that the black carbon, methane, and ozone-producing gases in air pollution may be responsible for more than a third of global heating.

Project Surya is a collaboration between Scripps, the United Nations Environment Programme, and other leading institutions in India and the U.S. to work with communities in India to enable switching to solar cookers, biogas plants, and other clean-cooking technologies to both reduce disastrous health effects as well as reduce global warming. A multidisciplinary team will measure and document the effects of the new technologies on both people and the planet.

Cell phones equipped with sensors take local measurements while NASA's "A-train" of satellites conduct remote sensing overhead. Qualcomm, one of the telecommunications industry's greatest start-up success stories, is helping Scripps on this project; the mix of science, policy, and execution is achieved by teamwork.



Project Surya is deploying its first 350 energy-efficient biofuel cookers to rural homes in the Uttar Pradesh State.

In Memoriam

Ellen Revelle (1910-2009)

"First Lady" of Scripps Institution of Oceanography, UC San Diego

Scripps Institution of Oceanography lost its beloved first lady when Ellen Revelle passed away on May 6, 2009. She was the wife of Roger Revelle, the late legendary statesman of science and founder of UC San Diego. With Ellen at his side for more than 60 years, Roger became a world-renowned scientist and is considered one of the pioneers of climate change research.

Ellen Virginia Clark Revelle was born July 31, 1910, in La Jolla, Calif. Her maternal grandfather was James E. Scripps, founder of *The Detroit News*. She was named for her great-aunt, Ellen Browning Scripps, a founder of both Scripps College and Scripps Institution of Oceanography. Ellen greatly admired her aunt Ellen and emulated her example, especially in public service and philanthropy. Ellen Revelle perpetuated the family interest in publishing and philanthropy, and acquired an interest in science through her marriage to Roger Revelle.

Ellen Revelle was a member of the first class of Scripps College (B.A. 1931) in Claremont, Calif., where she majored in psychology. She met Roger there and they married right after her graduation on June 22, 1931, and settled at the small and dusty shore station of Scripps Institution of Oceanography in La Jolla, where Roger completed his doctorate in oceanography. Like many of its young oceanographers, Roger went on active duty in the Navy during the war, and the Revelle family moved to Washington, D.C. After the war, the Revelles returned to La Jolla where Roger became director of Scripps Institution of Oceanography. In 1955 he began work to establish a general campus first known as the University of California at La Jolla, which was founded in 1960 as UC San Diego. Ellen Revelle worked closely with her husband in support of the university. The Revelles had four children, Anne, Mary Ellen, Carolyn, and William Roger.

Ellen served on the boards of many San Diego organizations and received several honors for her dedication to serving the community she loved. Her philanthropy began at Scripps Oceanography, where she and Roger donated sums to purchase oceanographic instruments that were beyond the means of the institution during the Great Depression. They supported Scripps Oceanography for more than 60 years. After Roger's death in 1991, Ellen carried on providing funds in support of the Institute of Geophysics and Planetary Physics at Scripps, which named the Revelle Building in her honor. When the Scripps Pier, which her great-aunt Ellen funded in 1912, needed to be replaced in 1986, Ellen contributed to the new Ellen Browning Scripps Memorial Pier.

Ellen christened the newest Scripps research vessel *Roger Revelle*, named in honor of her late husband in 1995, and then, at age 86, she went to sea with her daughter Mary on 10 days of its maiden voyage through the Panama Canal. Roger's major awards and prizes were numerous. One of them, his Agassiz Medal from the National Academy of Sciences, is displayed in the ship's conference room, along with his naval officer's dress sword. Both were gifts to the ship from Ellen.

Ellen and Roger were founders of the UCSD International Center, which named the Ellen Revelle Pavilion in her honor in 1986. At the dedication of the Pavilion, Roger suggested that his wife be honored as:

...a woman of character. We are honoring her for her gentle ways and her strong will, her self-effacing, modest behavior, her passionate love of justice and her generous support of many good causes.

Al Gore and the Roger Revelle Prize

The Roger Revelle Centennial Symposium concluded with a lecture by former Vice President Al Gore who was at Scripps Institution of Oceanography, UC San Diego, to accept the inaugural Roger Revelle Prize.

He was honored for his outstanding contributions in bringing the science and issues raised by environmental and climate change research to a worldwide audience.

Scripps' Roger Revelle Prize recognizes leaders in the public or private sectors whose outstanding contributions advance or promote research in ocean, climate, and earth sciences. These international leaders, like Roger Revelle, ask the big questions, recognize the interrelationships of global systems, and think on a planetary scale. Their pioneering work and their courage in pursuing scientific questions of critical importance to our world evoke Revelle's leadership and vision.

Gore credits Revelle, his Harvard professor in the 1960s, with sparking his passion for the environment.

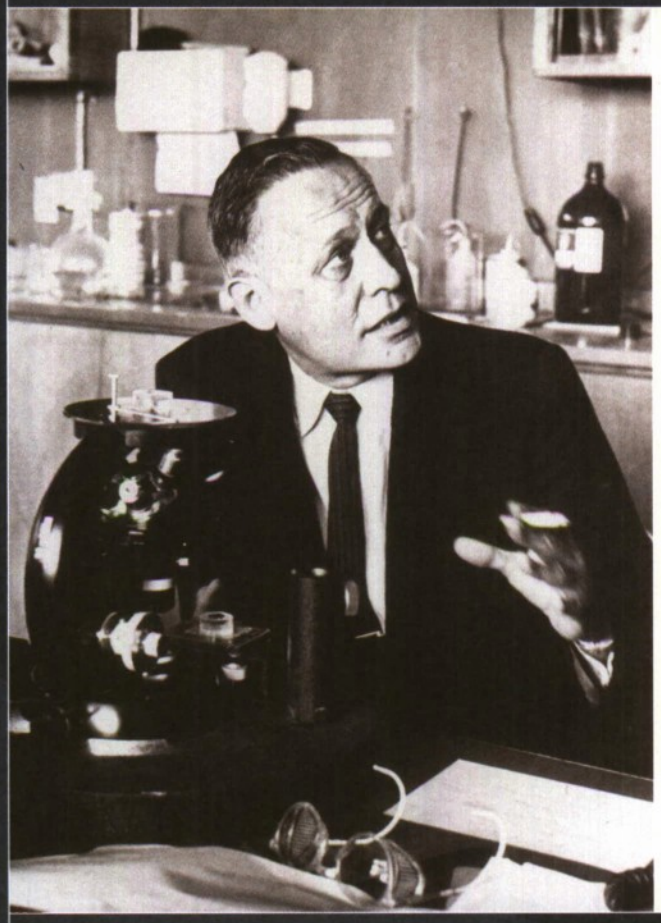
"It may be that the
OCEANS ARE THE LAST, BEST HOPE
of the earth."

—Roger Revelle

What I Learned about Roger

Charlie Kennel, *Director Emeritus, Scripps Institution of Oceanography*

I met Roger Revelle only once, but after a year as his successor as director of Scripps Institution of Oceanography, I felt as though I had known him all my life, so surrounded were we by his thoughts, sayings, and accomplishments.



About that time, I was invited to give a graduation talk at UCSD's Revelle College; the students wanted to know something about the person their undergraduate college was named for and the founder of their university. This is the gist of what I said.

I was educated during the greatest age of American science, and I got to meet many of its greatest figures; Oppenheimer, Dirac, Feynman, Gell-Mann, Hess, Oort, and many others; some were even my teachers, Eugene Wigner, Lyman Spitzer, and my Scripps predecessor, Ed Frieman. Revelle was certainly considered part of this distinguished company, but I do not believe his contemporaries thought him near the top in historical significance. But there is one very significant way in which he outstrips them all. All their accomplishments are safely in the history books, but Revelle asked mysteriously deep questions that we still struggle with today, whose answers we desperately need. I wonder how he will be ranked at the end of the 21st century, after a hundred years more of climate change.

SYMPOSIUM SPONSORS

National Oceanic and Atmospheric Administration
The National Oceanic and Atmospheric Administration conducts research and gathers data about the global oceans, atmosphere, space, and sun, and applies this knowledge to science and service that touch the lives of all Americans. NOAA warns of dangerous weather, charts our seas and skies, guides our use and protection of ocean and coastal resources, and conducts research to improve our understanding and stewardship of the environment which sustains us all. *www.nooa.gov*

National Science Foundation
The National Science Foundation (NSF), created over 50 years ago, is the premier Federal agency supporting basic research at the frontiers of discovery, across all fields, and science and engineering education at all levels. NSF invests in the best ideas generated by scientists, engineers, and educators working at the frontiers of knowledge, and across all fields of research and education. Our mission, vision, and goals are designed to maintain and strengthen the vitality of the U.S. science and engineering enterprise. *www.nsf.gov*

Office of Naval Research
The Office of Naval Research (ONR) has a history as the science and technology provider for the Department of the Navy, advancing the operational concepts and visions for the Navy and Marine Corps of the future. ONR plays a critical role in advancing scientific knowledge to support the generation of naval technology with a vision focused on future capabilities, hedging against the uncertainty of warfare. *www.onr.novy.mil*

The UC Discovery Grant
The University of California Industry-University Cooperative Research Program (IUCRP) promotes partnerships between UC researchers and California-based industries in the interest of supporting UC researchers and trainees, strengthening the state's economy, and serving the public good. *www.ucdiscoverygront.org*

UCSD-TV
UCSD-TV is a public-serving broadcast television station and website operated by University of California, San Diego. Through campus and community partnerships, UCSD-TV creates cultural, educational, and informational programs that provide viewers throughout the region access to the civic, scientific, intellectual, and artistic resources of the University. *www.ucsd.tv*

EVENT UNDERWRITERS

Proceeds from our generous sponsors and other guests have helped make the Roger Revelle 100th Birthday Celebration events possible. They also have been used to establish the Roger Revelle Leadership Fund at Scripps to help recruit and retain the most outstanding students, faculty, and researchers – an objective that was always paramount to Roger when he was Scripps' director.

The Revelle Family

Elizabeth Keadle

participant MEDIA

Anonymous
Edward A. and Joy Frieman
Audrey Geisel
Joan and Irwin Jacobs
Charles Kennel and Ellen Lehman
Stuart Goode and Leslie and Mac McQuown
George and Cynthia Mitchell
Stephen M. Strachan
Bob Yari

The Daily Transcript
San Diego's Business Daily

SCRIPPS INSTITUTION OF OCEANOGRAPHY

UNIVERSITY OF CALIFORNIA, SAN DIEGO
9500 GILMAN DR., # 0210
LA JOLLA, CA 92093-0210

NON-PROFIT ORG.
U.S. POSTAGE
PAID
SAN DIEGO, CA
PERMIT NO. 1909

SCRIPPS.UCSD.EDU
Printed on FSC Certified paper with soy inks.
09.2009