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CLIMATE CHANGE IMPACTS AND RESPONSES IN ISLAND COMMUNITIES

FIELD HEARING

BEFORE THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED TENTH CONGRESS

SECOND SESSION

MARCH 19, 2008

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

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WEDNESDAY, MARCH 19, 2008

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Honolulu, HI.

The Committee met, pursuant to notice, at 10 a.m. in room 325, Hawaii State Capitol Building, Honolulu, Hawaii, Hon. Daniel K. Inouye, Chairman of the Committee, presiding.

OPENING STATEMENT OF HON. DANIEL K. INOUYE, U.S. SENATOR FROM HAWAII

The CHAIRMAN. I'd like to thank all of you for joining us today.

Over the past year, climate change has become a topic of discussion, not only at the highest government levels, but throughout the world, and it's become a political issue.

New important research and assessments continue to be produced, which allow the public and policymakers to make more informed decisions, and engage in more meaningful discussions.

Speaking of discussions, I believe one of the most important ones was held last year at the United Nations Climate Change Conference in Bali. I considered this important enough to send some of my staff there.

This meeting, as you may be aware, established a road map to develop a new approach that will serve as the logical extension of the Kyoto Protocol.

Regardless of the causes of climate change, its effects are felt by everyone. That fact is never more apparent than for those who call this island community a home.

Islands have unique characteristics that make them especially vulnerable to climate change and variability. While our island state faces distinct challenges, it also has significant opportunities when it comes to climate change, because we're blessed with the full spectrum of renewable sources of energy. We have multiple days of sunshine, we have a healthy trade wind, most of the time, we have great, world-class waves, and geothermal hot spots, so we can decrease our dependence on fossil fuels.

Hawaii's consumers have suffered from some of the highest fuel and utility costs in the Nation. In fact, a few days ago, Maui hit the first $4 a gallon in the Nation. By producing our electricity from renewable sources locally, we keep those dollars in the state. This also means we can reduce our carbon dioxide emissions.

Clearly we possess the natural resources to lead the research, development and integration of clean, renewable energy technologies, and become a model for the rest of the Nation. We've already taken significant steps.

Locally, Honolulu is one of the more than 170 local governments participating in the Cities for Climate Protection. At the state level, Hawaii is one of only three states that have passed laws establishing mandatory, economy-wide, greenhouse gas emission limits, requiring the states or the utilities to provide 20 percent of electricity production from renewable sources by 2020.

In February, Hawaii partnered with DOE to produce 70 percent of the state's energy from renewable resources by 2030. We're the only state to create this kind of partnership, so we're ahead of the curve.

We're also addressing climate change issues beyond energy, for example, Hawaii has taken steps to lead in planning and adapting to the impacts of climate change and other natural disasters through the newly authorized National Disaster Preparedness Training Center, housed at the University of Hawai'i.

So, I look forward to the testimony of the distinguished witnesses we have assembled here, to hear more about our involvement in understanding climate issues, and how we're responding to the opportunities and challenges.

Our first witness is the Director of the Pacific Services Center, National Oceanic and Atmospheric Administration, Mr. Bill Thomas.

Mr. Thomas, welcome, sir.

STATEMENT OF BILL THOMAS, DIRECTOR, PACIFIC SERVICES CENTER, NOAA, U.S. DEPARTMENT OF COMMERCE

Mr. THOMAS. Thank you, Senator. Good morning, Senator Inouye, Members of the Committee. I'm Bill Thomas, Director of NOAA's Pacific Services Center, and I'd like to extend my sincerest *mahalo* for the opportunity to testify on the impacts of climate change on the Hawaiian Pacific Islands, and those efforts to assist the region in managing their resources in the face of this challenge.

It's well-documented in scientific literature and publicized in the media, that our changing climate will have impacts on a global scale, and as you stated earlier, island communities are particularly susceptible to climate change.

In 2007, a NOAA-sponsored Coastal Zone Visioning Session held right here, in Hawaii, identified climate change as its number one issue. In addition, at a recent meeting of all island coastal managers, every jurisdiction set climate change as their most important area of concern.

The Intergovernmental Panel on Climate Change's recently published Assessment Report, and other similar reports, have identified small island communities as particularly vulnerable to climate variability and change. The impacts highlighted in these reports include the following: sea level rise is expected to exacerbate coastal hazards, there's a projected reduction in water resources in many small islands—the Pacific and the Caribbean, alike—to the point where, by mid-century, resources may be insufficient to meet demand during low rainfall periods. Invasion of non-native species is expected to occur with rising temperatures, and other existing human influences on fisheries and marine ecosystems, such as over-fishing, habitat destruction, pollution and excess nutrients will be exacerbated.

But currently scientists and decisionmakers in the Pacific are engaged in individual and collaborative efforts to understand the nature of the climate change impacts described in the IPCC's report, and explore our options for both mitigation, and adaptation.

This shared effort involves NOAA, other Federal partners, state agencies, university scientists, community leaders, and non-governmental organizations. NOAA's Pacific Region is engaged in a number of initiatives to help our island communities both to collect atmospheric and oceanic data, and plan for, mitigate against, and adapt to climate change.

I'll now highlight a few prominent efforts, I also have a longer list in my written testimony.

Observations and data collection—NOAA is undertaking a number of critical climate programs and activities, including contributing to global and regional climate and ocean observing systems, providing operational forecasts on climate variability, and developing improved models that provide long-term projections on climate change.

In fact, NOAA's Mauna Lau Observatory has been measuring atmospheric gases for over 50 years, and the data has been instrumental in forming the basis for the theory of global atmospheric change.

On a regional scale, NOAA has developed the Pacific Climate Information System, or PaCIS, an integrated organization that brings together NOAA's regional assets, as well as those of its partners, to provide a programmatic framework to integrate ongoing and future climate observations, forecasting services and climate projections, and outreach and communications that will address the needs of American flag, and U.S.-affiliated Pacific Islands.

PaCIS will also serve as the United States contribution to the World Meteorological Organization's Regional Climate Centre for Oceania.

Risk management decision-support tools—discussions with Pacific disaster management agencies and coastal managers over the past decade have highlighted concerns about sea level rise and coastal inundation as one of the most significant climate-related issues facing our coastal communities in the Pacific.

As a result, in 2003 NOAA formed the Pacific Risk Management '*Ohana,* or PRMO, which is a network of partners and stakeholders involved in the development and delivery of risk management-related information, products and services in the Pacific.

This multi-agency, multi-organizational, multi-national group, brings together representatives from agencies, institutions and organizations involved in Pacific risk management-related projects and activities, with the overall goal of enhancing communication, coordination, and collaboration among the '*ohana* of partners and stakeholders involved in this work.

As a result of this collaboration, several ideas that emerged over the years have led to the development of decision-support and community planning tools that aid managers and the general public in better understanding risks, and in making the best possible socioeconomic decisions.

In conclusion, again, I'd like to thank you for the opportunity to appear before you today. NOAA's Pacific Region will continue to work with our island communities to develop tools, products and services, to move toward realizing NOAA's vision of an informed society that uses a comprehensive understanding of the role of the oceans, coasts, and atmosphere in the global ecosystem to make the best social and economic decisions. I'd be happy to answer any questions you may have.

[The prepared statement of Mr. Thomas follows:]

PREPARED STATEMENT OF BILL THOMAS, DIRECTOR, PACIFIC SERVICES CENTER, NOAA, U.S. DEPARTMENT OF COMMERCE

Introduction

Good morning, Senator Inouye and Members of the Committee. I am Bill Thomas, Director of the National Oceanic and Atmospheric Administration (NOAA) Pacific Services Center. I thank you for the opportunity to testify on the impacts of climate change on Hawaii and the Pacific Islands and NOAA's efforts to assist the region in managing their resources in the face of this challenge.

Over the last 50 years, researchers at NOAA's Mauna Loa Observatory (MLO) in Hawai'i have been measuring the increasing concentrations of carbon dioxide and other greenhouse gases in the Earth's atmosphere. This long-term carbon dioxide record has been instrumental in forming the basis for the theory of global atmospheric change as well as acting as a catalyst for international policies. It is now well-documented in scientific literature and publicized in the media that our changing climate will have impacts on a global scale. Today, we must now begin to understand and address the impacts of climate change in highly vulnerable locations.

Island communities, such as Hawai'i and other Pacific Islands, are particularly susceptible to climate change impacts. This was apparent to participants at a coastal zone visioning session held in Hawai'i in 2007, organized by NOAA and sponsored by its Pacific Region, where climate change was identified as the number one issue. In addition, at a recent meeting of island coastal managers, every jurisdiction cited climate change as their most important area of concern.

Changing Climate and its Impacts on Pacific Islands

The recently published Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC–AR4) has updated the projections of changing climate conditions (*i.e.,* temperature, rainfall, sea level, and extreme events) and the consequences for Pacific Islands and other small island states. IPCC–AR4 confirms the vulnerabilities identified in the 2001 Pacific Islands regional assessment and provides insights into then less widely understood climate-related challenges such as ocean acidification.

The IPCC–AR4 and similar climate assessment reports identify small island communities like those in the Pacific as particularly vulnerable to climate variability and change. There are similar threads regarding small island impacts that run through such reports including:

- Deterioration of coastal conditions is expected to affect local resources and reduce their value as tourist destinations (*e.g.,* the combined effect of increased ocean temperatures and ocean acidification on coral reef resources).
- Sea level rise is expected to exacerbate coastal hazards such as inundation, storm surge and erosion as well as reduction of freshwater availability due to saltwater intrusion, especially in low-lying islands.
- Climate change is projected to reduce water resources in many small islands (Pacific and Caribbean) to the point where, by mid-century, resources may be insufficient to meet demand during low rainfall periods.
- Invasion of non-native species is expected to occur with rising temperatures.
- Climate change will exacerbate other existing human influences on fisheries and marine ecosystems such as over-fishing, habitat destruction, pollution, and excess nutrients.

NOAA in the Pacific Islands: Developing Capacity to Deal with Climate Change

NOAA's Pacific Region is a hallmark of an integrated approach to problem-solving.

The Pacific Risk Management 'Ohana (PRiMO)

The Pacific Risk Management *'Ohana* (PRiMO) is a network of partners and stakeholders involved in the development and delivery of risk management-related information, products, and services in the Pacific and is led by the NOAA Pacific Services Center. Established in 2003, this multi-agency, multi-organizational, multinational group brings together representatives from agencies, institutions, and organizations involved in Pacific risk management-related projects and activities with the overall goal of enhancing communication, coordination, and collaboration among the *'ohana* of partners and stakeholders involved in this work. As a result of this collaboration, several ideas that emerged over the years have led to the development of decision-support and community planning tools that aid a cross section from managers to the general public in better understanding risks and in making the best possible socio-economic decisions. Examples of these collaborations include:

Decision Support Tools

- Hazard Assessment Tools (HATs) have been developed in partnership with NOAA's Pacific Region, local governments in American Samoa, Guam, and Hawai'i (County of Kaua'i). These tools use Geographic Information Systems (GIS) maps to integrate hazard risk information, such as sea level rise projections, along with local information on infrastructure, natural resources, and administrative boundaries to improve both short and long term decisionmaking.
- The Hazard Education and Awareness Tool (HEAT) is a template which allows any organization the ability to create a simple website which provides public access to local hazard maps for their community. Additional information on appropriate response and preparedness actions are also included.
- Nonpoint Source Pollution and Erosion Comparison Tool (N–SPECT) is a decision support tool which allows coastal managers to compare potential water quality impacts of land cover change that may occur from changes in climate.

Data

- The Coastal Change Analysis Program (C–CAP) is a nationally standardized database of land cover and land change information, developed using remotely sensed imagery, for the coastal regions of the U.S. C–CAP products inventory coastal intertidal areas, wetlands, and adjacent uplands with the goal of monitoring these habitats by updating the land cover maps every 5 years. Its primary objective is to improve scientific understanding of the linkages between coastal wetland habitats, adjacent uplands, and living marine resources. Land cover data from C–CAP has been developed for Hawai'i from satellite images acquired in both 2000 and 2005. High resolution elevation data for Hawai'i was collected in 2005 using Interferometric Synthetic Aperture Radar (IFSAR). This elevation data provides resource managers with the highest resolution elevation data currently available for Hawai'i. This data is invaluable for determining potential impacts of changes in climate, such as sea level rise, in areas where higher resolution data may not be available.

Community Planning Tools

- The Coastal Community Resilience (CCR) Guide presents a framework for assessing resilience of communities to coastal hazards. The work was the result of a partnership funded through the Indian Ocean Tsunami Warning System Program and is being piloted for application in Hawai'i. The framework, developed in concert with over 140 international partners, encourages integration of coastal resource management, community development, and disaster management for enhancing resilience to hazards, including those that may occur as a result of climate change.

The Pacific Enso Application Center (PEAC)

Pacific Island communities continually deal with dramatic seasonal and year-to-year changes in rainfall, temperature, water levels and tropical cyclone patterns associated with the El Niño-Southern Oscillation (ENSO) cycle in the Pacific. This dynamic system involving the Pacific Ocean and the atmosphere above it can bring droughts, floods, landslides, and changes in exposure to tropical storms. Fourteen years ago, NOAA joined forces with the University of Hawai'i, the University of Guam, and the Pacific Basin Development Council to begin a small research pilot project designed to develop, deliver, and use forecasts of El Niño-based changes in temperature, rainfall, and storms to support decisionmaking in the American Flag and U.S.-Affiliated Pacific Islands. That pilot project—the Pacific ENSO Applications Center (PEAC)—continues its work today as part of the operational National

Weather Service programs in the Pacific. The PEAC experience has demonstrated the practical value of climate information for water resource management, disaster management, coastal resource planning, agriculture, and public health.

The Pacific Climate Information System (PaCIS)

The experience gained from PEAC has helped inform the emergence of a comprehensive Pacific Climate Information System (PaCIS). As an integrated organization that brings together NOAA's regional assets as well as those of its partners, PaCIS provides, on a regional scale, a programmatic framework to integrate ongoing and future climate observations, operational forecasting services, and climate projections, research, assessment, data management, communication, outreach and education that will address the needs of American Flag and U.S.-Affiliated Pacific Islands. Within this structure, PaCIS will also serve as a United States' contribution to the World Meteorological Organization's Regional Climate Centre for Oceania and represents the first integrated, regional climate service in the context of emerging planning for a National Climate Service.

Scientists and decision-makers in Pacific Island communities are now engaged in individual and collaborative efforts to understand the nature of the climate change impacts described in IPCC–AR4 and explore our options for both mitigation and adaptation. This shared effort involves NOAA, other Federal programs, state agencies, university scientists, community leaders and nongovernmental organizations. Together they are bringing their unique insights and capabilities to bear on a number of critical climate programs and activities including: contributions to global and regional climate and ocean observing systems; operational forecasts of seasonal-to-interannual climate variability; development and analysis of improved models that provide long-term projections of climate change; multi-disciplinary assessments of climate vulnerability, climate data stewardship, the development of new products and services to support adaptation and mitigation in the Pacific, and education and outreach programs to increase the climate (and environmental literacy) of Pacific Island communities, governments, and businesses. One of the newest activities involves a summary of the most recently published work on climate change and vulnerability in key sectors such as agriculture, water resources, and coastal infrastructure in the context of a Pacific regional contribution to a new Unified Synthesis Report of the U.S. Climate Change Science Program. This work is being supported and led by NOAA through its Integrated Data and Environmental Applications (NOAA IDEA) Center in Honolulu. While led by the NOAA IDEA Center, the full range of regional assets of NOAA in the Pacific are being brought to bear on this critical issue.

Future planning for a number of climate programs in the Pacific will be organized in the context of PaCIS including building upon the PEAC, the Pacific Islands Regional Integrated Science and Assessment (Pacific RISA) program and other related climate activities in the region. In addition to meeting the specific needs of U.S. affiliated jurisdictions in the Pacific, PaCIS will also provide a venue in which to discuss the role of U.S. contributions to other climate-related activities in the Pacific including, for example, observing system programs in the region, such as the Pacific Islands Global Climate Observing System (PI–GCOS) and the Pacific Islands Global Ocean Observing System (PI–GOOS), as part of an integrated climate information system.

In order to further define the roles and capabilities of PaCIS, a steering committee has been selected incorporating PEAC, the Pacific RISA, PI–GCOS, U.S. National Weather Service Operations Service and Climate Services Division, and their partners, as well as experts and users of climate science and applications in the region. The PaCIS Steering Committee, made up of representatives of institutions and programs working in the fields of climate observations, science, assessment, and services in the Pacific, as well as selected individuals with expertise in similar regional climate science and service programs in other regions, will provide a forum for sharing knowledge and experience and guide the development and implementation of this integrated, regional climate information program.

The Pacific Region Integrated Coastal Climatology Program (PRICIP)

Discussions with Pacific disaster management agencies and coastal managers over the past decade have highlighted concerns about sea level rise and coastal inundation as one of the most significant climate-related issues facing coastal communities in the Pacific. In light of this need, NOAA, through its IDEA Center with support from the Pacific Services Center and working with colleagues throughout NOAA, the U.S. Army Corps of Engineers, U.S. Geological Survey and university scientists in Hawaii, Guam, Alaska, and Oregon, initiated the Pacific Region Integrated Coastal Climatology Program (PRICIP). PRICIP recognizes that coastal storms and the strong winds, heavy rains, and high seas that accompany them pose a threat to the lives and livelihoods of the people of the Pacific. To reduce their vulnerability, decision-makers in Pacific Island governments, communities, and businesses need timely access to accurate information that affords them an opportunity to plan and respond accordingly. The PRICIP project is helping to improve our understanding of patterns and trends of storm frequency and intensity within the Pacific Region and develop a suite of integrated information products that can be used by emergency managers, mitigation planners, government agencies, and decision-makers in key sectors including water and natural resource management, agriculture, fisheries, transportation, communications, recreation, and tourism.

As part of the initial build-out, a PRICIP web portal is serving a set of historical storm "event anatomies." These event anatomies include a summary of sector-specific socio-economic impacts associated with a particular extreme event as well as its historical context climatologically. The intent is to convey the impacts associated with extreme events and the causes of them in a way that enables users to easily understand them. The event anatomies are also intended to familiarize users with *in situ* and remotely-sensed products typically employed to track and forecast weather and climate.

Hawaiian Archipelagic Marine Ecosystem Research (HAMER)

The Hawaiian Archipelagic Marine Ecosystem Research Plan (HAMER) is a collaborative planning process to develop sustainable conservation and management throughout Hawai'i's marine ecosystem through improved understanding of the unique physical and biological attributes of the Hawaiian archipelagic marine ecosystem, their interconnected dynamics, and their interactions with human beings. By using Hawai'i as a large-scale archipelagic laboratory for the investigation of biophysical processes, comparing the protected Northwestern Hawaiian Islands to the heavily used Main Hawaiian Islands and integrating socioeconomic information, Hawai'i and comparable marine ecosystems worldwide should realize improvements in resource management and community response to changes in climate.

While this project is in its formative stages, the information generated by this projected 10-year multi-agency, collaborative program will:

- Fill critical and important research gaps in the underlying science of marine ecosystem dynamics.
- Complement national, international, and state ecosystem research initiatives.
- Improve understanding of the behavior of humans in a marine ecosystem approach to conservation and management.
- Formulate predictive theory of ecosystem dynamics relative to physical and biological variables, and
- Generate useful information for conservation managers.

Conclusion

NOAA's Pacific Region is engaged in a number of ways to help the Pacific Islands plan for, mitigate against, and adapt to climate change. This is not an exhaustive list. I have highlighted efforts that are most prominent at this time. The development of NOAA's products and services as they relate to climate change is as dynamic as the issue itself.

NOAA's Pacific Region will continue to work with our island communities to develop tools, products, and services to move toward realizing NOAA's vision of, "An informed society that uses a comprehensive understanding of the role of the oceans, coasts and atmosphere in the global ecosystem to make the best social and economic decisions."

Thank you for the opportunity to appear before you today.

The CHAIRMAN. I thank you very much, Mr. Thomas.

Next witness is the Director of the Hawai'i Institute of Marine Biology, Dr. Jo-Ann Leong.

Dr. Leong?

STATEMENT OF JO-ANN C. LEONG, PH.D., DIRECTOR, HAWAI'I INSTITUTE OF MARINE BIOLOGY, SCHOOL OF OCEAN AND EARTH SCIENCE AND TECHNOLOGY, UNIVERSITY OF HAWAI'I AT MĀNOA

Dr. LEONG. Thank you.

Good morning, Senator, and Members of the Committee. Thank you for the opportunity to speak before you on the impacts of climate change on Hawaii's species at the level of coral resilience and resistance to invasive species.

Again, my name is Jo-Ann Leong, and I serve as Director of the Hawai'i Institute of Marine Biology and I represent a group of scientists whose major research effort includes a study of coral reef ecosystems.

We also provide research for the new Papahānaumokuākea Marine National Monument through an MOA with the Pacific Island Regional Sanctuary Office.

One of the fundamental questions being addressed by HIMB researchers for the Monument is, what factors are important in coral reef resilience? In particular, we are examining the role of biological connectivity in reef restoration, and the role of genetic and species diversity in the ability of reefs to bounce back after a disturbance.

In today's testimony I would like to focus on the following points: One, thermal stress and bleaching, coral disease and ocean acidification are real threats to the coral reef ecosystem in Hawaii, and particularly, in the Northwestern Hawaiian Islands.

Two, genetic analysis, coupled with spatial and physical measurements are needed to tell us about the role of genetic diversity and coral resistance to temperature stress.

Three, biological connectivity studies indicate that we need to manage coral reefs as individual units, and not as a single chain of islands and atolls. Our studies show that these islands and atolls may not be biologically connected, and therefore capable of replenishing each other, should one member of the chain experience a stress event. And I'll get back to that.

Now, recommendations for controlling the spread of invasive species have been developed for the Northwestern Hawaiian Islands, and I've provided copies for the Committee, in the back. And genetic technologies are useful in identifying the origin of invasive species to truly find out whether they're really invasive, or that the ecosystem has changed, and an epedemic has now begun to take over.

Ocean acidification will affect the crustose coralline algae, as well as the stony corals, and that may have an even more dramatic effect on the future of coral reefs.

Now, I offer these points in the context of what Hawaii can offer to this study. We have a Hawaiian archipelago, the largest living coral reef ecosystem in the United States. It stretches over a distance of 1,500-plus miles, with 132 islands and atolls, reefs, shallow banks, shoals and sea mounts. This lovely set of islands, from Kure Atoll in the Northwest, to the Big Island of Oahu in the Southeast, offers natural gradients in island evolution, and now, temperature regimes; and a gradient of anthropogenic stressors with dense human populations in the South, to the relatively pristine environment in the Northwestern Hawaiian Islands. This makes Hawaii a natural laboratory to study the effects of climate change on global coral reefs, and in that process, develop recommendations to protect those reefs. It really is our responsibility, sir.

I have provided written testimony that far exceeds the amount of time I have before you today, so let me point out five findings that have bearing on our discussion.

The role of species diversity at both the organismal and genetic level in reef resilience has not been determined.

We assume from other ecological studies that redundancy in an ecosystem function offered by high species diversity will also work in a coral reef ecosystem. So, that if one goes out, you will have another to take its place. We are just beginning to conduct those studies, here in Hawaii. Scientists have finally put temperature monitors across a reef—so we've wired a reef—and sampled every coral in that reef, so that we know what the genotype of that coral is.

So, what we found is that in a reef there are hot spots, and there are cool spots. So, the patchiness of a bleaching may be due to those physical change dynamics.

The genotype and the symbiont in those corals are just being determined now, and I hope to be able to give you an update and a briefing in another 6 to 9 months.

The incidents of coral disease appears to be increasing in Hawaii. At least 17 coral diseases have been described. Experience with bleached corals in other parts of the world indicates that we will see more disease among our corals, because we've already had three episodes of bleaching in Hawaii.

The immunologic agents for these diseases have not been determined. Hawaii, and the Pacific Region, needs a safe facility for conducting studies that might identify these agents, and provide some methods for treating disease. We can not work on that—and we will not work on that—unless those safe facilities are available.

Invasive species come in many forms, that's point number three, and it is the small ones that usually escape our eye. This is the case for micro-algal symbiont for corals. I have highlighted a study in my written testimony from Ruth Gates and Michael State at HIMB. They have identified a genotype of zooxanthellae which is the micro-algae in the coral, it's a symbiont and it belongs to what we call clade A. And clade A is a genotype you normally don't find in the Pacific. It is found in a jellyfish called cassiopeia, which is a foreign introduction into Hawaii, from the Caribbean.

And what we found is that, we found this clade A in corals in the Northwestern Hawaiian Islands at French Frigate Shoals. And there was a high correlation with this Clade A in these corals, and disease susceptibility. So, we have to be careful at that level, about the introduction of invasive species.

Now, please note that we have provided the Committee with 20 copies of a plan for monitoring invasive species, and I've also provided these little booklets, or little cards, which contain coral diseases for the rest of the Committee. And they're provided from the Department of Aquatic Resources.

You need to tell me if I'm going over time.

Biological connectivity is one of the key factors that are used in the designs of marine protected areas. We work in the largest marine protected area in the United States, and we don't know whether this MPA can provide the protection to preserve these marine resources.

Rod Toonen and Brian Bowen have been tracking the movement of the larvae of fish and invertebrates to ask when—are any of these atolls and islands can serve to replenish a neighboring island or system. We have found the answers to that question differs greatly among species, and that no one species can represent any other species in that taxa.

So, I was going to refer you to my written testimony, which is showing on Figure 2. And in this it shows you blocks—yellow blocks—in the archipelago. And those yellow blocks identify barriers to gene flow exchange between one system and another system. That tells you that you have to be very careful in developing management of any ecosystem, because there might not be enough gene flow to replenish a system from another system that is protected in that area. And you need to know that information.

OK, ocean acidification will affect Hawaii, on its northern end first. Some of the key studies on the effect of pH on calcification rates was done in Hawaii. One of the most interesting findings that has just emerged, is that ocean acidification will affect the crustose coralline algae. The coral reef glue that holds reef together, and provides the cues for the settlement of coral larvae on the reef.

This is a critical finding, and we need to identify the effects of slight changes in pH on other marine calcifiers.

To end this testimony, I ask the Committee to carefully consider the recommendations on page 16 [of this transcript], for critical research needs. I made a plea for the need for facilities to conduct studies on coral disease with native and non-regional corals of the Coral Conservation Program workshop last year.

We also need, in the Pacific Region, sites where research will be able to conduct experiments on coral reef misocosms that can be replicated under controlled, measurable conditions. This is not available to anyone, anywhere.

And, thank you again for this opportunity, Senator Inouye, and Members of the Committee, and I'm willing to take questions.

[The prepared statement of Dr. Leong follows:]

PREPARED STATEMENT OF JO-ANN C. LEONG, PH.D., DIRECTOR, HAWAI'I INSTITUTE OF MARINE BIOLOGY, SCHOOL OF OCEAN AND EARTH SCIENCE AND TECHNOLOGY, UNIVERSITY OF HAWAI'I AT MĀNOA

Introduction

Good morning Senator Inouye and members of the Committee. Thank you for the opportunity to speak before you on the impacts of climate change on Hawai'i's myriad ocean species at the level of coral reef resilience and resistance to invasive species. My name is Jo-Ann Leong and I serve as Director of the Hawai'i Institute of Marine Biology. I represent a group of scientists whose major research effort includes the study of coral reef ecosystems and the biological connectivity between the islands and atolls of the Hawaiian Archipelago. We have a memorandum of agreement with the NOAA Pacific Regional Sanctuary office to provide research for the new Papahanaumokuakea Marine National Monument.

Current models for sea surface temperature (SST) and seawater CO_2 saturation in the coming decades suggest that the Hawaiian Archipelago will experience rises in sea levels, increased episodes of coral bleaching, and decreased aragonite saturation in its ocean waters (Guinotte, Buddemeier, Kleypas 2003; IPCC, 2007 working group I report; E. Shea, Preparing for a Changing Climate, 2001). Higher sea surface temperatures produced severe bleaching events in the main Hawaiian Islands in 1996 and in the Northwestern Hawaiian Islands (NWHI) in 2002 and 2004. Climate experts are virtually certain that more episodes of coral bleaching are in store for Hawai'i. Moreover, by 2049, ocean acidification is expected to have a marked effect in the waters surrounding Kure and Midway Atolls. These climate changes will have an impact on the marine resources of the Hawaiian Archipelago.

One of the fundamental questions being addressed by the research at HIMB is what factors are important in coral reef resilience. In particular, we are examining the role of biological connectivity in reef restoration and the role of genetic and species diversity in the ability of reefs to bounce back after a disturbance. In today's testimony, I would like to focus the following points:

1. Thermal stress and bleaching, coral disease, and ocean acidification are real threats to the coral reef ecosystem in Hawai'i and particularly in the NWHI.
2. Genetic analysis coupled with spatial and physical measurements are needed to tell us about the role of genetic diversity in coral resistance to temperature stress.
3. Biological connectivity studies indicate that we need to manage coral reefs as individual units and not as a single chain of islands and atolls. Our studies show that these islands and atolls are not biologically connected and therefore capable of replenishing each other should one member of the chain experience a stress event.
4. Recommendations for controlling the spread of invasive species have been developed for the NWHI and genetic technologies are useful in identifying the origin of invasive species.
5. Ocean acidification will affect the crustose coralline algae as well as the stony corals and that may have an even more dramatic effect on the future of coral reefs.

Coral Bleaching Events in Hawai'i

Although coral bleaching due to high temperature was first described in Hawai'i by Jokiel and Coles (1974) off Kahe Point (O'ahu) electric generating station, the isolated subtropical location of Hawai'i was thought to be sufficient to protect its corals from the bleaching outbreaks that have ravaged coral communities elsewhere. However, in the late summer of 1996, the first large-scale bleaching event in the main Hawaiian Islands occurred (Jokiel & Brown, 2004) and another major bleaching event occurred in the Northwestern Hawaiian Islands (NWHI) in the Summer of 2002 (Brainard, 2002; Aeby *et al.,* 2003). In September 2004, a third Hawaiian coral bleaching event occurred at the three northern atolls (Pearl and Hermes, Midway, Kure) (Kenyon & Brainard, 2005). Clearly, Hawai'i is not immune to large scale coral bleaching events.

Mean summer monthly temperatures in Hawaiian waters are approximately 27 ± 1 °C. A 30-day exposure to temperatures of only 29–30 °C will cause extensive bleaching in Hawaiian corals (Jokiel & Coles, 1990). Combined with high irradiance (clear days) and low winds, water temperatures can be 1–2 °C higher in certain coastal regions. The "degree heating weeks" (DHW) (1 week of SSTs greater than the maximum in the monthly climatology) over a rolling 12 week period now serves as an indicator of the likelihood of bleaching. Whether the single factor of temperature increase is sufficient to predict coral bleaching is unclear since hind sight analysis of SST data note the absence of bleaching reports in Hawai'i when SST data indicated that there should have been bleaching in 1968 and 1974. Nevertheless, DHW is used by NOAA's Coral Reef Watch program because it gives a first alert to investigators and the public of possible coral bleaching events.

Hawai'i's coral reefs did recover from the bleaching. During the 1996 episode on O'ahu, the corals were closely monitored for recovery in Kāne'ohe Bay. A month after the height of the bleaching episode, the slightly bleached corals regained pigmentation, and 2 months later, the completely bleached corals had recovered. Overall coral mortality during the event was less than 2 percent. The rate of recovery was related to bleaching sensitivity, *i.e.,* the first corals to bleach were the last to recover. Most of the bleached corals at Kure, Midway and Pearl and Hermes involved in the September 2002 event also recovered by December 2002 except for the *Montipora capitata.* Estimates of 30 percent of the montiporids did not recover from this bleaching event in the back reef sections of Midway, Pearl and Hermes Atolls (Kenyon and Brainard, 2006).

A comparison of the sensitivity of different corals to bleaching is shown in Table 1. In general, the montiporid and pocilloporid corals were sensitive to thermal stress and the poritid corals were more resistant. But even these more sensitive corals have resistant members in a bleaching event and scientists are beginning to focus on these coral "survivors" for answers to the question of whether coral reefs will survive to 2100. The first question asked by Steve Karl, a researcher at HIMB, was whether the temperature gradients across a reef were uniform. Thus, if corals responded to thermal stress by bleaching, then perhaps those corals that did not bleach were those corals that inhabited cool spots on the reef. A careful study with miniature temperature monitors placed at 4 M intervals throughout a reef has shown that there are hot spots and cool spots within a reef and this may account for the patchiness of coral bleaching. In addition, Steve and his group have mapped every single coral in the reef and the genotype for each coral is being determined. The question being addressed is whether the corals are genetically distinct (produced by sexual reproduction) or clonally derived (produced by breakage and regrowth from a parent colony). This research may provide some answers regarding the role of genotype in thermal resistance. Steve's study is being carried out at Kāne'ohe Bay, French Frigate Shoals, and Pearl & Hermes Atoll. In addition to the genotype analysis, Steve is working with HIMB researcher Ruth Gates to determine if there are differences in the zooxanthellae symbiont type in the resistant and sensitive corals. Symbiont type has been identified as a key factor in resistance to thermal stress in corals (Baker, 2004; Little, van Oppen, & Willis, 2004; Berkelmans and van Oppen, 2006; Middlebrook, Hoegh-Guldberg, and Leggat, 2008)).

Table 1. Relative Resistance of Corals to Bleaching in Hawai'i

Kāne'ohe Bay 1996	NWHI 2002, 2004
Highly Resistance	
Porites evermanni *Cyphastrea ocellina* *Fungia scutaria* *Porites brighami*	*Porites compressa* *Porites lobata* *Montipora flabellata*
Moderate Resistance	
Porites compressa *Porites lobata* *Montipora patula* *Montipora capitata*	*Porites evermanni* (Maro, Laysan, Lisianski) *Montipora patula* (Maro, Laysan, Lisianski)
Low resistance (most sensitive to bleaching)	
 Montipora flabellata *Pocillopora meandrina* *Pocillopora damicornis* *Montipora dilitata.*	*Montipora turgescens* *Montipora patula* *Montipora capitata* *Pocillopora damicornis* *Pocillopora ligulata* *Pocillopora meandrina*

Compiled from Jokiel & Brown, 2004; Aeby, Kenyon, Maragos, and Potts, 2003; Kenyon and Brainard, 2006.

Coral Disease in Hawai'i

Coral diseases have emerged as a serious threat to coral reefs worldwide and Hawai'i has its own set of coral diseases. There are at least 17 described coral diseases in Hawai'i (Work & Rameyer 2001; Work *et al.,* 2002; Aeby, 2006; Friedlander *et al.,* 2005). In general, coral disease is found to be widespread on reefs but occurs at a low prevalence. However, disease outbreaks with more serious effects are starting to occur in Hawai'i. The white syndrome resulting from tissue necrosis and loss in *Acropora cytherea* has appeared at French Frigate shoals, a pristine area presumably free from anthropogenic stressors. In Kāne'ohe Bay on O'ahu, *Montipora capitata* are showing progressive signs of tissue loss (Figure 1F). The etiology (cause) of these diseases has not been determined because no facility for the safe conduct on this research is available in the Pacific. Nevertheless, we must continue to monitor these outbreaks. Experiences with bleached corals in other parts of the world indicate that bleached corals are more susceptible to disease (Bally and Garrabou, 2007). If this is true, Hawai'i should expect more disease outbreaks.

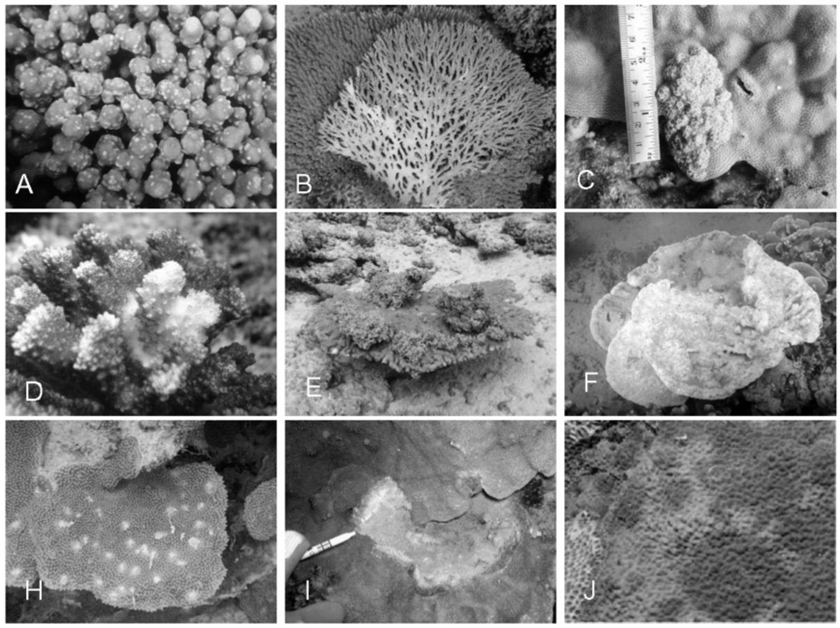


Figure 1. Some coral disease found in Hawai'i. A. *Porites* trematodiases. B. *Acropora* white syndrome. C. *Porites* growth anomalies. D. *Pocillopora* white band disease. E. *Acropora* growth anomalies. F. *Montipora* white syndrome. H. *Montipora* multi-focal tissue loss syndrome. I. *Montipora* dark band. J. Dark spot disease caused by endolithic hypermycosis.

Genetics, Diversity, and Coral Reef Resilience

Resilience of ecosystems was originally defined by C.S. Holling in 1973 as the ability of systems to absorb, resist or recover from disturbances or to adapt to change while continuing to maintain essential functions and processes. For coral reefs, resilience is the term used to describe the ability of coral reefs to bounce back or recover after experiencing a stressful event such as bleaching. Resistance, in turn, refers to the ability of coral communities to remain relatively unchanged in the face of a major disturbance.

Ensuring reef resilience is an important aim for all present and future marine protected areas in Hawai'i. The Nature Conservancy (TNC) has done an admirable job in developing a model of reef resilience. The four principles of reef resilience that TNC have identified are:

1. Provide adequate replicates of habitat types to decrease the risk of catastrophic events, such as bleaching, from destroying the entire ecosystem.
2. Identify as high priority conservation targets those areas vital for the survival and sustainability of the coral reef ecosystem, *i.e.,* nursery habitats, regions of high diversity.
3. Ensure connectivity among reefs to ensure replenishment of coral communities and fish stocks to enhance recovery in case of a catastrophic event.
4. Reducing threats to the environment by effective management.

In the HIMB-Monument research partnership, we are examining the issue of biological connectivity among the reefs and atolls in the Northwestern Hawaiian Islands and its possible connectivity to the Main Hawaiian Islands. The work of HIMB researchers Rob Toonen and Brian Bowen and their colleagues shows that the answer to this question differs greatly among species, and that single studies of individual species tell us little about how to manage any other population (Bird *et al.,* 2007). Although these are preliminary results, the extensive survey currently underway suggests that many of the fishes are well-connected throughout the archipelago. In contrast, the corals and other invertebrates that form the reefs are far more isolated, and must therefore be managed carefully on a local scale to persist. Despite the differences among species, however, some striking patterns of isolation emerge; there are consistent breaks in exchange of individuals across many species that divide regions of the Hawaiian Archipelago (Figure 2). Notably, there is a consistent break between populations found at the Big Island, Kauai, and between the Main and NWHI, with the predominant direction of exchange being to the northwest rather than to the southeast. Additionally, even for fishes—which show the highest degree of connectivity in our studies—the rate of exchange is too low to subsidize fisheries stocks in the Main Hawaiian Islands, suggesting that regional or community-based management will be the most effective route for the future (Bird *et al.,* 2007).

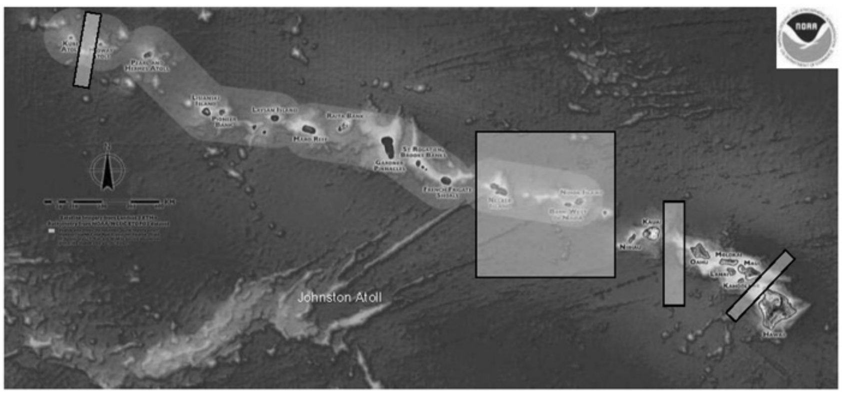


Figure 2. Shared genetic breaks among diverse species (including Spinner dolphins, sharks, opihi, tube snails, lobsters, and sea cucumbers) across the Hawaiian Archipelago. Although patterns of population structure differ by species in each case, the four regions highlighted in this figure appear to limit exchange across a broad range of marine taxa.

A major contributor to reef resilience is species diversity at both the organismal level and the genetic level. Although we have a listing of the species found in the Hawaiian Archipelago to date, the actual species diversity in the NWHI is largely unknown. A recent Census of Marine Life Cruise to French Frigate Shoals uncovered 30–50 invertebrate species new to science, 58 new ascidian records, 33 new records of decapod crustaceans, and 27 new opistobranch mollusks of record (R. Brainard, personal communication). It is clear that we don't know the extent of species diversity in the NWHI and it is critical that we find out if we are to understand how that ecosystem functions and what levels of redundancy in function are available (McClanahan, Polumin, and Done, 2002). HIMB scientists are beginning to examine the genetic diversity of different coral species in Hawai'i.

Symbiont diversity, we are learning, is a vital factor in the resistance of corals to bleaching. The symbiotic dinoflagellate genus *Symbiodinium* is genetically diverse containing eight divergent lineages (clades A–H). Corals predominantly associate with clade C *Symbiodinium*, although clades A, B, D, F, and G are also found to a lesser extent in corals. There is ample evidence that some type of symbiont "shuffling" occurs during the process of acclimatization of corals to higher thermal stress (Berkelmans and van Oppen, 2006; Middlebrook, Hoegh-Guldberg, and Leggat, 2008). In fact, there is growing evidence that corals with clade D symbionts are more resistant to thermal stress than the same species with clade C symbionts, the more common coral symbiont clade in the Pacific region. HIMB researchers Ruth Gates and Michael Stat found *Symbiodinium* clade A1, a rare symbiont type, and clade C associated with the *Acropora cytherea* corals at French Frigate Shoals. The A symbiont type is rare, and genetic evidence suggests that this clade was introduced with *Cassiopea* (Stat & Gates, 2007). Moreover, the presence of clade A was highly associated with disease. None of the diseased corals had clade C as the dominant symbiont (Stat & Gates, preliminary communication).

Invasive Species

Living in KĀne'ohe Bay, we are confronted daily by the invasive algae that impact our coral reefs. Our associates, Cindy Hunter, Celia Smith, the Division of Aquatic Resources, and The Nature Conservancy are part of an organized effort to keep the algae from taking over our reefs. As part of our efforts to prevent this from ever happening in the NWHI, we have developed a set of recommendations to restrict the transport of non-indigenous species to the NWHI. They include hull inspections for vessels planning to enter the NWHI and requiring treatment of ballast water.

Copies of the document are provided for the members of the Committee: S. Godwin, K. S. Rodgers, and P. L. Jokiel (2006) Reducing Potential Impact of Invasive Marine Species in the Northwestern Hawaiian Islands Marine National Monument.

The power of the genetic tools we use to detect invasive species can also be used to uncover the origins of invasive species and I provide this example for our discussion. When the snowflake coral, *Carijoa riseii,* was first observed growing at high densities on the black coral beds in Hawai'i, it was labeled as a foreign invasive from the Caribbean. It was thought to have been brought in by ships coming to Hawai'i from the continental United States. Genetic evidence no longer supports this finding (Concepcion *et al.,* in review). Rather, the "Hawaiian snowflake coral" was closer genetically to the snowflake corals identified throughout the Pacific Islands, and that there are multiple species of Hawaiian snowflake coral (Concepcion *et al.,* 2007). It is clear that this is not a Caribbean introduction and the data cannot rule out a natural colonization of Hawai'i by the snowflake coral. If that is the case, then the ecology of the black coral ecosystem has been altered to allow the snowflake coral to overgrow these precious coral beds.

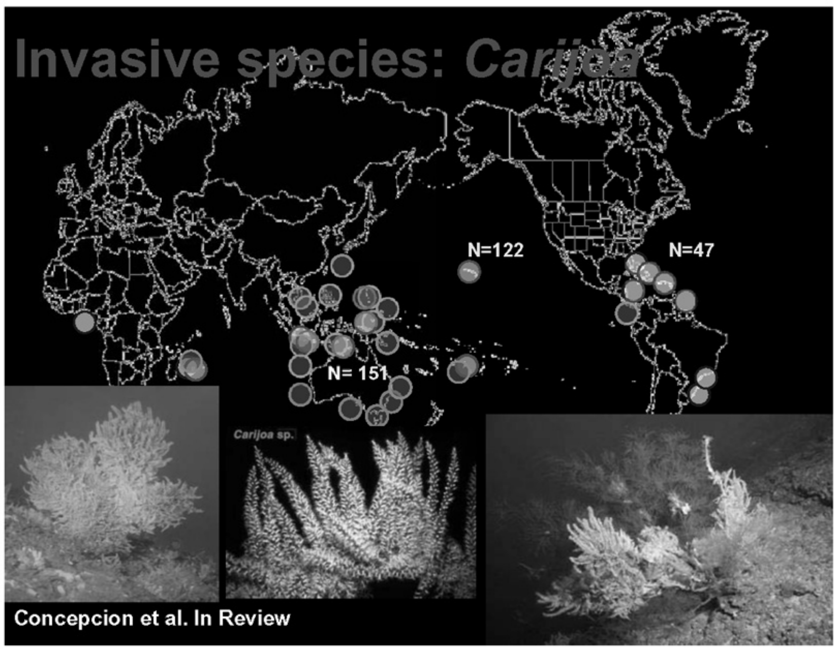


Fig. 3. Distribution of genotypes of Carijoa riseii. Each colored circle is characteristic for a specific genotype of Carijoa. Note that Hawai'i does not share any genetic types with the Caribbean.

Ocean Acidification

Several models for changes in aragonite saturation at today's CO_2 concentration (375–380 ppm) to the projected saturation state for years 2040–2049 (465 ppm) indicate that Kure Atoll and Midway Island will be affected by rates of aragonite saturation that are marginal for coral growth (Guinotte, Buddemeier, & Kleypas, 2003; Hoegh-Guldberg *et al.,* 2007). Experiments in mesocosms containing corals exposed to lower pH suggest that coral calcification rates will slow (Ries, Stanley, & Hardie, 2006; Marubini & Atkinson, 1999), and, in some cases, the corals will actually decalcify to form sea anemone-like soft bodied polyps (Fine and Tchernov, 2007). Ilsa Kuffner and her colleagues at HIMB have shown that crustose coralline algae are dramatically affected by acidified ocean water (Figure 4). This is an important finding because members of this group of calcifying algae act as framework organisms, cementing carbonate fragments into massive reef structures, providing chemical settlement cues for reef-building coral larvae, and is a major producer of carbonate sediments (Kuffner *et al.,* 2008).

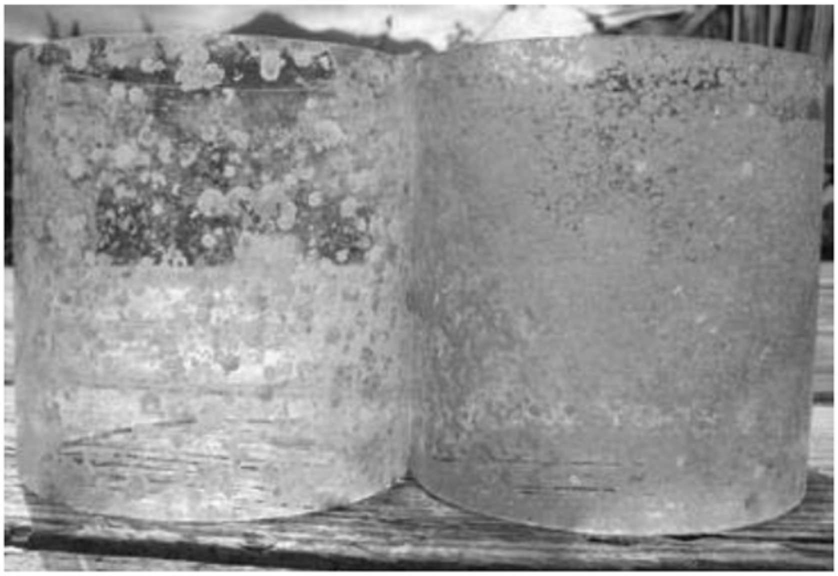


Figure 4. Encrusting algal communities on experimental cylinders. Control cylinder on the left was exposed to normal seawater at pH 8.17 and shows the pink crustose coralline algae colonies. On the right, this cylinder exposed to seawater at pH 7.91 shows growth of on non-calcifying algae.

Recommendations:

Management strategies will need to focus on increasing coral reef resilience, usually by managing other stressors on reefs, *i.e.,* nutrient overload, sediments, human induced disturbances, resource extraction. Management will also require:

1. An accurate survey of the biodiversity of the coral reef ecosystems in Hawai'i.
2. A study of ecosystem function in these reefs to identify keystone species and redundancy in the system.
3. Management must be based on an accurate assessment of the biological connectivity between the different reefs and atolls. Temporal and spatial contributions to replenishment from healthy reefs must be determined.
4. Coral reef ecosystem management and fisheries management must work together to provide sustainable harvest while preserving habitat and ecosystem functions.
5. Research needs include:
    a. Identification of the etiologic agents of coral disease within an appropriate containment facility.
    b. Understanding the epizootiology of coral diseases (transmission, rate of spread, virulence, etc.).
    c. Measurement of the impacts of reduced calcification on a wide range of marine organisms including pteropods, coccolithophores, foraminifera . . .
    d. Determine the calcification mechanisms across many different calcifying taxa.
    e. Large mesocosms equipped with seawater that can be regulated for temperature, flow rate, wave action, pH and CO_2, and light are needed to conduct replicate studies on the effects of these thermal stress and/or lowered pH on coral reefs.
6. We support the recommendations of the report: Impacts of Ocean Acidifcation on Coral Reefs and Other Marine Calcifiers: A guide for future research. Authors: J. A. Kleypas, R. A. Feely, V. J. Fabry, C. Langdon, C. L. Sabine, and L.L. Robbins.

References

Aeby, G. S., J. C. Kenyon, J. E. Maragos, and D. Potts. (2003) First record of mass coral bleaching in the Northwestern Hawaiian Islands. *Coral Reefs* 22:256.

Aeby, G. S. (2006). Baseline levels of coral disease in the Northwestern Hawaiian Islands. *Atoll Research Bulletin* 543:471–488.

Baker, A. C., C. J. Starger, T. R. McClanahan, & P. W. Glynn. (2004). Corals' adaptive response to climate change. *Nature* 430:741.

Baker, A. C. (2001). Reef corals bleach to survive change. *Nature* 411:765–766.

Bally, M. and J. Garrabou. (2007). Thermodependent bacterial pathogens and mass mortalities in temperate benthic communities: a new case of emerging disease linked to climate change. *Global Change Biology* 13:2079–2088.

Berkelmans, R. and M. J. H. van Oppen (2006) The role of zooxanthellae in the thermal tolerance of corals: a "nugget of hope" for coral reefs in an era of climate change. Proceedings of the Royal Society of London, Series B., *Biological Sciences,* doi: 10,1098/rspb.2006.3567

Bindoff, N. L., J. Willebrand, V. Artale, A. Cazenave, J. M. Gregory, S. Gulev, K. Hanawa, C. Le Quere, S. Levitus, Y. Nojiri, G. C. Shum, L. D. Talley, and A. Unnikrishnan. (2007). Observations: Oceanic Climate Change and Sea Leve. In: *Climate Change 2007: The Physical Science Basis. Contribution of the working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Avery, M. Tignor, and H. L. Miller [eds]). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Bird, C. E., B. S. Holland, B. W. Bowen, and R. J. Toonen. 2007. Contrasting population structure in three endemic Hawaiian limpets (Cellana spp.) with similar life histories. *Molecular Ecology* 16 (15):3173–3187.

Brainard, R. (2002) Bleaching in NW Hawaiian Isalnds. Bleaching Report, National Environmental Satellite, Data, and Information Service. ORA/ORSPD Coral Reef Team, Coral Reef Bleaching Hotspots. *http://www.osdpd.noaa.gov/PSB/EPS/SST/data/als_bleaching.10.16.2002.*

Brown, B. E., R. Dunne, M. S. Goodson, and A. E. Douglas. (2000) Bleaching patterns in reef corals. *Nature* 404:142–143.

Concepcion, G., M. Crepeau, D. Wagner, S. E. Kahng, & R. J. Toonen. 2008. An alternative to ITS—a hypervariable, single-copy nuclear intron in corals, and its use in detecting cryptic species within the octocoral genus *Carijoa. Coral Reefs.* Online first, DOI: 10.1007/s00338–007–0323–X.

Concepcion, G., S. E. Kahng, M. Crepeau, E. C. Franklin, S. Coles, & R. J. Toonen. *In Review.* Molecular data refute a Caribbean introduction and suggest multiple origins for the invasive snowflake coral in Hawai'i. *Molecular Ecology.*

Cooper, T. F., G. De'ath, K. E. Fabricius, and J. M. Lough. (2008) Declining coral calcification in massive porites in two nearshore regions of the northern Great Barrier Reef. *Global Change Biology* 14: 529–538.

Friedlander, A., G. Aeby, E. Brown, A. Clark, S. L. Coles, S. Dollar, C. Hunter, P. L. Jokiel, J. Smith, B. Walsh, and Wiltse, W. (2005) The State of Coral Reef Ecosystems of the Main Hawaiian Islands, pp. 222–269. In: J. Waddell (ed.), *The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005.* NOAA Technical Memorandum NOS NCCOS 11. NO AA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Sping, MD. 522 pp.

Guinotte, J. M., R. B. Buddemeier, and J. A. Kleypas. (2003). Future coral reef habitat marginality: temporal and spatial effects of climate change in the Pacific basin. *Coral Reefs* 22: 551–558.

Holling, C. S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4:1–23.

Jokiel, P. L., and S. L. Coles. (1974). Effects of heated effluent on hermatypic corals at Kahe Point, O'ahu. *Pacific Sciences* 28(1):1–16.

Jokiel, P. L., and E. R. Brown. (2004) Global warming, regional trends and inshore environmental conditions influence coral bleaching in Hawai'i. *Global Change Biology* 10:1627–41.

Jokiel, P. L., and S. L. Coles. (1990) Response of Hawaiian and other Indo-Pacific reef corals to elevated temperatures associated with global warming. *Coral Reefs* 8:155–162.

Kenyon, J. C. and R. E. Brainard. (2006) Second Recorded Episode of Mass Coral Bleaching in the Northwestern Hawaiian Islands. *Atoll Res. Bull.* 543:505–523.

Kuffner, I. B., A. J. Andersson, P. L. Jokiel, K. S. Rodgers, and F. T. MacKenzie. (2008) Decreased abundance of crustose coralline algae due to ocean acidification. *Nature Geosciences* 11:114–117.

Little, A. F., M. J. H. van Oppen, and B. L. Willis. (20040. Flexibility to algal endosymbioses shapes growth in reef corals. *Science* 304:1492–1494.

Marubini, F., and J. J. Atkinson. (1999). Effects of lowered pH and elevated nitrate on coral calcification. Marine Ecology progress Series 188:117–121.

McClanahan, T., N. Polumin, and T. Done. (2002). Ecological States and the resilience of coral reefs. *Conservation Ecology* 6(2):18.

Middlebrook, R., O. Hoegh-Guldberg, and W. Leggat. (2008). The effect of thermal history on the susceptibility of reef-building corals to thermal stress. *Journal of Experimental Biology* 211:1050–1056.

Ries, J. B., S. Stanley, and L. A. Hardie. (2006). Scleractinian corals produce calcite, and grow more slowly, in artifical Cretaceous seawater. *Geology* 34:525–528.

Shea, E. L., G. Dolcemascolo, C. L. Anderson, A. Barnston, C. P. Guard, M. P. Hamnett, S. T. Kubota, N. Lewis, J. Loschnigg, and G. Meehl. (2001). *Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change, Pacific Islands.* Pub. East-West Center, Honolulu, HI. ISBN: 0–86638–197–X.

Stat, M., and R. D. Gates (2008). Vectored introductions of marine endosymbiotic dinoflagellates into Hawai'i. *Biological Invasions* 10(4):579–583.
Van Oppen, M. J. H., and R. D Gates. (2006) Conservation genetics and the resilience of reef-building corals. *Molecular Ecology.*
Work, T. M., and R. A. Rameyer. (2001). *Evaluating Coral Health in Hawai'i.* U.S. Geological Survey, National Wildlife Health Center, Hawai'i Field Station, 42 pp.
Work , T. M., S. L. Coles, and R. A. Rameyer. (2002) *French Frigates Shoals Reef Health Survey.* U. S. Geological Survey, National Wildlife Health Center, Hawai'i field Station, 25 pp.

The CHAIRMAN. I wish to assure all witnesses that your prepared statements will all be made part of the record, and other exhibits that you may have. We will study them when we get back.

Our next witness is the Professor Emeritus, Department of Oceanography, School of Ocean and Earth Science and Technology at the University of Hawai'i, Dr. Fred T. Mackenzie.

Dr. Mackenzie?

STATEMENT OF FRED T. MACKENZIE, PH.D., DEPARTMENT OF OCEANOGRAPHY, SCHOOL OF OCEAN AND EARTH SCIENCE AND TECHNOLOGY, UNIVERSITY OF HAWAI'I AT MĀNOA

Dr. MACKENZIE. Thank you, Senator Inouye.

Senator Inouye, ladies and gentlemen, I want to thank you very much, a *mahalo,* for giving me the opportunity to address the Subcommittee.

As you all know, just very recently the Intergovernmental Panel on Climate Change came out with their 2007 report on the physical science of climate change, but also with two volumes on adaptation and mitigation. All volumes were about the same size, 800 pages each.

What I would like to do today is to show you some recent findings relevant to global warming and the Pacific Region, in terms of climate impacts that were not in the recent IPCC science report, and have come forward within the last couple of years.

So the Intergovernmental Panel on Climate Change produced their last climate change science report in 2007. However, research was excluded from the 2007 document if it were controversial, not fully quantified, or not yet incorporated into models. Papers published after 2005 could not be used. Now, this is very important, the importance is shown below.

Of importance to any discussion of Pacific Region climate impacts are the post-2005 observations. Land and ocean surface temperatures have risen relatively rapidly, just in this century. Global climate models had assumed that ice sheets would melt slowly in response to increased warmth. What really happens is that ice sheets fracture as they melt, and they allow water to penetrate rapidly toward the bottom of the sheet, with the result that the ice sheet surges and breaks up.

The rate of ice loss in Greenland has more than tripled, just in this century, and there has been rapid loss of sea ice around Antarctica, and mass loss of ice in West Antarctica.

A few other post-2005 observations are that: (1) global sea is rising about 50 percent faster in the early 21st century than in the recent past decades. This may be a sign of accelerated sea level rise.

Based on recent predictions, sea level rise in 2100 is probably going to be about 1 meter under a business-as-usual emissions scenario. (2) Interestingly enough, it appears that the Gulf Stream has slowed about 30 percent between 1997 and 2004. This Stream transports heat to high latitudes in the North Atlantic, and its slowing would have major climatic implications.

(3) Arctic sea ice has decreased 15 percent just in this half-decade. In 2007, there was a record decrease in the area of sea ice, and the Northwest Passage was open for the first time in centuries.

(4) The North Pacific Region around Hawaii, of relatively low productivity and nutrient-deficient surface waters, has expanded to the East as the surface water, ocean water has warmed, with poorly known consequences for pelagic fishes, like our tuna fisheries.

(5) In certain regions of the ocean, the strength of the oceanic sink of anthropogenic carbon dioxide is weakening, as the partial pressure difference of carbon dioxide between the atmosphere and the ocean decreases. The oceans are the major reservoir besides terrestrial plants on land for uptake of anthropogenic carbon dioxide, and that reservoir, that sink, is weakening, in terms of taking up the carbon dioxide.

Now, I would like to turn to regional projections of climate change variables on into this century. They're based mainly on climate models, and although these models are much improved, they are still not as robust as the global projections.

Large deviations among models make regional estimates across the Pacific Region uncertain. However, the following diagrams that I'll show you for precipitation—temperature, precipitation, and sea level projections for this Century, for the Pacific Region, are based on the U.K.'s Hadley Centre for Climate Prediction and Research Model, HADCM2 General Circulation Model. After this, I will make a brief comment on storminess, and along with Dr. Leong, I will have something to say about ocean acidification.

First, temperature—the 2007 global mean annual carbon dioxide concentration of 380 parts per million globally, and at Mauna Lau at present, 385 parts per million, is higher today than it has been in the past more than 600,000 years. And this is due to fossil fuel burning and land use changes.

The global mean surface temperature has risen nearly 1 degree centigrade since the 18th century. The global mean temperature anomaly between just the 5 years of 2000 and 2005, was about a half a degree centigrade. And that anomaly in the high latitudes of the Northern hemisphere was a whopping 2 degrees centigrade. You wonder why Greenland is melting! You wonder why the permafrost is melting! This is the reason, it's getting warm in the high latitude of the North Atlantic.

The 2007 IPCC science report concluded that the probability that the warming is caused by natural climatic processes alone is less than 5 percent. Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.

I apologize to you, these maps do not show up as good as they do on the PC, but this one shows regional surface temperature changes between the end of the 20th century, and the end of the 21st century for the Pacific Region. Hawaii will be two to three, and probably 3 degrees centigrade warmer at the end of this century in a business-as-usual scenario of fossil fuel emissions. Note, importantly, the seasonal and geographical variability in the temperature changes. The real red harsh colors mean, are hotter, the yellows are not as hot.

This shows the projections for Pacific rRgion changes in precipitation between the end of the 20th Century and the end of the 21st. Hawaii may be wetter, Hawaii may be drier—this will all depend on how the elevation of the trade wind inversion above Hawaii changes.

If the inversion decreases in elevation, Hawaii will become drier, and that's the anticipation. If it increases in elevation, Hawaii will become wetter. Once more, I want you to note, the big variability seasonally, and geographically, in precipitation. The blues, very wet, the reddish color in here and here, dry.

This slide shows the Pacific Region projections of sea level rise for two scenarios—late 20th to mid-21st century, late 20th to the end of this century. And you can see, from just this frame, that Hawaii under a business-as-usual, fossil fuel-emissions scenario, it's project to have at least 40 centimetered high sea level in the latter part of this century.

But, because of our recent knowledge on the rate of ocean thermal expansion, the rate of the melting of mountain and valley glaciers, and—and most importantly—the rate that the Greenland Ice Sheet is melting, we are now predicting a 1 meter rise in sea level by the year 2100.

And just within the week, the National Research Council's Transportation Board has released a report demonstrating how vulnerable our transportation system will be to that 1 meter rise, including Hawaii.

I live in Hawaii Kai—I drive Kalanianaole Highway. With a 1 meter rise in sea level, and any kind of small storm surge, that highway will be under water, considerably, with a 1 meter rise in sea level.

This slide shows what Waikiki and environs would look like with a 1 meter rise in sea level.

My own personal feeling is that we in the state need to prepare for the possibility of a 1 meter rise in sea level. We will have to prepare by adaptation, since Hawaii does not emit much carbon dioxide into the atmosphere, mitigation is not going to play a big role.

Storminess—this has been a big problem, it's still a problem today. There's still considerable uncertainty concerning how storm and hurricane frequency and intensity will change for the Pacific Region in a warmer world. Multi-model ensembles do not give a clear picture of how storms in the Pacific Region will be affected by temperature change, and water—hydrological—change.

The Hadley Model projects increased storminess for the Hawaiian Islands, as well as the Federated States of Micronesia, and the Republic of the Marshall Islands. Storminess is projected to decrease for the region around Fiji, and the French Polynesian Islands.

However, and very importantly, to date there is no rigorous observational proof that there is a trend in the intensity or frequency of hurricanes in the Atlantic or Pacific. Inter-annual, El Niño/La Niña, and inter-decadal Pacific and Atlantic natural climate phenomena, I think, are masking whatever influence global climate change is having on storms, at the moment.

Ocean acidification—and Dr. Leong went through this in quite detail, but I think it's worth emphasizing, because this is a very serious issue for us. Ocean acidification is simply due to emissions of carbon dioxide to the atmosphere, because of fossil fuel combustion, and land use changes. And their partial absorption in surface waters—this is a major environmental problem today. The observational record of surface ocean pH, measure of acidity, and model calculations—those done on my own laboratory—show that since the 18th Century, the oceans have become more acidic.

Accompanying the increase in acidity, is a decline in the carbonate saturation state of the world's surface oceans, with respect to all carbonate minerals. And thus, this makes it much more difficult for organisms to calcify.

Under a business-as-usual emissions scenario, in the year 2100, surface water pH could decrease to 7.85—its pristine, pre-industrial level was 8.1, 8.2. This will be accompanied by a 30 percent decrease in carbonate saturation state. Obviously, these decreases would very likely affect the calcification rates of both benthic coral and algae corals, pelagic flora, calcifying organisms—and be accompanied, and this is important by major changes in marine ecosystem communities, their structure, and ability to recruit.

Coastal ocean acidification will be especially detrimental to the coral reefs of Hawaii, and the rest of the Pacific Region. Only 50 years from now, much of the surface water that bathes Pacific reefs will be more warm, and more acidic, and hence marginal for vigorous reef growth.

Unfortunately, the only way to resolve this problem is by the reduction of anthropogenic carbon dioxide emissions to the atmosphere. I cannot emphasize that more—no matter what the climate does in the future, as long as we put carbon dioxide into the atmosphere, the oceans will continue to acidify.

Finally, I have a list of key concerns and needs for Hawaii and Pacific Island communities, I'm not going to go through these in detail, they're written out in both of the handouts we have. I would, however, like to end by looking at these two down here with diamond symbols on the slide.

I feel now there is a need for a new Pacific Region assessment of climate variability and change, in light of improved models, and these improvements are going on every year—and particularly the observations of the last 10 years, which are not documented well in the 2007 report of the IPCC. I would like to see regional-based climate information services established in the Pacific Region, and to some extent this is going on, but not to the extent that I perceive. It could be handled by UH, it could be handled by NOAA, to provide climate services that bridge the gap between local weather, and global climate information for island communities, for the people. These services should include community educational resources, such as the one that I have given out here, and is available for all of you—on climate change, its variability, and the anticipated impacts and vulnerability and adaptation to climate change and rising sea level for the Pacific Region.

I'd like to thank you for giving me the opportunity to address the Committee, I know I ran a little over time, my apologies. I look forward to your questions.

[The prepared statement of Dr. Mackenzie follows:]

PREPARED STATEMENT OF FRED T. MACKENZIE, PH.D., DEPARTMENT OF OCEANOGRAPHY, SCHOOL OF OCEAN AND EARTH SCIENCE AND TECHNOLOGY, UNIVERSITY OF HAWAI'I AT MĀNOA

Introduction

Good morning, Senator Inouye, Members of the Committee, ladies and gentlemen. Thank you for giving me the opportunity this morning to speak to you on global climate issues and how they might impact island communities. My name is Fred Mackenzie and I am an Emeritus Professor in the Department of Oceanography at the University of Hawai'i. My research is quite broad in scope but focuses on the behavior of the Earth's surface system of oceans, atmosphere, land, and sediments through geologic time and its future under the influence of humans, including the problems associated with greenhouse gas emissions to the atmosphere, global warming, and ocean acidification. I have been an academician for more than 45 years and published more than 250 scholarly publications, including six books and nine edited volumes in ocean, Earth and environmental science. Today you have asked me to comment on how climate change might affect island communities and on our recent work developing climate and sustainability case studies for Pacific island resources that can be used to educate and inform the community, including local decision-makers.

Many of my comments are derived from the report of the Pacific Islands Regional Assessment Group, for which I served as a member, entitled *Preparing for a Changing Climate. The Potential Consequences of Climate Variability and Change* (Shea *et al.*, 2001), and the case study *Climate Change, Water Resources, and Sustainability in the Pacific Basin: Emphasis on O'ahu, Hawai'i and Majuro Atoll, Republic of the Marshall Islands* (Guidry and Mackenzie, 2006). I and my colleagues have used these materials and my books *Our Changing Planet: An Introduction to Earth System Science and Global Environmental Change* (Mackenzie, 2003) and *Carbon in the Geobiosphere—Earth's Outer Shell* (Mackenzie and Lerman, 2006) to educate the public and students at all levels in Hawai'i and elsewhere about climate change and its impacts. We also have run an immersion course for native Hawaiian students and a course for the Myron B. Thompson Charter School in Hawai'i employing these texts and an interactive website as resource materials.

General Comments on Climate Change

The science of climate change has been assessed in a series of four reports by the Intergovernmental Panel on Climate Change (IPCC), a body of 2500 scientists that, as you are aware, shared the 2007 Nobel Peace Prize for their work on distilling the scientific community's research on the physical and biogeochemical basis for climate change into authoritative reports. Similar sized volumes on mitigation and impacts, adaptation and vulnerability have accompanied the more recent science volumes. The panel's latest 2007 physical science report *Climate Change 2007: The Physical Science Basis* (IPCC, 2007) includes a full chapter on regional climate projections that for temperature, precipitation, and extreme weather projections are very similar to the Third Assessment Report (TAR) of the IPCC in 2001, as are the global climate assessments and projections. The major difference between the TAR and the 2007 report is that generally the projections have a higher level of confidence due to a larger number of simulations, improved models, a better understanding of model deficiencies, and improved detailed analyses of the results. It should be kept in mind that the distillation of the science of climate change by the IPCC in their 2007 report only dealt with findings up until the year 2005. More recent findings from 2005–2007 studies are included in this testimony. Also it is still very difficult to take the information from the IPCC physical science report and use it to predict the future of regional and short-lived annual events, like day-long high sea levels and floods, or even inter-annual (El Niño/La Niña) or decadal (North Atlantic and Pacific Decadal Oscillations) climate changes and their effects on precipitation, sea level, and hurricane frequency or intensity.

At its most basic level, the balance between incoming solar radiation and outgoing infrared heat radiation determines Earth's climate. The absorption of the outgoing Earth radiation by atmospheric greenhouse gases of methane (CH_4), nitrous oxide (N_2O), and especially carbon dioxide (CO_2) and the consequent heating of the lower atmosphere are what constitute the well-recognized "greenhouse effect". It should be kept in mind that water vapor (H_2O) is the most potent greenhouse gas. The greenhouse gases have for most of planetary history resided in our atmosphere and by trapping outgoing Earth radiation have maintained the Earth at a temperature amenable to life. Thus, there has always been a greenhouse effect, but humans by adding greenhouse gases to the atmosphere are increasing the strength of the greenhouse effect. The Earth without greenhouse gases in the atmosphere would be −18 °C, 33 °C colder than the late pre-industrial global mean temperature of 15 °C. We have had an "enhanced greenhouse effect" operating since at least the beginning of the industrial era.

It is well known and documented that the greenhouse gases of carbon dioxide (CO_2), methane CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CFCs) have increased markedly in the atmosphere due to human activities. The global increase of atmospheric carbon dioxide from 1750 to 2007 has been about 36 percent, from 280 ppm (parts per million) to 382 ppm globally and 385 ppm at the Mauna Loa Observatory on the Big Island of Hawai'i. Atmospheric carbon dioxide levels are higher today than they have been in more than 600,000 years. The global increases in carbon dioxide concentration are mainly due to fossil fuel use and land use changes. The increases of methane from 715 to 1774 ppb (parts per billion) and nitrous oxide from 270 to 320 ppb are primarily due to agriculture. The concentrations of the potent synthetic halogenated greenhouse gases, like CFC–12, have risen from zero to hundreds of ppt (parts per trillion) concentrations. For example, CFC–12 has risen from zero to 538 ppt. This rise is due to industrial activities and use of the compound as a coolant in refrigeration and air conditioning units. Another greenhouse gas, tropospheric ozone (O_3) (not to be confused with stratospheric ozone), is formed from reaction of anthropogenic sources of nitrogen oxides and volatile organic compounds in the atmosphere derived from the burning of fossil fuels and biomass. The 1987 Montreal Protocol and its amendments have had a significant effect on slowing the rise of the chlorofluorocarbons in the atmosphere, but other halogenated compounds that have replaced the chlorofluorocarbons are rising in concentration in the atmosphere. With the well-documented rise in the concentrations of the greenhouse gases in the atmosphere, one would anticipate an increase in global temperatures. In addition, the anthropogenic greenhouse gases persist in the atmosphere for years to decades to centuries implying impacts on the climate far into the future.

Natural and anthropogenic micrometer-sized aerosol particles in the atmosphere also affect climate directly or indirectly. In general, the aerosols in the lower atmosphere are removed on time scales of days to weeks and their climatic impacts are mainly that of cooling, particularly on a regional scale. The most notable of the aerosol compounds is that of sulfate (SO_4) aerosol which may affect climate directly by reflecting sunlight back toward space or indirectly by acting as cloud condensation nuclei (CCN) and leading to cloud formation, the type and distribution of which affect climate. For example, the eruption of Mt. Pinatubo in the Philippines in 1991 that spewed sulfur compounds high into the upper atmosphere led to a cooling of the planet on a time scale of several years of about 0.5 °C. The burning of fossil fuels, particularly coal, generates sulfur gases that in the atmosphere are converted to sulfate aerosols and the cooling and cloud formation effects of these particles are considered in present climate models.

Global dimming is the gradual reduction in the amount of direct solar irradiance at the Earth's surface that has been observed for several decades after the start of systematic measurements in the 1950s. It appears to be caused by air pollution and the increase in particulates such as sulfur aerosols in the atmosphere due to human activities. The effect varies geographically. Worldwide it has been estimated to have resulted in a 4 percent reduction in irradiance between 1960 and 1990. The trend appears to have been reversed during the past decade, as the lower atmosphere has become less polluted in some regions. The dimming has affected the water cycle by reducing evaporation and likely was the cause of droughts in some areas. Dimming also creates a cooling effect that may have partially masked the enhanced greenhouse effect.

The sun's output of solar energy also affects climate. In actual fact, during the past four billion years, the sun's luminosity has increased about 30 percent. More germane to the present global warming issue is that during periods of high sunspot activity, the Earth receives slightly more solar radiation at the top of Earth's atmosphere; the converse is true at times of low sunspot activity. The cool period of the Little Ice Age of 1350–1850 was probably due in part to a decrease in the amount of solar radiation received from the sun at the top of the Earth's atmosphere However, for the period 1750 to 2005, it appears that the sun's forcing on climate has only been about + 0.12 (0.06–0.30) W m^{-2} out of the total net anthropogenic forcing of +1.6 (0.6–2.4) W m^{-2}. The global average radiative forcings on climate of the various major factors involved in climate change from 1750–2005 are shown in Figure 1.

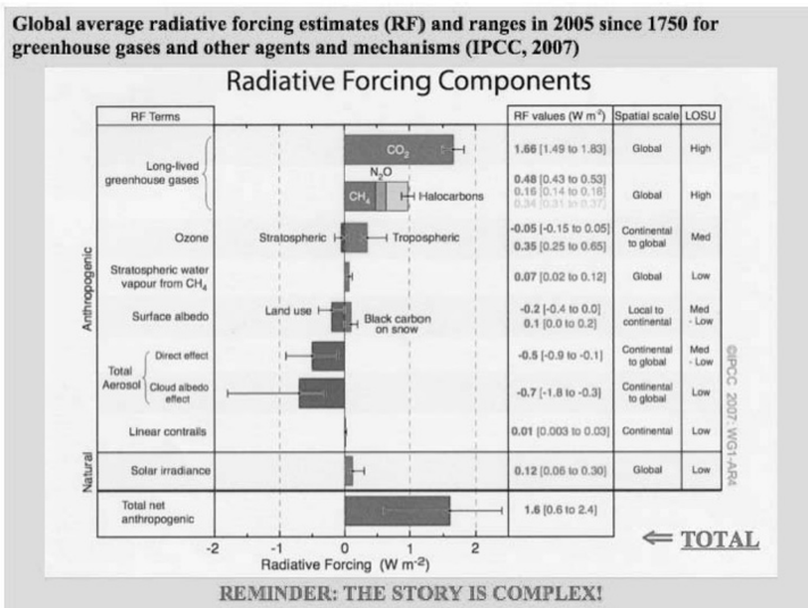


Figure 1. Global average radiative forcing estimates (RF) and ranges in 2005 since 1750 for greenhouse gases and other agents and mechanisms (IPCC, 2007).

The first report of the IPCC in 1990 suggested that the warming of 0.3 °C to 0.6 °C during the twentieth century was reasonably consistent with projections from the climate models in operation at the time but also within the ballpark of natural climate variability. The attribution of the warming to human or natural causes was not definitive at that time. By 2007, the IPCC stated that there is a *very high confidence* that "the global average net effect of human activities from 1750 to 2005 has been one of warming, with a radiative forcing of +1.6 (0.6–2.4) W m^{-2}". This climatic forcing has led to a nearly 1 °C rise in temperature since 1750. This temperature change is remarkably close to that predicted for a climate system that has a climate sensitivity response to increasing greenhouse gas concentrations of 2–3 °C (best climate sensitivity estimate is 2.8 °C) for a doubling of effective atmospheric carbon dioxide concentration over its 1850s concentration of 280 ppm. In addition, the IPCC concluded that the probability that the warming is caused by natural climatic processes alone is less than 5 percent. Most (>50 percent) of the observed increase in globally averaged temperatures since the mid-twentieth century is very likely (confidence level >90 percent) due to the observed increase in anthropogenic greenhouse concentrations (IPCC, 2007).

Recent Findings Relevant to Global Warming

We should bear in mind in the material discussed in later sections that the IPCC has a very rigorous review process. However, research was excluded from the 2007 document if it were controversial, not fully quantified, or not yet incorporated into models. Furthermore, no papers published after 2005 could be discussed in the report.

Positive feedbacks to the rate of atmospheric greenhouse gas accumulations and climate and "tipping points" (a point at which the climate system and biogeochemistry suddenly switch from one mode to another) were not always included in the IPCC 2007 chapter discussions. Of importance are the post-2005 observations that:

1. Land and ocean surface temperatures have risen relatively rapidly in the early twenty-first century (Figure 2). Ocean temperatures down to 3000 meters are also on the rise.

2. Current climate models assume that ice sheets will melt slowly in response to increased warmth. Recent work shows that ice sheets fracture as they melt, allowing water to penetrate rapidly toward the bottom of the sheet with the result that the ice sheet surges and breaks up. The rate of ice loss in Greenland has more than tripled in this century (Velicogna and Wahr, 2006) and there has been rapid loss of sea ice around Antarctica and mass loss of ice in West Antarctica. If the Greenland ice sheet melted completely, this would lead to a 6–7 meter rise in sea level. The Larsen B ice shelf collapsed in 2005. The melting of the West Antarctic ice sheet would add 5–6 meters of sea level rise.

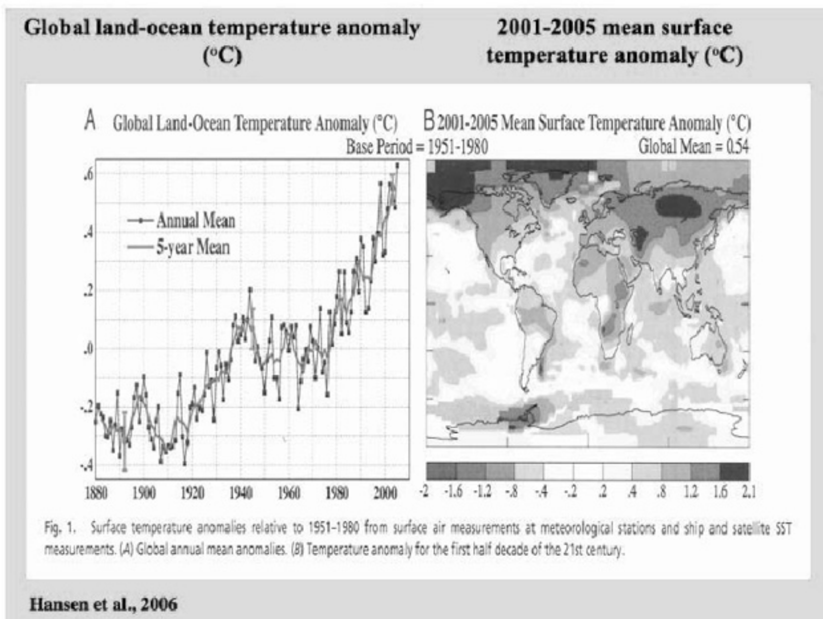


Figure 2. Global land-ocean anomaly for 1880 to 2005 and the 2001–2005 mean surface temperature anomaly. In just the latter period of time, the anomaly was 0.54 °C and of more importance is the fact that the anomaly over the high latitude of the Northern Hemisphere was up to 2.1 °C. It is this abnormal heating that is the cause of the warming at high latitudes of surface seawater and the melting of the Greenland ice sheet and the permafrost.

3. Global sea level is rising about 50 percent faster in the early twenty-first century than predicted by the IPCC in their 2001 report, perhaps the first sign of accelerated sea level rise. Average rates of sea level rise during the last several decades were about 1.8±0.5 mm/yr, with a larger rate of increase during the most recent decade of 3.1±0.7 mm/yr. However, the IPCC 2007 report in their worse case scenario for global sea level rise reduced their sea level rise estimates from 88 to 59 centimeters for the period 2000 to 2100, but the new observational findings of this century were not incorporated in the models used in the IPCC 2007 report.

4. It appears that the Gulf Stream has slowed about 30 percent during the period 1957–2004. This is a crucial current in terms of transporting heat to high latitudes in the North Atlantic and its slowing would have major climatic implications and is a key aspect of models of past climatic change and tipping points.

5. The positive feedback of the effect of rising temperatures on the release of carbon dioxide and methane from soils, permafrost, and the seabed were not considered in detail in the 2007 IPCC report. The permafrost is melting rapidly in western Canada and Siberia. Indeed, standing bodies of water are forming in the Siberian permafrost with high methane concentrations.

6. Arctic sea ice area has decreased about 15 percent since October 2005 (Nghiem *et al.,* 2006) and in 2007 there was a record decrease in the area of sea ice and the Northwest Passage was opened for the first time in centuries.

7. Higher rates of precipitation are now observed at mid to high latitudes and lower rates in the tropics and subtropics, with corresponding changes in surface seawater salinities.

8. The North Pacific region of relatively low productivity and nutrient deficient surface waters has expanded to the east as the surface ocean has warmed with poorly known consequences for pelagic fishes, like tuna.

9. Ocean surface water pH has fallen 0.1 pH unit ("ocean acidification") (Orr *et al.,* 2005; Andersson *et al.,* 2005) (the pH scale is logarithmic so this represents a significant increase in hydrogen ion concentration) since 1700, and the projected rate of change in ocean surface water pH will increase on into this century and beyond unless anthropogenic emissions of carbon dioxide to the atmosphere are curtailed. Invasion of carbon dioxide into the deeper ocean has resulted in the shoaling of the depth at which the calcareous skeletons of sinking pelagic organisms can be dissolved (Feely *et al.,* 2004).

10. In certain regions of the oceans, the strength of the oceanic sink of anthropogenic carbon dioxide is weakening as the partial pressure difference of carbon dioxide between the atmosphere and the ocean decreases.

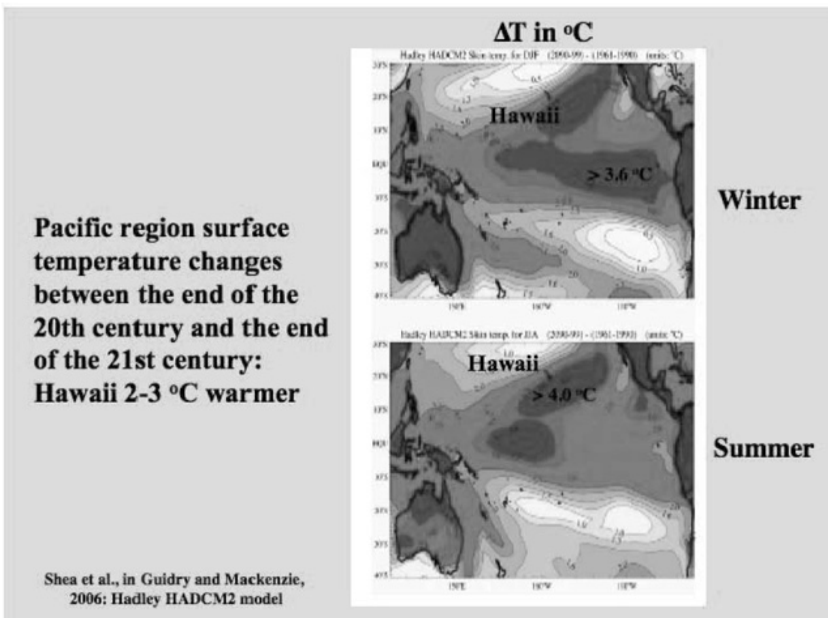
The Pacific Region Temperature, Precipitation, Sea Level and Storm Projections

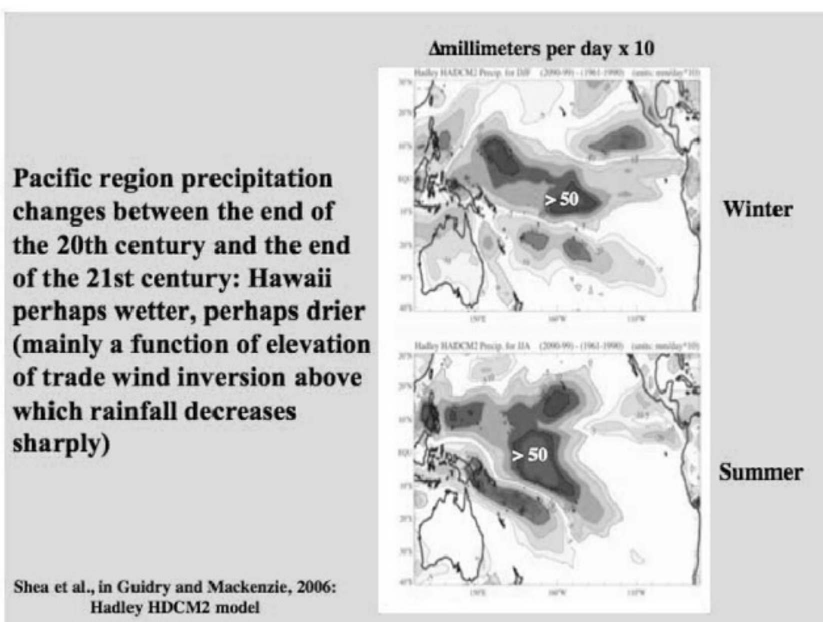
Regional projections of climate change variables on into this century, based mainly on climate models, although much improved, are still not as robust as global projections. Large deviations among models make regional estimates across the Pacific region uncertain. However, the following diagrams show the temperature, precipitation, and sea level projections for this century for the Pacific region based on the United Kingdom's Hadley Centre for Climate Prediction and Research HADCM2 General Circulation Model (GCM). Notice that Australia and the Pacific tropics and subtropics are very likely to warm the most, with temperatures in Hawai'i in the late twenty-first century being 2–3 °C higher than at the beginning of this century. There are likely to be strong seasonal and geographical changes in temperature for the Pacific region induced by global warming.

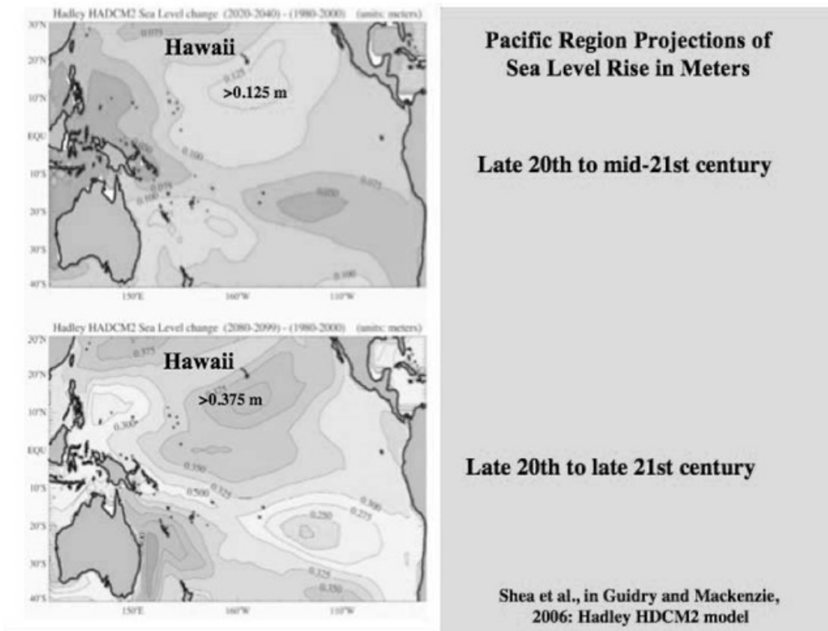
Annual rainfall is likely to increase in the equatorial belt of the Pacific on into this century and likely to decrease over southwestern Pacific islands, with Hawai'i perhaps being wetter or drier. The latter is more likely. Whether Hawai'i is wetter or drier in a globally warmer word is mainly a function of the behavior of the trade wind inversion above which rainfall decreases sharply.

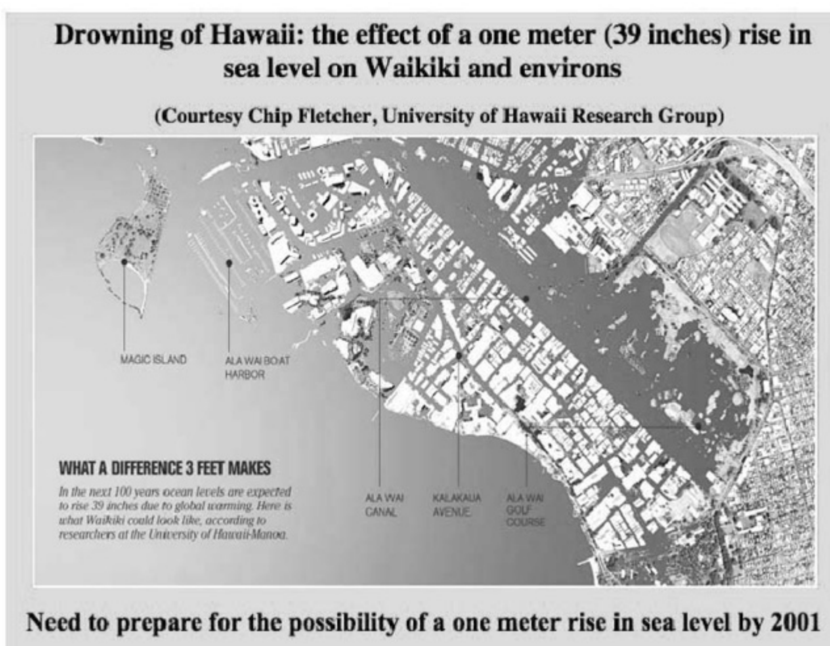
Sea level using the HADCM2 GCM is projected around Hawai'i to be about 40 centimeters higher in the late twenty-first century than at the beginning of this century. However, the HADCM2 model projections do not include the melting of the ice sheets, and it is likely because of ice sheet melting, warming of surface waters, and acceleration of the melting of valley and mountain glaciers that global mean sea level could reach a level one meter higher than in the year 2000 by the end of the twenty-first century. As with precipitation, the rise in sea level is not likely to be uniform throughout the Pacific region but geographically variable making regional estimates uncertain. Notice, however, that with a one-meter rise in sea level, areas like Waikīkī in O'ahu, Hawai'i (a high Pacific island) will be drowned. New marshes would be formed and salt water during storms with inordinate daily high sea levels would be prevalent in sewer drains and an important component of the flooding. Beach erosion would intensify and the distribution of beach sand about the Hawaiian Islands would change. Homes close to the present shoreline would be more susceptible to flooding, erosion and damage. For low-lying Pacific islands like Majuro in the Republic of the Marshall Islands, a one-meter rise in sea level would have devastating consequences. For example, for the Laura atoll region of the Marshall Islands, the shoreline would retreat by about 150 meters on each coast, which would result in a loss of more than 25 percent of the atoll's surface area. In addition, approximately 50 percent of the volume of Laura's freshwater lens would be salted out and unusable as a fresh water resource (Miller and Mackenzie, 1988; Holthus *et al.,* 1992). The damage due to storms and resulting surges would be amplified considerably by the rise in sea level.

There is still considerable uncertainty concerning how storm and hurricane frequency and intensity will change for the Pacific region in a warmer world. Multimodel ensembles do not give a clear picture of how storminess in the Pacific region will be affected by temperature and hydrologic changes. It is likely with global warming that the warm water (Pacific warm water pool) and intense atmospheric convection that are normally confined to the western equatorial Pacific will move eastward into regions that presently only experience warm waters during El Niño events. In part as a result of this, the HADCM2 model projects increased storminess in the Hawaiian Islands as well the Federated States of Micronesia and the Republic of the Marshall Islands. Storminess is projected to decrease for the Pacific region that includes Fiji and the French Polynesian Islands. It should be kept in mind that these findings are not as robust as we would like, but we do know that the patterns of storms will change in the Pacific region due to global warming.









Ocean Acidification

The modern environmental problem of ocean acidification due to emissions of carbon dioxide to the atmosphere because of fossil fuel combustion and land-use changes and their partial absorption in surface ocean waters has been discussed in the literature since at least the early 1970s (Broecker *et al.,* 1972). More recently the observational record of surface ocean water pH and model calculations show that surface water pH has declined about 0.1 pH unit since the 18th century (Caldeira, *et al.,* 2005; Orr *et al.,* 2005; Andersson, *et al.,* 2005). Accompanying this decline in pH is a decline in the carbonate saturation state of the world's surface ocean waters with respect to all carbonate minerals. Model calculations show that under a Business as Usual emissions scenario (Intergovernmental Panel on Climate Change IS92a), surface water pH could reach 7.85 by the year 2100 accompanied by a 30 percent decrease in carbonate saturation state (Figure 3). Such a decrease would very likely affect the calcification rates of both benthic calcifying organisms, like corals and coralline algae, and pelagic calcifiers, such as foraminifera, pteropods, and Coccolithophoridae, accompanied by other major changes in marine ecosystem communities, structure and recruitment. Coastal ocean acidification will be especially detrimental to the coral reefs of Hawaii and the rest of the Pacific region. *The only way this problem can be alleviated is by reduction of anthropogenic carbon dioxide emissions to the atmosphere.*

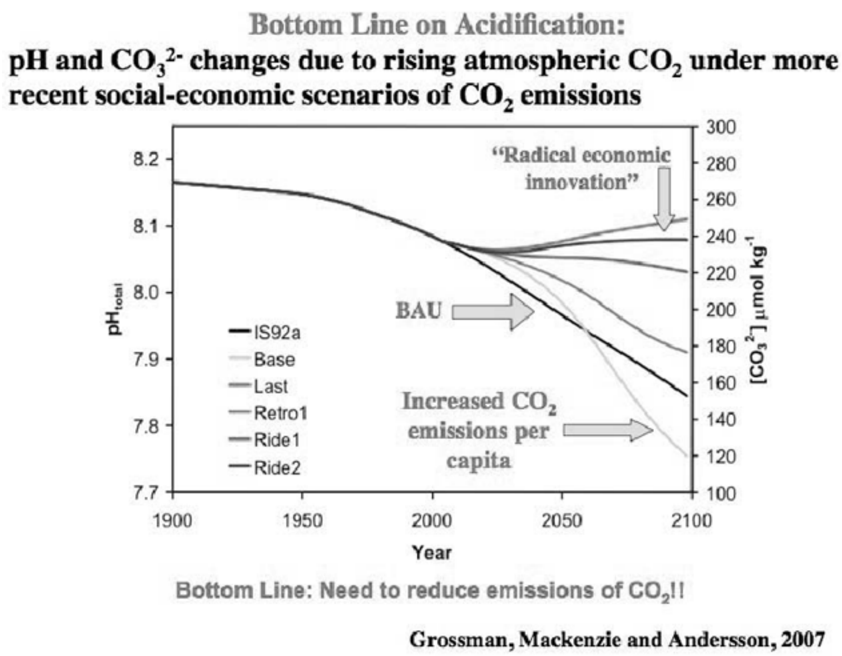


Figure 3. pH and carbonate ion concentrations, a measure of carbonate saturation state, as predicted under various greenhouse gas emissions scenarios. Only radical innovation measures will prevent the oceans from becoming more acidic.

Conclusions and Recommendations

Future global climate change and the resultant impacts to water resources are very serious problems for Pacific island communities. For small low-lying island communities like Majuro and large volcanic islands like the southern Hawaiian Islands, water is a most precious natural resource. Majuro and Hawai'i represent the end points for two different types of Pacific island communities. Majuro in the Republic of the Marshall Islands is a small low-lying atoll two to three meters above sea level. The impact of projected sea level rise on Majuro's water resources is potentially severe. The low-lying atoll lacks groundwater resources for its freshwater needs and relies primarily on rainwater catchment systems for freshwater supply. The groundwater reservoir does provide a freshwater source for times when rainfall is low and thus rainfall catchment is reduced. Rising sea level, exacerbated by storm activities, all due to climate change, will reduce Majuro's volume of fresh groundwater and that of other low-lying Pacific islands. In addition to climate change, rising population will place additional pressures on the groundwater resource. To undertake shoreline protection measures for low-lying Pacific islands is costly but will be necessary to protect its groundwater and land area resources from rising sea level and storm events. Desalinization is another measure that could be implemented to support, at least in part, present and future freshwater needs of both high- and low-lying Pacific islands, albeit at considerable cost.

Compared to the low-lying atolls and island communities like Majuro, the island of O'ahu is a relatively large volcanic island with a peak elevation of over 1200 meters (3,936 feet) and a much larger groundwater resource. This groundwater resource already supplies O'ahu with 92 percent of freshwater use. The development and use of the groundwater system have reached the point where the sustainability of current and future water usage rates is in doubt. Even if future climate change were to lead to increased precipitation for O'ahu, the elevated temperature, via its influence on evaporation rate, could result in a reduction in groundwater recharge rates and thus a decrease in the groundwater reservoir size. Add to this the increased groundwater usage due to population growth and also the background of future sea level rise and O'ahu's groundwater resource could be significantly taxed. The future rise in sea level could also threaten the economy of Hawai'i by negatively impacting vital areas (*e.g.,* airport runway and Waikīkī) in close proximity to shorelines. The rise in sea level could also result in the flow of salt water from the ocean to land via the storm drainage system that during storm events can result in flood damage to areas such as the Mapunapuna industrial district.

A summary of the some key concerns and needs for Hawai'i and Pacific island communities follows:

- The adaptive capability of the human systems is generally low for small islands and their vulnerability is high; small island communities are likely to be among those regions most seriously impacted by climate change.
- The projected global sea level rise and its geographical variability in this century will cause enhanced coastal erosion, loss of land and property, dislocation of people, increase risk from storm surges, reduced resilience of coastal ecosystems, saltwater intrusion into freshwater resources, and high resource costs to respond to and adapt to these changes.
- Islands with very limited water supplies are highly vulnerable to the impacts of climate change on their water balance.
- Coral reefs are likely to be negatively affected by bleaching due to increasing temperature and by reduced calcification rates due to higher carbon dioxide levels and consequent ocean acidification; mangroves, sea grass beds, and other coastal ecosystems and their associated biodiversity are likely to be adversely affected by rising temperatures, accelerated sea level rise, and increasing acidity of seawater.
- Declines in the water quality and pH and increasing temperatures of coastal ecosystems could negatively impact reef fish and threaten reef fisheries, those who earn their livelihoods from reef fisheries, and those who rely on the fisheries as a significant food source.
- Limited arable land and soil salinization make agricultural practices for small islands, both for domestic food production and cash crop exports, highly vulnerable to climate change.
- Tourism, an important source of income and foreign exchange for many islands, likely would face severe disruption from climate change and sea level rise.
- Island communities will mainly have to adapt to climate change and its impacts. Mitigation of greenhouse gas emissions is important from a strategic and sustainability viewpoint but will have little effect on rising atmospheric greenhouse gas concentrations.
- There is a need for a new Pacific regional assessment of climate variability and change in light of improved models and observations made since the last assessment of 2001.
- Regional-based climate information services should be established for the Pacific region, perhaps by the University of Hawai'i or by NOAA, to provide climate services that bridge the gap between local weather and global climate change information for island communities. These services should include community educational resources on climate change and variability and on the anticipated impacts and vulnerability and adaptation to climate change and rising sea level.

Thank you for giving me the opportunity to address the Committee. I look forward to answering your questions.

Selected References

Andersson, A. J., Mackenzie, F. T. and Lerman, A., 2005, Coastal ocean and carbonate systems in the high CO_2 world of the Anthropocene. *American Journal of Science,* v. 305, p. 875–918.

Broecker, W. S., Y.-H. Li and T. H. Peng., 1972, Carbon dioxide—man's unseen artifact. In: D. W. Hood (ed.), *Impingement of Man on the Oceans,* Wiley Interscience, New York, p. 387–324.

Caldeira, K. and M. E. Wickett, 2005, Ocean model predictions of chemistry change from carbon dioxide emissions to the atmosphere and oceans. *Journal of Geophysical Research (Oceans),* v. 110, C09SO4, doi: 10.1029/2004JC002671.

Feely *et al.,* 2004, Impact of anthropogenic CO_2 on the C_aCO_3 system in the oceans. *Science,* v. 305, No. 5862, p. 362–366.

Grossman, W., F. T. Mackenzie and A. J. Andersson, 2007, in preparation.

Guidry, M. W. and F. T. Mackenzie, 2006, *Climate Change, Water Resources, and Sustainability in the Pacific Basin: Emphasis on O'ahu, Hawai'i and Majuro Atoll, Republic of the Marshall Islands,* University of Hawai'i NOAA Hawai'i Sea Grant Publication, Honolulu, Hawai'i, 100 pp.

Hansen *et al.,* 2006, Global temperature change. *Proceedings of the National Academy of Sciences,* v. 103, No. 38, p. 14288–14293.

Holthus P., M. Crawford, C. Makroro and S. Sullivan, 1992, *Vulnerability Assessment for Accelerated Sea Level Rise. Case Study: Majuro Atoll, Republic of the Marshall Islands.* SPREP Reports and Studies Series No, 60, 107 pp.

IPCC, 2001, *Climate Change 2001. The Physical Science Basis.* Cambridge University Press, Cambridge, United Kingdom, 881 pp.

IPCC, 2007, *Climate Change 2007: The Physical Science Basis.* Cambridge University Press, Cambridge, United Kingdom, 996 pp.

Mackenzie, F. T., 2003, *Our Changing Planet—An Introduction to Earth System Science and Global Environmental Change.* Prentice Hall, Pearson Education, Inc., Upper Saddle River, New Jersey, 580 pp.

Mackenzie, F. T. and A. Lerman, 2006, *Carbon in the Geobiosphere—Earth's Outer Shell.* Springer, Dordrecht, The Netherlands, 402 pp.

Miller, D. L. R. and F. T. Mackenzie, 1988, Implications of climate change and associated sea level rise for atolls. *Proceedings of the 6th International Coral Reef Symposium, Australia,* v. 3, p. 519–522.

Nghiem, *et al.,* 2006, Depletion of perennial sea ice in the East Arctic Ocean. *Geophysical Research Letters,* 10.1029/2006GL027198.

Orr, J. C. *et al.,* 2005, Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature,* v. 437, p. 681–686.

Shea *et al.,* 2001, *Preparing for a Changing Climate. The Potential Consequences of Climate Variability and Change.* Report of the Pacific Islands Regional Assessment Group, East-West Center, Honolulu, Hawai'i, 102 pp.

Velicogna, I. and J. Wahr, 2006, Acceleration of Greenland ice mass loss in spring 2004. *Nature,* v. 443, p. 329–331.

Visbeck, M., 2008, From climate assessment to climate services. *Nature Geoscience,* v. 1, No. 1, p. 2–3.

The CHAIRMAN. On behalf of the Committee, I thank all of you for your testimony. It's a bit frightening. However, I should tell you that in the past several weeks, articles prepared supposedly by scientists with various degrees have been circulated and distributed among Members of Congress, and these articles suggest that we are giving too much credit to the greenhouse gases for what is happening. They're suggesting that what is happening is a natural phenomenon. They point to the Ice Age, and the fact that the oceans have been there for 4 billion years.

Yesterday on my way into Hawaii, flying, there was a documentary on the screen, I believe it was prepared by a British company, that showed the drying out of the Mediterranean caused by the two continents coming together. It showed this warm belt that goes underneath, by Alaska, and that's been affected.

It suggested the importance of one-cell plankton which, if reduced, would affect all living organisms in the ocean.

What are your thoughts on these articles? Because although they are not taking hold in the Congress, it does provide certain people with arguments to slow it down. And all of you have been suggesting that now is not the time to slow down.

Do you have any thoughts about this? Yes, sir?

Dr. MACKENZIE. I have considerable thoughts on them. As you well know, there's a move out there amongst certain scientists, working for certain organizations, to come up with information to try to falsify the hypothesis of global warming, and that's the way science works—we try to destroy the hypothesis, we try to tear it apart. That's the way that scientific method works. And so, some of them are doing it, I think, fairly, they're doing it, but others, I do think have certain political or other motivations.

Having said that, let me backtrack in geologic time, and come forward to today, because I think it will answer your question about what we've seen in the past—and the past has been great, why is the future so frightening, maybe? Through the last 600 million years of Earth's history, we have had changing atmospheric carbon dioxide concentrations. Indeed, 400 million years ago, carbon dioxide concentrations in our atmosphere were 18 times the present pre-industrial level of 280 parts per million.

Coming closer to today, during the Cretaceous, at 100 million years ago, those concentrations were 8 to 10 times higher. During both of those periods, the Earth was warmer.

Now, between those periods, we had carbon dioxide concentrations that looked much like those of the pre-industrial age—concentrations much like what we had before we came into this human anthropogenic scene. And at that time, one was the so-called Permian Triassic, we had big glaciers. Now we have big glaciers. So, we are in a relatively cold period of Earth's history.

During that whole time, as atmospheric carbon dioxide concentrations were changing, oxygen concentrations were changing, and sea water chemistry was changing dramatically. But, these were very slow changes—they weren't changes that occurred on a scale of tens of years to hundreds of years. These were changes on a scale of 5 million, to 10 to 100 million years.

Coming close to the present, during this last great Ice Age, the Pleistocene glaciation developed 1.8 million years ago. Since then, we have seen a series of warm and cold stages. The last glacial maximum ended 18,000 years ago, and we are currently in an inter-glacial, a warming phase of those great inter-glacial warm/cold cycles, each lasting about 100 million years.

Those cycles had nothing to do with the anthropogenic CO_2. Those cycles were driven mainly by what is known as the Milankovitch Hypothesis, which is a hypothesis which shows how much more or less radiation the Earth receives as it moves about its sun, and its orbit about the sun changes with time. Even then, when the Milankovitch 4 scene changed, the carbon dioxide, methane, and nitrous oxide levels in the atmosphere also changed. So that, during the ice ages, carbon dioxide was very low—on 180 parts per million by volume, 18,000 years ago. Methane was low, nitrous oxide was low. Going back to the last, but ultimate, interglaciation, the converse was true—carbon dioxide was about 280 parts per million by volume, almost like late pre-industrial age time, methane was high, and nitrous oxide was high.

But during this whole—the record now, the ice core record, which is the observational data for what I've just said—goes back more than 600,000 years. And at no time during that period of time, did we have atmospheric carbon dioxide concentrations above 280 parts per million. That only started when humans began to influence the system in the 18th century.

And so, the rise in CO_2 from the late 19th century, on up until today, is totally due to fossil fuel burning, and land use activity. And anyone that denies that is sadly mistaken.

The same is true for all of the other anthropogenic gases. They have risen far above their pristine levels in the atmosphere.

The CHAIRMAN. Do most of the scientists involved in these studies agree that the sea level in the next 50 years will rise about a meter?

Dr. MACKENZIE. I think up until the recent news that we received, most people would have believed the IPCC, which in their 2001 report under a business-as-usual scenario, the largest rise they anticipated at that time was on the order of 88 centimeters—almost a meter. They have reduced that in their 2007 report to 58 centimeters.

However, that report does not take in the recent evidence of melting of our ice sheets—not just Greenland, but West Antarctica, too. And they're melting at increasing rates, the ocean is warming quickly, and part of the rise in sea level is due to the warming of the ocean and its volume increase, because of isothermal expansion.

I'm a mountaineer by avocation, I've climbed all over the world, and I can tell you that most of the valley and mountain glaciers are melting very rapidly. And so, all of that water is going into the ocean. So now the presumptive idea is that we are probably—let me, let me phrase in the way the IPCC 2007 phrases it, it is very likely we will see a 1 meter rise in sea level by the year 2100.

The CHAIRMAN. Dr. Leong, Mr. Thomas, do you agree or disagree?

Dr. LEONG. This is not in my field, so I can't speak as expert, as Dr. Mackenzie does. But I do agree that we have to plan for that, that this might happen. And we have to plan for thermal warming, because our coral reefs will have, within the next 10 years, many episodes of coral bleaching.

Mr. THOMAS. Perhaps I can put this more on a policy level, in how we integrate our science with policymaking.

As you know, NOAA is a science agency, and we have a very public purposes. And we take our sense of mission very seriously. And as part of science, we have to ensure that what we do is justifiable, is defensible, is scientifically significant, and more importantly, it's socio-economically significant.

So, I'd like to follow up on Dr. Mackenzie's comments by not only reiterating what he said, but also in addition to the historical data—this is something that is really on a global scale. And research takes a long time—to really determine what is scientifically significant.

We have 50 years, and counting, worth of data that backs up everything that Dr. Mackenzie has said. And, you know, to the point where NOAA—and, you know, Federal agencies are reluctant, at times, to say things very unequivocally, but NOAA has come out very publicly, and said unequivocally that warming of the climate system is unequivocal, and most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in greenhouse gases caused by humans. I mean, that is a very clear statement we have from NOAA based on its research.

But there are uncertainties, I mean, with that statement, there's still a lot of things that we don't know. And, you know, things like the rate of warming, including the abrupt and extreme changes, I think, which is what some of the scientists that you've heard are referring to, as well as regional climate variations and change.

But with that, also, goes the fact that we have to create policies that require some mitigation and adaptation, but we don't really know what the effect of those strategies will be. Those things are still uncertain. But, I think from our standpoint, based on our understanding of our own data, as well as the data of many other scientists, that we state unequivocally that global warming is here.

The CHAIRMAN. As you may have concluded, most Members of Congress, on a bipartisan basis, are becoming a bit more concerned, and a little fearful of what may happen to us. We have passed laws that will set certain standards and levels.

However, a recent report suggests that the two major culprits of greenhouse gas emissions are China and the United States. Scientists suggest that even if the U.S. and the rest of the world should decide to do something about it, but if one major country the size of China continues business-as-usual, it would be an effort that might not pay a dividends.

Do you agree?

Dr. MACKENZIE. If I understand the question correctly, you're implying that perhaps the United States may take action but China would just continue on, and what that—just our taking action—have impact, if China did not. Is that, generally, the—?

The CHAIRMAN. Well, Congress is now considering laws that may be considered unfriendly, such as if products being shipped into the United States have been produced without consideration of carbon dioxide emissions, they will not be permitted to be sold in the U.S. And hopefully, by doing that, influence producers of products. But we have no idea whether they will work or not.

Dr. MACKENZIE. This worries me, and it worries me mostly from the standpoint that global warming is not a regional issue, it's not a national, single nation issue, it's a global issue.

China is not the only country that's moving forward quickly, and unfortunately in their case, using mainly their coal resource to burn, but they are also, now, importing oil. And I believe either this year or—well, probably this year, if they haven't already, because the statistics are hard to get—China has passed the United States in total emissions of CO_2 to the atmosphere.

But China's not the only one. India is growing very rapidly, all of Southeast Asia. So, if I were, myself, were doing anything, I would rather see global action on the problem, global agreement on how we deal with all of this, rather than individual nations being punitive, or taking actions simply on their own for whatever reason.

You know, there's a lot of talk about mitigation here, in Hawaii, but you know, mitigation is not going to do this problem, global warming, one bit, in terms of Hawaiian mitigation. I think it's great from a sustainability standpoint.

The CHAIRMAN. That's why we're hoping that the Kyoto Protocol would be a good first step, but the U.S. has not adopted it, completely, you know.

Dr. MACKENZIE. I think the other issue there is we've got to reign in the deforestation, because that's 20 percent of the carbon dioxide emissions. So, while we're looking at the fossil fuel issue, and how we're going to deal with that globally, we also have to be looking at the deforestation issue, which is mainly in the developing world, and how we're going to deal with that in an equitable way.

The CHAIRMAN. We're aware of that, and we are concerned. I'd like to thank all of you for your participation here, and we will be submitting, if we may, questions that we hope you can respond to.

Dr. LEONG. Thank you.

Dr. MACKENZIE. Well, thank you for the invitation.

The CHAIRMAN. We could have had an informal gathering and just have discussions, but because of the severity of the problem, we decided to at least give it an official mantle and so that it would be on the record.

And we do intend to do the right thing, but as you may be aware, there isn't a single scientist in the Congress of the United States. We have no idea what's happening, but we have to take your word, so your answers to our questions will be very important.

Thank you very much.

Dr. MACKENZIE. Thank you.

Mr. THOMAS. Thank you.

The CHAIRMAN. Our next panel consists of the Director of the Hawaii Natural Energy Institute, School of Ocean and Earth Science and Technology, University of Hawai'i, Mānoa; Dr. Richard E. Rocheleau, Dr. Karl Kim, Professor and Chair, Department of Urban and Regional Planning, University of Hawaii at Manoa; and Dr. Goro Uehara, Professor, Department of Tropical Plant and Soil Sciences, University of Hawai'i at Mānoa.

STATEMENT OF RICHARD E. ROCHELEAU, PH.D., DIRECTOR, HAWAII NATURAL ENERGY INSTITUTE, SCHOOL OF OCEAN AND EARTH SCIENCE AND TECHNOLOGY, UNIVERSITY OF HAWAI'I AT MĀNOA

Dr. ROCHELEAU. I am the Director of the Hawaii Natural Energy Institute at the School of Ocean and Earth Science and Technology at the University of Hawai'i.

And I just wanted to take one moment to acknowledge my co-author on this testimony, Dr. Terry Surles, who prior to joining the HNEI faculty was the Associate Lab Director in charge of Energy at the Livermore National Laboratory, and has served on the National Academies of Science Committee examining federally funded energy research programs.

Our faculty at HNEI conducts research on many technologies in the areas of renewable energy and ocean resources, including hydrogen fuel cells, conversion of biomass to fuels, and high-value products, seabed methane hydrates, photovoltaics, battery technology and microbial systems. We are also leading the UH effort to establish an ocean energy center in Hawaii.

Support for this work comes from a variety of government and private sources, and HNEI operates a number of laboratories to conduct this work. And I just wanted to say, information on these specific projects is available on our website, but that wasn't the focus of my talk today.

While I was asked to discuss our work related to clean energy technologies, I want to make a few comments about the relation between global climate change and energy. These largely derive from the IPCC report that many people have referred to. And then to give a few concrete examples of the magnitude of this issue, in regards to managing CO_2 by transforming our energy infrastructure, and finally, talk about HNEI's efforts to develop partnerships to accelerate the development and deployment of renewable energy technologies.

We've heard this before, but at the most basic level, the balance between incoming solar radiation and outgoing infrared radiation determines the Earth's climate. And greenhouse gases, including CO_2, do affect this balance whether naturally occurring or from man.

The most recent Intergovernmental Panel on Climate Change is unequivocal in its conclusion that the Earth is warming, and attributes this to greenhouse gas concentrations in the atmosphere. And the most often-cited evidence is the increase in the CO_2 concentration from the pre-Industrial Revolution level of 280 parts per million to today's level of 380.

The concerns about global climate change, global warming and CO_2 emissions has been much more publicly visible and of interest since the Kyoto meeting in 1997. In spite of this increased awareness, the rate at which carbon dioxide is being released into the atmosphere continues to increase, from around 6.4 billion tons per year in the 1990s to over 7 billion tons per year in the 2000–2005 time frame.

In fact, a report that just came out today from U.S. DOE, or at least a citation of a report, reported that power plant carbon emissions in the U.S. went up 3 percent between 2006 and 2007. So, in spite of the awareness, not much is being done to reverse the trend.

We just heard from a panel that talked about the implications of this, and I'll simply state that the bottom line is that the impact on island nations is likely to be significant, and some island nations may simply cease to exist if the sea level rises that are predicted do occur.

The magnitude of this problem is daunting. I noted just a minute ago that we currently emit about, worldwide, about 7.2 billion tons of carbon per year. To put this in perspective, I want to talk about the energy infrastructure changes that would need to be made just to displace one of those 7 gigatons.

We would need to replace seven hundred 1,000-megawatt coal plants that are currently in operation today with coal plants that include carbon capture and geological storage. Neither of those technologies are available today.

We will have to install 150 times the current world capacity in wind turbines, or replace 2 billion 30 miles per gallon efficiency cars with 60 miles per gallon. And that would only make a 1 gigaton, or a 15 percent reduction in our annual output.

So, the next question is, what would we need to do to make a significant impact on global emissions? The IPCC targets immediate action in an attempt to limit carbon dioxide in the atmosphere to 550 ppm, twice the pre-industrial level, and more than 50 percent of what we have today. To meet this goal—basically to reduce—we will have to reduce our carbon intensity, which is the carbon emissions per dollar of productivity, to approximately 10 percent of what it is today—it's a huge reduction.

To give you some idea of what this would require, we will have to generate 75 percent of all our electricity from non-fossil sources, we will have to increase energy end-use efficiency by 1 percent per year, every year, and nearly double the efficiency of our electricity generation, and also increase average passenger car mileage up to 50 miles per gallon. Even then, we will need additional technological breakthroughs to get to the 10 percent carbon intensity level. So, the magnitude of the problem is huge.

People talk about potential solutions, obvious ones are use less energy—helpful, it won't do it all by itself. Carbon sequestration—necessary, not yet available. And significant increases in renewable and nonfossil-based energy. And the numbers you just heard show how daunting that task is, but we basically need to try to make progress in all areas.

So now I'm just going to discuss for a few minutes, 2 minutes or so, remaining, some of the HNEI efforts.

As we've already heard, Hawaii imports a majority of its energy, about—over 90 percent. Well, it's characterized by an unusually high dependence on oil for power generation. And this reliance on fossil fuel is juxtaposed against an abundance of renewable resources which could be used for energy. And so, our position is, you know, with this—and other people in the sdtate—with this array of renewable resources, and the opportunity for high-productivity energy crops in Hawaii, renewable electricity and bio-derived fuels offers great promise for Hawaii to reduce its dependence on fossil fuel, and for Hawaii to serve as a model to demonstrate the ability to do this for the rest of the Nation.

As the Chair has already noted, this potential has attracted the attention of the Department of Energy, which recently signed an MOU with the state identifying 70 percent of our energy from renewable resources by 2030, as a goal, and the state has, itself, enacted renewable portfolio standards, targeting 20 percent of our electricity by renewables by 2020.

Given today's energy system, and some of the difficulties, even the more modest goal is going to be a challenge. HNEI is committing its resources to developing partnerships which will help provide analysis and tools to help identify paths forward—ways to make the proper decisions to move forward, and to identify critical projects that can demonstrate the ability to integrate today's technologies into the grid. The ultimate goal is to use Hawaii as a model for high-penetration renewable energy generation. And I'm going to speak very briefly about two projects that have been underway and are continuing today.

As documented in my written testimony where I summarize some of the energy technologies, there are a number of commercial and emerging technologies—wind, solar, ocean energy systems—

that do offer the potential for large-scale penetration into our grid. However, these are inherently more variable and less dispatchable than conventional energy.

The utilities, the operators, and planners will have to change the way they do business. HNEI has partnered with the local utility, with GE Global Research, with the state and with the U.S. Department of Energy to identify solutions to this problem. The thrust of this is to develop models and other tools that can be used to direct future development of renewable energy systems on the islands. This was initiated on the Big Island, now includes Maui and this year is expected to move to O'ahu and Kauai.

These tools are providing information on approaches for placing more renewable energy into the mix, and it will help identify enabling technology so the utility can do so.

The Department of Energy is interested in this because our current stability/reliability issues on these islands will eventually be faced on the mainland, as well.

In the biomass arena, we do do work on basic research, but again, we are trying to develop partnerships to move our technologies forward, using partly what is available today.

Researchers at HNEI and the College of Tropical Agriculture are working collaboratively on new energy production systems. This includes crop screening for high-productivity, high-yielding crops and conversion technologies that can be integrated for the maximum energy production potential. The economic feasibility of the integrated bio-energy systems will be used to select the appropriate technology to move forward.

We are also working with local and national industry to try to demonstrate promising biofuels technologies in a small-scale, tropical bio-refinery. This effort is in its infancy, but the eventual goal will be a pre-commercial demonstration of a tropical bio-refinery system, which could then be replicated in many of the high-production, high-productivity tropical regions around the world, to provide biofuels.

A quick note—one of the key tools to moving forward with new energy technologies is policy, and HNEI is working closely with the Department of Energy, the PUC, state energy office, and the energy providers to provide unbiased information to help develop appropriate policy to move the state forward.

Just kind of going back and repeating again—Hawaii provides—and in closing—a very unique environment that will allow quantitative evaluation of grid integration and commercialization of renewable technologies, and it can be a model for our state and our county. It's really unlikely that the public or the private sectors alone will be able to solve this—it's going to take an integrated, concerted effort.

Just as a note, the issue today was global warming, but the issues associated with renewable energy also impact our energy security both in the state and in the Nation, so these are objectives we should try to meet regardless of your position on global warming. And, as I said, this is going to require concerted and collaborative effort among all of the partners, and continuity of funding to move this forward in the national interest, and thank you very much for this opportunity to testify.

[The prepared statement of Dr. Rocheleau follows:]

PREPARED STATEMENT OF RICHARD E. ROCHELEAU, PH.D., DIRECTOR AND TERRY SURLES, RESEARCHER, HAWAII NATURAL ENERGY INSTITUTE, UNIVERSITY OF HAWAI'I AT MĀNOA

Introduction

Good morning, Chairman Inouye and Members of the Committee. Thank you for the opportunity to testify on this very important matter—Climate Change Impacts and Responses in Island Communities. My name is Richard Rocheleau. I am Director of the Hawaii Natural Energy Institute (HNEI). The Institute is an organized research unit in the School of Ocean and Earth Science and Technology at the University of Hawai'i at Mānoa. HNEI's faculty and staff conduct a range of research in the areas of renewable energy and ocean resources and manage several larger public-private partnerships to accelerate the acceptance and deployment of renewable energy technologies into Hawaii's energy mix. Our primary areas of emphasis includes development and deployment of hydrogen and fuel cell technologies, conversion of biomass into fuels and other high value products, advanced batteries and their applications, photovoltaics, seabed methane hydrates, and analysis of integrated energy systems to facilitate high penetration of intermittent renewable energy technologies into electrical grid systems. As the renewable technologies mature, the ability to deploy them in an economic and environmentally sound manner without negatively impacting the reliability of our energy systems becomes of paramount importance.

My own personal research has been in the areas of photovoltaics, hydrogen technology and fuel cells. As Director, I have focused considerable effort on development of public-private partnerships directed toward the implementation and deployment of renewable energy technologies into the islands' energy mix. My coauthor of this testimony, Dr. Terry Surles, is a member of the HNEI faculty. Prior to joining HNEI he was the Associate Lab Director at Livermore National Laboratory for Energy, was General Manager of Environmental Programs at Argonne National Laboratory, was the head of the Public Interest Energy Research Program at the California Energy Commission, and served on a National Academy of Sciences committee examining prospective benefits of federally funded energy research. Dr. Surles' primary interests are integrated energy systems as they relate to solutions for global climate change and energy security issues.

I have been asked by this Committee to discuss our work related to clean energy technologies. Hawaii is very concerned about global climate change and energy security. It is unique among the 50 states in its dependence on oil for the production of electricity—about 86 percent of Hawaii's electricity is produced from oil. The grid systems are small by mainland utility standards and on the neighbor islands are relatively sparse leading to high costs for transmission and distribution. These factors, and Hawaii's abundant supply of renewable energy resources, offer a unique opportunity for Hawaii to serve as a "living laboratory" to identify the achievable limits for the deployment of renewable energy systems and to evaluate the impacts, benefits, and issues associated with such deployment to ameliorate global climate change and petroleum dependency.

The problems are not simple. Even renewable energy systems can have a CO_2 footprint—some such as ethanol from corn can be almost as large as that from petroleum. Due to intermittency and reliability, there are practical limits to the penetration of renewable systems on the grid. Can these limits be pushed sufficiently far and fast enough to have a significant impact on emissions and global climate change? HNEI and its partners are attempting to address these issues. In the last section of this testimony I do describe a few of HNEI's activities in this area, ones which if successful will impact not only the state but also the Nation. However, before describing what HNEI's activities are, I would like to take a few minutes to address global climate change and energy from the larger context. This discussion comes largely from the recent reports of the Intergovernmental Panel on Climate Change (IPCC) and related publically available studies.

Energy and Global Climate Change

At the most basic level, the balance between incoming solar radiation and outgoing infrared radiation (as heat) determines Earth's climate. Earth, it should be noted, is a greenhouse gas planet. Greenhouse gases, which include water vapor, absorb this infrared radiation, thus trapping heat near the earth's surface. Other gases, such as carbon dioxide, methane, and nitrous oxide, are also greenhouse gases. While these occur naturally, anthropogenic emissions of these gases, as well as man-made greenhouse gases (*i.e.,* chlorofluorocarbons), have substantially increased the amount of these heat trapping gases in the atmosphere.

Warming of the earth, according to the most recent Intergovernmental Panel on Climate Change (IPCC, 2007), is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea levels. The IPCC attributes this warming to the increase in greenhouse gas concentrations in the atmosphere. For example, the concentration of carbon dioxide, arguably the most important greenhouse gas, in the atmosphere has increased from about 280 parts per million (ppm) in the atmosphere prior to the Industrial Revolution to over 380 ppm at present. The continuously recorded data at the Mauna Loa Observatory demonstrate a seasonal, but monotonic, increase from about 315 ppm in 1958 to today's levels.

There are arguments that these changes are part of the natural climate cycles of the earth and not attributable to human factors. However, paleo-climate information supports the interpretation that the warmth of the last 50 years is unusual over at least the last 1,300 years. The last time the Polar Regions were this warm for an extended period was about 125,000 years ago. Vostok (the Russian research station in Antarctica) ice core data suggest that the earth may be as warm as it has been in the past 400,000 years.

Recent data also support the fact that the past 10 years contain many of the warmest years since weather data were being recorded. In fact, despite the increasing concerns about climate change and global warming, the rate at which carbon dioxide is being released into the atmosphere continues to increase from 6.4 Gigatonnes carbon (GtC) per year (6,400,000,000 tonnes C/yr) during the 1990s to about 7.2 GtC per year between 2000 and 2005, an increase in the rate of emission release of over 10 percent in 10 years.

The IPCC report provides projections for the future of earth's climate which include significant continued increases in temperature. For temperature change, the models are reasonably consistent in predicting increased temperatures based on the amount of carbon dioxide being emitted over this coming century. Since carbon dioxide will remain in the atmosphere for a very long time, even an aggressive response for reducing emissions is expected to result in an increase in temperature. Thus, a best case estimate for a low emissions and related temperature rise scenario will be between 1.1 °C to 2.9 °C (a global temperature increase of about 3 °F) by 2100. Other scenarios predict likely temperature increases in the range of 2.4 °C to 6.4 °C (a global temperature increase of about 7 °F) by 2100.

The implications of this considerable increase in temperature have been documented in numerous peer reviewed journal articles. Some of these impacts would include changes in cropping patterns due to an increase in drought and precipitation in agricultural areas. Other impacts on our food supply can include the introduction of invasive species, such as plant and animal pests as the climatic conditions may change. Additional impacts may be related to human health as tropical diseases become prevalent in formerly temperate climates.

The impacts of the changing climate are now beginning to manifest themselves. Over the past decade, we have seen increased precipitation in the mid-latitudes, further drying of lower latitudes (leading to increased desertification), and more intense and longer droughts in the tropics and sub-tropics. The lack of water will potentially impact Pacific Island nations in the nearer-term. There is reasonable expectation for these precipitation trends to continue.

In the longer term, some island nations may simply cease to exist due to rising sea levels associated with melting land-based glaciers and sea water expansion due to increased water temperature. *Conservative projections for sea level rise, even under the best of circumstances, are for a rise of slightly over three feet over the course of this century.* For many low lying islands, this amount of sea level rise would have a substantive impact. Sustained temperature increases that are implied in the higher scenarios, described in the preceding paragraph, could eventually—over the course of this century—melt the Greenland ice sheet, causing a sea level rise on the order of twenty feet.

A substantial amount of carbon dioxide emissions is due to our use of energy. The onset of the Industrial Revolution is generally equated with the start of large-scale burning of coal in England. The majority of today's carbon dioxide emissions arise from the burning of fossil fuel including coal, oil, and natural gas. In the mainland U.S., coal-fired power plants, the worst emitters, account for slightly more than 50 percent of the electricity generation. In Hawaii, about 86 percent of electricity is provided by oil-fired generation and 7.4 percent is provided by coal-fired generation.

For transportation, the situation is similar and possibly even worse. Almost all of our Nation's transportation fuel is derived from petroleum. It should be noted that this dependence on petroleum is also a key contributor to our Nation's energy security issues as well as the foreign debt/balance of payments problems. Thus, there is clear reason for linking security and climate change issues for our country's well-being.

The magnitude of this problem is daunting. For example, we discussed the fact that the world is currently emitting 7.2 gigatonnes of carbon a year. To put this into perspective we offer some examples of the changes to our energy infrastructure that would be required to reduce emissions of carbon dioxide by one gigatonne per year (from R. Socolow, Stanford Hydrogen Workshop, 2003). These include:

- Install 700 1000 MW coal-fired power plants that include carbon capture and geological storage (not even available yet);
- Install two thousand times (2000×) the world's current supply of photovoltaics.
- Install 150 times (150×) the current worldwide capacity of wind turbines;
- Replace two billion 30 mpg efficiency cars with 60 mpg efficiency cars.

The implication of climate change mitigation is that we must try to stabilize the concentration of carbon dioxide in our atmosphere to a doubling of pre-industrial concentrations in order to not suffer unknown, but potentially catastrophic effects. In other words, we need to take immediate action to limit carbon dioxide in the atmosphere to a concentration of 550 ppm. Since we are already seeing impacts at 380 ppm concentrations, even this may be too high. However, as discussed in the preceding paragraph, the changes in our energy infrastructure required to control carbon dioxide emissions are daunting. In order to achieve and maintain a 550 ppm atmospheric concentration of carbon dioxide by the end of the century, we will need to reduce our carbon intensity to less than 10 percent of what it is today. (Carbon intensity is the measure of carbon dioxide emitted to the atmosphere divided by the gross domestic product.)

Projected requirements to achieve this 10 percent goal include accomplishing *all* of the following:

- Generate 75 percent of all electricity from non-fossil sources.
- Increase end-use energy efficiency increases by 1 percent per year every year.
- Increase electricity generation efficiency to 67 percent (currently about 35 percent) by 2050.
- Increase passenger car mileage to average 50 mpg by 2050.

Even if all of these are achieved, we will need additional technological breakthroughs to achieve a carbon intensity goal of less than 10 percent of our current value and even that will only limit the planet to a doubling of its atmospheric carbon dioxide concentrations from pre-industrial times.

For our country and for our state, we must pursue all technology solutions. The most effective solution is to simply use less energy. The highest priority for many state public utility commissions starts with end-use energy efficiency. This needs to involve not only the request to change lifestyles, but to develop and commercialize new end-use technologies that are more energy efficient in meeting the demands of the economy.

Another mechanism is to sequester (capture and store) carbon dioxide from coal-fired power plants. This is currently a technology under development that still faces a number of environmental, engineering, and financial challenges before reaching any stage of commercialization. Recent estimates report that CO_2 capture may require at least 25 percent of a pulverized coal-fired power plant's total output (C&E News, March 3, 2008). Newer technologies, such as oxy-combustor and integrated gasification/combined cycle systems, may allow for the continued use of coal and the more cost-effective capture and geological storage of carbon dioxide. This will allow our country to continue to utilize indigenous national energy resources.

Another approach—and one which will now be discussed at greater length—is the increased utilization of renewable energy resources. The greater use of these indigenous resources will allow us to reduce our dependence on foreign energy resources, while at the same time reducing carbon dioxide emissions for the amount of energy we consume. As noted earlier, the carbon emissions for any renewable resource technology are not zero. When one takes the technology's life cycle into consideration, carbon dioxide and other greenhouse gases are emitted during the fabrication or operation of these technologies.

As indicated, if we are to make progress against increasing CO_2 emissions, the solutions will necessarily be multifaceted. Renewables offer one potential solution for reduction of fossil fuel usage in both the electricity and transportation sectors. With its wealth of renewable resources, renewables can be a particularly effective approach for the state of Hawaii. The issue before the state is how to utilize these resources in an economic, environmentally-sensitive, and societal-acceptable manner. The next section provides a very brief summary of the status of various renewable energy resources and issues related to the deployment of related commercial technologies.

Renewable Energy Technologies

Hawaii is blessed with almost every renewable energy resource imaginable. With its high cost of electricity and fuels, wealth of renewable resources, and stand-alone grid systems, Hawaii can serve as a model system for the rest of the Nation in the deployment of renewable energy systems. However, before moving onto the Hawaii energy situation and HNEI's energy activities, I would like take a few minutes to provide a very brief review of the status, potential and unresolved challenges associated with the various renewable energy technologies.

Wind

Other than conventional hydroelectric power, wind is arguably the most developed of the renewable technologies. Megawatt (MW) sized wind turbines are available from a number of suppliers and have been shown to be cost effective where siting and integration are not issues. However, wind is characterized by restrictive operational constraints in terms of its intermittency (on both a second-by-second and day-by-day basis) that can have a substantive effect on the stability and reliability of the electricity grid limiting the allowable penetration onto the grid system. Siting can also be a challenge. Resource maps for wind can be useful, but wind is a localized resource. These resources are not always located where the electricity load is. Thus, long distance transmission is a challenge. Additionally, there can be localized opposition to wind due to perceived visual, noise, and aesthetic effects. Off-shore wind development has been proposed as an answer to land-use issues, but deployment is limited to relatively shallow regions which open the door for visual impact concerns. This has been part of the on-going discussions over the development of a wind farm in the near-shore area of Cape Cod in Massachusetts. Wind capacity factors (percent of energy relative to nameplate) are typically around 35 percent and only 45 percent in best wind regimes. Thus, as with other intermittent renewable resources, the utility must have nearly equal back-up capacity for each MW of wind. Even when the operating utility has spinning and regulating reserve on line to control power quality and to allow rapid response to sudden losses in wind, sudden changes in wind speeds can destabilize the grid. Power quality and response issues increase non-linearly as wind penetration increases and become significant at percentages in the 10 to 20 percent range. Issues, as we are finding in Hawaii, are seen first on smaller grid systems. However, even on a large continental-based grid, reliability issues may arise. For example, just 2 weeks ago, the Texas grid system almost went down when there was a sudden and significant loss of wind.

Biomass

Biomass, organic matter of biogenic origins, is currently used as a feedstock for the production of fuels, chemicals, power, and heat. This flexibility to serve both fuels and power applications is a major difference between biomass and other renewables. The three primary sources of biomass in the U.S. today are wood, waste (*e.g.,* Municipal Solid Waste), and crops for alcohol and plant oil based fuels. The first two groups are used almost exclusively for the generation of heat and power, and in 2005 accounted for 82 percent of biomass consumption on an energy basis. (EIA, *http://www.eia.doe.gov/cneaf/solar.renewables/page/biomass/biomass.html*).

The current development efforts for biofuels in the U.S. has focused primarily on ethanol produced from corn and biodiesel produced from soybeans. Ethanol production from corn approached 5 billion gallons in 2006 (~3 percent of overall gasoline consumption) and is expected to show continued growth. Biodiesel production was significantly less at ~100 million gallons representing only about 0.25 percent of distillate fuel consumption. The impacts of rising petroleum prices and growth in demand for biofuels have resulted in increased biofuel production and, even at these modest levels of production, have led to competition with food supplies. Unlike electricity, where several renewable technologies can be used to displace fossil fuel power generation, renewable liquid transportation fuels are expected to come almost exclusively from biomass.

It is generally agreed that current biofuels systems (crops and conversion technology) are not sustainable, certainly not at the scale needed to impact long-term energy security or climate change. To achieve sustainable biofuels systems, production of biomass will need to focus on the use of marginal agricultural lands, improved crop yields, reduced production inputs (*i.e.,* water, fertilizer, etc.), development of non-agricultural biomass resources, and improved biofuel production technologies and end-use efficiency. The transition from fossil fuels to biofuels will only be achievable with development of appropriate policy that will provide the sustainability and stability needed for long-term investment at all points along the value chain.

The development of technology to produce transportation fuels from materials less valuable than corn or sugar has focused on using fiber (*i.e.,* wood, straw, bagasse, etc.) as the feedstock. Integrated biochemical and thermo-chemical technologies currently under development are positioned for use in bio-refineries of the future and show great promise. However considerable time and investment in R&D and commercialization are required. These efforts need to be afforded a high priority.

Photovoltaics

Solar photovoltaics are reliable and commercially available but continue to suffer from high costs. The current market is dependent on subsidies and/or tax credits with a significant part of the commercial sales taking place in only a few places (Germany, California, and New Jersey) where aggressive subsidies are provided. The majority of the market today is served by some form of silicon wafer but a number of thin-film and 3rd and 4th generation materials are under development. Since a PV system includes the other module components, hardware for mounting and installation, and balance of plant for integration to the household or grid; cost of the actual semiconductor is only one of the cost factors that must be addressed. Integration into the grid is simpler than for wind (predictability better) but the relatively high cost is likely to limit deployment except in locations with high electricity costs such as Hawaii.

Solar Thermal

This technology is of interest in that it can provide for the use of power even when the sun isn't shining through the use of heat transfer and storage fluids in its system. Currently, these systems are in use in parts of the world, such as the Negev Desert, where there is little scattering of the incident light. Their potential, while considerable in Hawaii, still awaits further reductions in operational costs and in confirmation of longer term efficacy of stable operation.

Geothermal

This is a proven technology where the resource allows use of conventional power generation technologies, *i.e.,* geothermal resource provides steam for power generation. Newer technologies such as engineered geothermal systems (EGS) which use water injection to utilize dry geothermal heat for steam production are under development. There are positive projections of cost for EGS, but these systems have not yet been demonstrated in a commercial setting. Under heavy use, long term viability of a geothermal resource can be an issue. Siting for naturally occurring geothermal fluid systems is an issue in that they are only available in a limited number of locations. EGS systems however have a much greater area upon which to draw and could form the basis of a distributed generation system. Unlike most other renewable technologies, intermittency is not an issue. Thus, geothermal energy can be used for base load power.

Ocean Energy Technologies

Ocean Thermal Energy Conversion (OTEC)—Net power production has been demonstrated from OTEC but questions remain about the efficiency of the process, cost, demonstrated lifetime, and design efficiency. In addition, there is limited potential for the mainland U.S. without some form of chemical energy transfer which today is too expensive. At the gigawatt scale, this technology uses enormous amounts of deep sea and surface sea water which may have significant long term environmental impacts.

Wave —There are many (up to 40) competing wave energy technologies worldwide. While there has been significant progress in recent years, many ocean deployments to validate system performance have met with limited success. Capital, including installation costs, is a significant factor. One point that is seldom made, although obvious, is that the ocean environment is harsh from both corrosion and simple wear and tear. Therefore, longer term efficacy related to O&M needs to be demonstrated. Intermittency will require back-up energy generation technology, but rapid transients such as those associated with wind are not expected to be apparent. Thus, high penetration is theoretically possible.

Hydrogen and Fuel Cells

Hydrogen is an energy source, such as the sun or a fossil fuel. Rather, hydrogen is an energy carrier like electricity. While hydrogen is the most plentiful element in the universe it does not occur freely. It must be manufactured from compounds in which it is bound. Hydrogen can be produced by electrolyzing water and from the gasification of biomass.

Hydrogen can be used to generate electrical power electrochemically in a fuel cell or to produce mechanical energy by thermo-chemical combustion in an internal combustion engine. In the case of a fuel cell, the product of combustion is pure water; in an engine it is water and some nitrogen oxide. Economics dictate that renewable electricity is best utilized to power the utility grid with any surplus used for hydrogen production via electrolysis.

When considering hydrogen as a potential energy carrier, all of the elements making up the system must be considered. These elements include the production, storage, and transport requirements, plus the end-use utilization of the hydrogen. Although considerable progress has been made over the past 10 years, all of these components of the hydrogen system are in the development stage and not yet commercial. However as the price of oil increases, the value of clean energy solutions becomes more important, and technical progress is made, hydrogen is expected to become an important component of future energy systems, and Hawaii could be one of the earliest adopters.

HNEI Activities Related to Clean Energy Technologies

Hawaii imports fuel for generation of the majority of its energy (93 percent) characterized by an unusually high dependence on oil for power generation. This substantial reliance on fossil fuels is juxtaposed against an abundance of renewable resources which could be used for energy. With this array of renewable resources and the opportunity for high productivity energy crops; renewable electricity and bio-derived fuels offer great promise to reduce the states' dependence on fossil fuels and for Hawaii to demonstrate for the Nation, the potential of energy independence through renewable energy. This was recognized in the recent MOU between the State of Hawaii and U.S. Department of Energy where a goal of 70 percent of the state's energy from renewable sources by 2030 was announced. While an admirable goal, and arguably one that is necessary nationally and internationally if we are to impact CO_2 emissions and climate there are very significant hurdles—technical, economic, and policy—to be overcome if there is to be significant progress toward this goal within the critical 10 to 15 year time-frame in which consensus estimates agree that world-wide conventional oil and gas resources will not meet demand. Although the goals are less aggressive, in 2004, the State enacted a new Renewable Portfolio Standards law (S.B. 2474) setting a renewable energy goal of 20 percent for 2020. However, implementation even at this modest level of penetration remains a challenge.

As summarized in the introduction, HNEI conducts research and development in a number of technology areas. HNEI has also committed substantial resources and effort to development of public-private partnerships which will: (1) provide for development of analysis and tools to identify the optimal path(s) forward and (2) identify critical projects to validate key renewable technologies and the ability to integrate these technologies into the energy mix. It is these latter integration activities which can most quickly effect change in the state and for that reason, will be the focus on my discussion today of HNEI activities.

Renewable Energy Deployment: There are a number of commercial and emerging technologies such as wind, solar, and ocean energy systems that offer the potential for large scale penetration of renewable electricity into the grid. However, each of these technologies is inherently more variable and less dispatchable than conventional generation. Their implementation will require utility system planners and operators to adopt new technology and new strategies to ensure reliable and efficient electric grid operation. HNEI, in partnership with the local utility, GE Global Research Center, the state, and U.S. DOE, has developed a substantial program to identify potential solutions to high penetration of renewables. HNEI holds a unique position in being able to merge interests and funding from a variety of public and private resources.

The thrust of this current project is to develop models and other analytical tools that can be used to evaluate the future development of renewable energy systems on each of the islands, addressing specific island energy systems and resources. This effort was initiated on the Big Island, now includes Maui, and is expected later this year to include Oahu and Kauai. Using the Big Island effort as an example, operations and modeling show that the electricity that is available from existing wind power on the island can compromise the stability and reliability of the grid. At the same time, the state Renewable Portfolio Standard is mandating additional renewable energy installation between now and 2020 and independent power producers are pushing for increased use of wind by the utility. Use of these scenario analysis and management tools is providing information on approaches for placing more renewable energy systems on the Big Island. These analyses also demonstrate the need for development, demonstration, and deployment of enabling technologies for renewable systems. These enabling technologies will necessarily include electricity storage systems (for both second-by-second response and for bulk storage), advanced power electronics, and demand-response technologies.

These scenario analysis and management tools also allow characterization of the benefits, costs, performance issues, environmental and societal issues, and impacts of various solution scenarios for each of the main islands.

Additional projects in these areas have been proposed using the existing partnerships to leverage resources to validate technology integration solutions through field demonstrations. As discussed in more detail below, these analyses also help provide robust policy analysis to support legislative solutions to ensure a systematic and reliable transformation of Hawaii's energy systems. The Department of Energy is interested in this work, since the current stability and reliability issues facing the Big Island are expected to be replicated on the mainland.

Tropical Biofuels: In the biomass arena, there are numerous technologies in various stages of development in Hawaii and elsewhere with potential to contribute to Hawaii's energy solutions. Analogous to the integration issues being addressed for high penetration of renewables onto the electricity grid, cost-effective deployment of these emerging biomass conversion technologies for power or fuels production require substantial integration to effectively utilize the biomass resource. Additionally, many of the biomass resources and conversion technologies are yet to be validated for commercial deployment. HNEI has embarked on a number of partnerships to address these issues.

Researchers in HNEI and the College of Tropical Agriculture and Human Resources are working collaboratively to develop new bioenergy production systems for Hawaii. Crop production research activities include screening candidate crops suited for the tropics under different soil and climatic conditions (benchmark locations) and selecting for high yielding varieties with the greatest energy production potential. The feedstock properties that are important in bioenergy conversion vary between crops and may depend on environmental factors. These properties are quantified for selected candidate feedstocks and conversion tests are performed in laboratory or bench-scale equipment to optimize biomass conversion methods across the range of fuel properties. The economic feasibility and energy productivity of an integrated bioenergy system based on the production of candidate crops and selected conversion technology options are evaluated. This integrated approach provides necessary analysis in support of bioenergy systems development.

Finally, HNEI is working with private industry to demonstrate promising biofuel technologies in small scale tropical biorefinery. Under this activity, HNEI is undertaking technology assessment including models of resource requirements for crop production and conversion technologies, integrated systems evaluation including characterization of benefits, costs, performance issues, and environmental and societal impacts of various systems. The eventual goal of this work is pre-commercial demonstration of a tropical biorefinery system.

The latter activity will be used to validate key process components and production targets and provide continuous, operational data at a scale sufficient to lower the technical risks associated with financing future commercial plants. All three tasks will seek to build partnerships with entities (land owners, businesses, State agencies, etc.) in the Hawaii biomass community and with groups from outside Hawaii that can provide technology, capabilities, and significant leveraging of project funds to help overcome the technical, economic, and resource barriers which have, to date, prevented significant progress in the development of new bioenergy projects in Hawaii.

Policy: HNEI is working closely with the U.S. DOE, the State Energy Office, the PUC, and energy providers to provide unbiased information for development of a set of policies which can help move the state forward. This project effort and other HNEI activities allow for the integration of knowledge gained from technology assessment with public policy analysis. One of the most efficient paths forward for commercializing new technology in this area is to link technology advances with public policy tools and initiatives. The information gained from this effort will provide the state Public Utilities Commission, for example, with information on how new power purchase agreements may be configured to reduce costs to the rate payer. This project can also provide information to commercial technology interests on how best to modify and configure their technologies for emerging electricity markets that are increasingly dependent on renewable and distributed energy. In short, there are many means and mechanisms for how public policy initiatives and technology development can be linked to provide benefits to consumers and—more broadly—to the state and nation. HNEI is working on ensuring that these mechanisms are as effective as possible.

Closing Remarks

Hawaii can and should be a "living laboratory" to explore the potential for validating the performance of various renewable energy technologies in commercial deployment. Our state also can provide a unique environment to allow for a quantitative evaluation of grid integration and commercialization of new technologies, not only for our state, but for the country as a whole. The active interest by state government, Congress, the energy community and the private sector allows for the integration of technology, commercial deployment and policy. While these are initially directed to Hawaii, in the future they can be applicable to national needs. This is particularly important for many of the larger scale issues facing our energy systems. It is unlikely that either the public or the private sectors can solve any of the large scale issues independently of the other. These issues—global climate change, energy security, grid modernization, and critical infrastructure, to name a few—require concerted and collaborative efforts and continuity of funding to be solved in the national interest.

The CHAIRMAN. Thank you.
Dr. Kim?

STATEMENT OF KARL KIM, PH.D., PROFESSOR AND CHAIR, DEPARTMENT OF URBAN AND REGIONAL PLANNING, UNIVERSITY OF HAWAI'I AT MĀNOA

Dr. KIM. Good morning, Senator Inouye. Thank you very much for this opportunity to testify. I'm honored to have this opportunity to speak about the impacts of climate change, and the response in island communities.

I'm also happy to follow my distinguished colleagues which make my testimony all that more easy.

I've just come from Tokyo, and the United Nations University, where I've been participating in meetings related to climate change, sustainability, disaster management and renewable energy. I'm also engaged in some research related to the modeling of efforts to reduce carbon emissions through urban planning and transportation, with the National Institute for Environmental Studies in Japan, and I'd like to report to you that these organizations are very much concerned about the anthropogenic sources of greenhouse gases.

Earlier today there was mention of a report issued by the Transportation Research Board, National Research Council, which I'm a member of. Next year, they will be focusing on the impacts of climate change on transportation infrastructure. I've prepared a paper for presentation at that meeting, so I want to again reiterate that there are many science-based organizations that are taking, very seriously, these issues of climate change, global warming and sea level rise.

Much of my research involves modeling the impacts of climate change, especially on critical infrastructure and on the social and economic life of communities, particularly in Hawaii. Cities or urban areas are, at once, both a cause and a solution to the problem of climate change.

On the one hand, as we've heard this morning, they consume tremendous amounts of land, resources, and energy, and generate vast amounts of greenhouse gases—cities store heat and are constructed of impervious surfaces contributing to runoff, flash-flooding and other ecological problems. And urban expansion, then, has also meant, globally, the loss of forests, agricultural lands, and other sinks for carbon sequestration.

So, but at the same time, cities also provide opportunities for increased density of development—reduction of travel distances for work, shopping, education, and opportunities to use new technologies for energy, communications, commerce and economic development. Adoption of sustainable, renewable green design planning and building techniques will not only help reduce the ecological footprint of cities and urban areas, but will also provide a pathway for continued growth and prosperity.

And it's really critical that our planning regime, including our comprehensive plans, our general plans, our development plans, our zoning codes, our building codes and other various community plans and project plans are realigned to address the conditions and needs created by climate change. If we start now, we can change this regime.

There have been some really important recent studies that have looked at, for example, the costs and benefits of hardening the shoreline versus managed realignment strategies, in which you encourage development to occur further inland. This is work that we can do now over the long term that will make a lot of sense.

And there are obvious technological issues, as well as political and social issues associated with these policy changes. And I think our University can play a critical role, in not just developing these technologies, but also working to re-train planners and other policymakers that are involved in this type of forward-thinking, forward decisionmaking.

As you've noted in your introductory comments, and as we've heard this morning, already, climate change greatly impacts island communities. In my written testimony, I've summarized some of the key research. Fortunately, most of it was published after 2005, so I feel safe with it.

Some of the pieces that I cited were done in 1998, and before the more dire predictions of sea level rise were identified. The way that I look at this is, even back before these dire predictions came out, the impacts upon Pacific Islands, on small island settings, were well-noted. So, it can only get worse.

In order to lessen the probability of these natural events, and climate-induced events from turning into disasters, there's a need to develop effective programs, training and an integrated system of disaster preparedness, response, and recovery. An integrated system includes Federal, State and local governments, as well as international agencies, non-governmental organizations and the private and volunteer sectors.

A comprehensive approach includes consideration of all phases of the disaster cycle, including preparedness response, recovery, mitigation, development and adaptation to environmental change.

While there's been research and training on various aspects of response and preparedness, there's a need for more research and training on adaptation, and addressing the vulnerabilities of populations exposed to natural hazards. There is particular need to address natural hazards in the Pacific Region, and in many areas throughout the Nation.

With the creation of the Department of Homeland Security, significant effort has gone toward the prevention and response to acts of terrorism. The National Domestic Preparedness Consortium was established in September 1998, and reconfirmed in public law in 2001. The original members, the Center for Domestic Preparedness, LSU, Nevada Test Site, New Mexico Tech, Texas A&M—these original members of the consortium addressed counterterrorism preparation needs, within the context of chemical, biological, radiological and explosive weapons of mass destruction. Not a one of these centers is focused on natural hazards.

Reauthorized in the Homeland Security legislation in 2007 through 2011, the consortium was expanded, as you know, to include all hazards, including technological and natural hazards. The two new members that were added include the Transportation Technology Center in Colorado, and the National Disaster Preparedness Training Center at the University of Hawai'i. And, within the DHS, the consortium is located within FEMA now, under the National Preparedness Directorate.

The focus of our center, the National Disaster Preparedness Training Center, is on building community resiliency to all hazards, by developing and providing training to first responders, decisionmakers, policy analysts and urban planners. Our center will partner with key Federal, State, local, international partners to develop and implement training on disaster preparedness, response, recovery, relevant to the special needs and conditions of Pacific Island communities, and others at risk from natural and technological hazards.

We will provide training consisting of formal degrees and certificate programs, as well as specialized courses, workshops, conferences, and coordinate the sharing of data and information related to preparedness, mitigation, response and recovery, and serve as an incubator for new ideas, technologies, businesses and partnerships between the University, business and government.

To date, we have attended two meetings, two quarterly meetings, of the consortium, to learn about the training activities of the other six centers. We've also had productive and informative meetings with the Emergency Management Institute under FEMA, and others within the Department of Homeland Security.

We've interacted with the Natural Hazards Center at the University of Colorado, Boulder, as well as other national and international training partners.

We've also been working very closely with entities and organizations within Hawaii, involved with disaster management to become a model of how information and technology can be shared across our community. And it is evident that the Center will play an important role in addressing the needs of both island communities as well as other coastal communities and those affected by natural disasters throughout the Nation.

I want to, on behalf of the University and the State and others involved in this area, I want to thank you for your efforts in this area, in creating the National Disaster Preparedness Training Center.

[The prepared statement of Dr. Kim follows:]

PREPARED STATEMENT OF KARL KIM, PH.D., PROFESSOR AND CHAIR, DEPARTMENT OF URBAN AND REGIONAL PLANNING, UNIVERSITY OF HAWAI'I AT MĀNOA

Introduction

Good morning, Senator Inouye and Members of the Committee. I am Karl Kim, Professor and Chair of the Department of Urban and Regional Planning at the University of Hawaii. I am honored to have this opportunity to speak to you about the impacts of climate change and responses in island communities. I have just come from Tokyo and the United Nations University where I have been participating in meetings related to climate change, sustainability, disaster management, and renewable energy. I am also engaged in research related to modeling of efforts to reduce carbon emissions through urban and transportation planning with the National Institute for Environmental Studies in Japan. I also serve as an Advisor to the Korea office of the International Council of Environmental Initiatives, which is focused on sustainable development in the Asia-Pacific region. I would also note that I am a member of the Transportation Research Board, National Research Council which will also be addressing the impacts of climate change on transportation at its Annual Meeting in 2009. I am currently working on a study estimating the impacts of climate change and sea level rise on coastal roadways and business activities in Hawaii. My current research also involves modeling evacuation decision-making in coastal communities. Much of my research over the past two decades has involved sustainable development and urban and transportation planning.

Climate Change and Urban Planning

Cities are both a cause of and a solution to the problem of climate change. They consume tremendous amounts of land, resources and energy and generate vast amounts of greenhouse gases. Cities store heat and are constructed of impervious surfaces, contributing to urban runoff, flash flooding, and other ecological problems. Urban expansion has also meant the destruction and loss of forests, agricultural lands, and other sinks for carbon sequestration. Cities also provide opportunities for increased density of development, reduction of travel distances for work, shopping, and education, and opportunities to utilize new technologies for energy, communications, commerce, and economic development. Adoption of sustainable, renewable, green design, planning, and building techniques will help to not only reduce the ecological footprint of cities, but also provide a pathway for continued economic growth and prosperity. It is critical that the planning regime, including comprehensive and general plans, development plans, zoning and building codes and various community and project plans, is realigned to address the conditions and needs created by climate change. Turner, et. al. (2007) have recently examined the costs and benefits of hardening the shoreline versus managed realignment of development further inland. There are technological issues with obvious political and economic consequences to these policy changes. The University of Hawaii plays a critical role in not just developing but also applying new technologies to the planning and design of human settlements. Islands provide a unique opportunity for studying the impacts of climate change, and, more importantly, for designing and implementing appropriate responses.

Climate Change Greatly Impacts Island Communities

Island communities are disproportionately affected by climate change. See Huang (1998) for a summary of the vulnerabilities of small islands to the impacts of climate change and State of Hawaii (1998) for a comprehensive discussion of the impacts of climate change in Hawaii. Like all coastal communities, the effects of sea level rise in terms of erosion and inundation of roadways, urban infrastructure, and coastal assets have become a matter of national concern. In addition to the potential loss of beaches and other areas important to our island economy, sea level rise also threatens our water system and increases the risk of sewage spills and toxic releases into our environment (Schiedek, et. al., 2007). Climate change means increased variability in weather conditions with an increase in extreme events such as both heavy rainstorms and also periods of drought. See *New Scientist* (2007) for a discussion on how climate change will lead to more wild weather. Heavy rainfall increases the probability of urban floods while drought increases the risk of wildfire. Native trees, especially in rainforest areas are not as resistant to either drought or wildfire, so climate change can also affect the make-up of forests and in turn affect wildlife habitat. Drought also increases municipal and agricultural ground water use which increases the chance of salt water intrusion into the aquifer. Increased temperatures as well as prolonged rainfall can also contribute to the increase in vector-borne diseases such as dengue fever which is also spread by both urbanization and the increased movements of human hosts between remote locations across the planet. See Haines, et. al. (2006) for more discussion of the impacts of climate change on public health.

In the Pacific region, climate change, global warming, sea level rise, and extreme weather events have increased the risk of natural events becoming disasters. Because more people and activities have located in coastal and other hazard prone areas, the risks of weather and natural events (hurricanes, storms, tsunamis, earthquakes, floods, droughts, wildfires, and others) turning into disasters where people are killed, injured, or lose their homes, property, businesses, jobs, and other assets are increased. Worldwide, there is increasing concern about the impacts of climate change on visitor destinations (Phillips and Jones, 2006). More people living and working in hazard prone areas means more exposure to disaster. The International Red Cross/Red Crescent describes a disaster as "an exceptional event which suddenly kills or injures large numbers of people." The Center for Research on the Epidemiology of Disasters (CRED) defines a disaster as a "situation or event which overwhelms local capacity, necessitating a request to a national or international level for external assistance." Because of the increased risks of natural disaster, there is need for further efforts focused on preparedness, response, relief, recovery, and mitigation in the region.

Response to Climate Change

In order to lessen the probability of natural events turning into disasters, there is a need to develop effective plans, training programs, and integrated systems of disaster preparedness, response, and recovery. An integrated system includes Federal, state, and local governments as well as international agencies, non-governmental organizations, and the private and volunteer sectors. A comprehensive approach involves consideration of all phases of the disaster cycle including: (1) preparedness; (2) response; (3) recovery; (4) mitigation; (5) development; and (6) adaptation to environmental change. While there has been research and training on various aspects of response and preparedness, there is need for more research on adaptation and vulnerability (Smit and Wandel, 2006). Each of these phases require different tools, methods, technologies, resources, and commitments. It should be noted that an "all-hazards" approach is one in which many of the same concepts, methods, and resources are transferable across different natural, technological, and human caused disasters.

There is a particular need to address natural hazards in the Pacific region and in many areas throughout the Nation. With the creation of the Department of Homeland Security (DHS), significant effort has gone toward the prevention of and response to acts of terrorism. The National Domestic Preparedness Consortium was established by Congressional Mandate in September 1998 (House Conference Report [H.R. 2267]) and reconfirmed in Public Law 107–273 in 2001. The original members (Center for Domestic Preparedness, Louisiana State University, Nevada Test Site, New Mexico Institute of Mining and Technology, and Texas A&M University) of the Consortium addressed counterterrorism preparedness needs of our Nation's emergency responders within the context of chemical, biological, radiological, and explosive (Weapons of Mass Destruction [WMD]) hazards. Re-authorized in Homeland Security legislation (H.R. 1) in 2007 through FY 2011, the Consortium's mission was expanded to include all hazards, including technological and natural hazards. Two new members were added to the Consortium (Transportation Technology Center, Inc. and the National Disaster Preparedness Training Center at the University of Hawaii). Within DHS, the Consortium is located within the Federal Emergency Management Agency (FEMA) under the National Preparedness Directorate.

National Disaster Preparedness Training Center

On August 3, 2007, President Bush signed H.R. 1 "Implementing Recommendations of the 9/11 Commission Act of 2007" which authorized the establishment of the National Disaster Preparedness Training Center (NDPTC) at the University of Hawaii. Housed at the University of Hawaii, a premier research university, the NDPTC is uniquely positioned to develop and deliver natural disaster preparedness training to governmental, private, and non-profit entities, incorporating urban planning with an emphasis on community preparedness and at-risk populations.

The focus of the NDPTC is on building community resilience to all hazards by developing and providing training to first responders, decisionmakers, policy analysts and urban planners.

The NDPTC will partner with key Federal, state, local and international partners to develop and implement training on disaster preparedness, response, and recovery relevant to the special needs and conditions of Pacific island communities and others at risk from natural and technological hazards.

The NDPTC will provide training consisting of formal degrees and certificate programs, as well as specialized courses, workshops and conferences; coordinate the sharing of data and information related to disaster preparedness, mitigation, response and recovery; and serve as an incubator for new ideas, technologies, business and partnerships between academia, business and government.

As a land, sea, and space grant institution with national and international recognition for its academic and research excellence in the fields of urban planning and earth sciences, the University of Hawaii has the expertise and research and training programs in the fields of disaster management and related topics to conduct research and develop specific models and tools for monitoring natural hazards and evaluating risk to urban areas. Planning for the response, recovery and reconstruction of communities affected by natural disasters will include a special emphasis on islands and at-risk, vulnerable populations.

To date, we have attended two quarterly meetings of the Consortium to learn about the training activities of the other six centers. We have also had productive and informative meetings with the Emergency Management Institute (FEMA) and others within the Department of Homeland Security involved with training and community preparedness, response and recovery. We have also interacted with the Natural Hazards Center at the University of Colorado, Boulder as well as other national and international training and research partners. We have been also working closely with other entities and organizations within Hawaii and the region involved with disaster management. It is evident that the work of the NDPTC will play an important role in addressing needs of both Pacific island communities and also other coastal communities as well as those affected by natural disasters throughout the Nation.

References

Haines, A., R.S. Kovats, D. Campbell-Ledrum, and C. Corvalan. (2006) Climate Change and Human Health: Impacts, Vulnerability and Public Health. *Public Health. 120. Pp. 586–596.*

Huang, J.C.K. (1998) Climate Change and Integrated Coastal Management: A Challenge for Small Island Nations. *Ocean and Coastal Management.* Vol. 37. No. 1. Pp. 95–107.

New Scientist (2007). 2100: A World of Wild Weather. January 20, 2007. Pp. 6–7.

State of Hawaii (1998). *Hawaii Climate Change Action Plan.* Department of Business, Economic Development and Tourism, Energy, Resources and Technology Division and Department of Health, Clean Air Branch. State of Hawaii. Honolulu. HI.

Phillips, M.R. and A.L. Jones (2007) Erosion and Tourism Infrastructure in the Coastal Zone: Problems, Consequences and Management. *Tourism Management.* 27. Pp. 517–524.

Schiedek, D., B. Sundelin, J. Readman, and R. Macdonald. (2007) Interactions Between Climate Change and Contaminants. *Marine Pollution Bulletin.* 54. Pp. 1847–1856.

Smit, B. and J. Wandel. (2006) Adaptation, Adaptive Capacity and Vulnerability. *Global Environmental Change.* 16. Pp. 282–292.

Turner, R.K., D. Burgess, D. Hadley, E. Coombes N. Jackson. (2007) A Cost-Benefit Appraisal of Coastal Managed Realignment Policy. *Global Environmental Change.* 17. Pp. 397–407.

The CHAIRMAN. Dr. Uehara?

STATEMENT OF DR. GORO UEHARA, COLLEGE OF TROPICAL AGRICULTURE AND HUMAN RESOURCES, UNIVERSITY OF HAWAI‘I AT MĀNOA

Dr. UEHARA. Thank you, Senator Inouye for this opportunity to describe some opportunities and challenges when climate change hits us.

Agriculture in Hawaii is undergoing constant change, and for over the 30 years we have been involved in finding new crops in new locations in Hawaii, and involved in obtaining grants with your help, and looking at international transfer of technology from one location to another.

And, basically, in the past these changes have been compelled and forced upon Hawaii by economic reasons. From here on, we will be forced to look for new crops, because of climate change. This presents new challenges for agriculture.

One of the crops we are currently looking for in Hawaii is to replace, not only food and fiber crops, but to begin to introduce energy crops to Hawaii. We feel that Hawaii presents tremendous opportunity with new technologies to provide Hawaii with alternative feedstock for biofuels production, as Dr. Rocheleau has indicated.

Hawaii and the Pacific Islands vary in environments, greatly. Hawaii's environment ranges from balmy beaches, to snow-capped mountains. It ranges from drenching rainforests to scorching deserts, and we must find different crops for these environmental niches. The question is, how do we do this?

Hawaiians—the early Hawaiians brought taro and sweet potato, they brought ulu. And over the years, over 100 years, they were able to transform the few taro varieties they brought to Hawaii, into 100 varieties. So, we have the capacity to find new crops for new locations.

There are three ways to find new crops for new locations, we call this matching the biological requirements of crops to the physical characteristics of land. Climate change will bring about a mismatch between crops and environment, and we now must find new crops to match the changing environment.

The three ways of matching crops to land is one, the most common way, is trial and error. Now, we have been doing this for years, since Captain Cook, we have been introducing hundreds of varieties to Hawaii—pineapple, papaya, sugar cane—these are all introduced crops. We have also introduced hundreds of other crops which are, today, invasive species. We can no longer depend on the slow and costly process of introducing new crops to Hawaii by trial and error.

There is a second way of looking for new crops when climate changes. This is called "transfer by analogy." We must travel around the world, look for similar environments, and see what grows in different environments that are similar to Hawaii's. And we have been introducing crops to Hawaii from different parts of the tropics based on this analogy concept. And if you travel around the world, you also see Hawaiian sola papaya, you see Hawaiian pineapple, you see Hawaiian macadamia nut, and how would these technologies take into different areas? By analogy. So, we have trial and error, and we have analogy.

Unfortunately, these methodologies are too slow and too costly, and will not allow us to accommodate the rapid changes that climate change will bring about.

There is a third way of bringing technology and crops to Hawaii, and this is called systems analysis and simulation, using crop models. And some 20 years ago, the University of Hawai'i established an international project to begin to use—not trial and error experiments to find new crops, but to use knowledge—to capture and condense this knowledge in computer simulation models, to show how crops will perform in different environments at different times.

There are two things that are needed to drive these simulation models, and I have given in my written testimony, an example of how we have used these techniques to try to locate new crops for Hawaii by this method. It is fast, it is simple, and it is relatively accurate.

Unfortunately, this method requires historical weather as inputs into the simulation models. The historical weather gives you a full range of variability in the climate, it needs a mean, the average climate, and the variance, extremes, the tails of the distributions, the storminess. Means and variances.

Unfortunately, these models which are currently used, these models developed by the University of Hawai'i, currently used by NOAA, it's also used by world meteorological organizations, used widely, globally today, will not be useful during climate change, because we can no longer use historical weather to drive these models. It's the problem of stationariness, scientists call this.

So, I will just simply close that we have trial and error, we have analogy, and we have system simulation. We will all use these three methods to find new crops for Hawaii. However, the success and the capability of Hawaii and the Pacific Islands to find replacement crops for Hawaii will depend not on what agricultural scientists do and what economists do, but it will depend on atmospheric science to be able to forecast with a high degree of accuracy, means and variances of climate in the future.

Thank you very much.

[The prepared statement of Dr. Uehara follows:]

PREPARED STATEMENT OF DR. GORO UEHARA, COLLEGE OF TROPICAL AGRICULTURE AND HUMAN RESOURCES, UNIVERSITY OF HAWAI'I AT MĀNOA

Agriculture cannot remain constant in the face of climate change and thus must change as climate changes. The question, therefore, is when and how this change will occur, and what options decisionmakers ranging from policymakers to producers will have to meet this challenge. But before we answer this question, we need to know the bio-physical factors that link agriculture to climate.

Agriculture is the art and science of matching the biological requirements of crops (plants and animals) to the physical characteristics of land. Farming is about minimizing mismatches between crops and environment to optimize agricultural performance, and abrupt changes in the amount and distribution of rainfall and temperature will widen mismatches and lower performance.

It is important to note that reduced yields associated with climate change will not necessarily be caused by diminished land quality, but will primarily be a consequence of mismatches between crops and land characteristics currently cultivated on a given parcel of land. In fact climate change may transform land now too dry or cold into prime agricultural land to expand the land area suitable for food production. The issue therefore is to have in hand, effective methods to match crop requirements to changing land characteristics in a timely and cost-effective manner.

There are three ways to match crops to suitable agro-environments. The first and most frequently used method is by trial-and-error. Our ancestors carried seeds of their favorite crops as they migrated to new unoccupied lands, and preserved seeds of those plants that performed well in the new location. Some wise farmers saved seeds from the best performing plants, and were able to improve farm productivity by repeating this process for many plant generations. The early Hawaiians were able to produce over a hundred taro varieties through this process. But the Hawaiians had centuries to complete this task and taro is no longer the primary food staple in Hawaii. The trial-and-error method of matching crops and crop varieties to locations with suitable growing conditions is too slow and costly. With climate change already upon us, we no longer have the luxury of time and resources to conduct endless trial-and-error field trials.

There is second and better ways to find crops that will do well on your land. This method called matching by analogy depends on assuming that crops that perform well on land similar (analogous) in soil and climate to your land will perform well on your land. This approach is possible in the U.S. and Hawaii because the entire country has been or is in the process of being inventoried and mapped in detail according to soil type and climate. This system of inventorying our land resources on the basis of soil and climate was developed by the Natural Resource Conservation Service of USDA (USDA Staff, 1999). Using this method, one can search for crops that are suitable for a particular location in Hawaii by looking for analogous soils in Botswana, Guam, India or Panama and see what crops perform well there. In 1974, the University of Hawai'i conducted a 10-year project to test the applicability of the approach on an international scale and showed that test crops not only performed well in similar soils and climates in Brazil, Indonesia, Cameroon, Philippines and Hawaii, but responded to similar management practices to attain high grain yields (Silva, 1985). The limitation of matching crops to land characteristics by analogy is its exclusion of crops that have never been grown in that particular type of environment. We need a method that enables growers to evaluate the profitability of growing the widest possible range of crops on their land quickly and at prices they can afford.

This brings us to the third methods of identifying crops to replace those that have become unprofitable from the effects of climate change. It is worth repeating that a crop or crop variety that performs poorly in one location can regain its yield potential in another location where its biological requirements are more adequately met. Climate change does not require us to abandon or discard existing crops and crop varieties, but requires finding new environments for them. In Hawaii this may mean growing Kapoho papaya in Mountain View. Does this also imply that Mississippi soybean can be transferred to Minnesota with global warming? Unfortunately Mississippi and Minnesota differ in day length and photoperiod sensitive soybean that performs well in the southern U.S. will not do well in the northern states. But should climate change shift moisture from Mississippi to Arizona, it should be possible to transfer photoperiod sensitive crops between the two states.

Mismatches between crops and land characteristics caused by climate change will not only cause yields to decline but most probably will also cause yield variances to increase. Every grower's goal is to produce high yields and profit, and to avoid high yield variances, or feast to famine fluctuations in yield and profit. High yield variance adds risk and uncertainty to farming and is sufficient in itself to cause farmers to abandon farming. Random, uncontrollable meteorological factors introduce risk and uncertainty to farming and compel decisions to gamble with nature.

Gambling is a risky game of probabilities. Thus, to determine how a crop will perform in a new climate requires many years of testing to expose hidden dangers which one or 2 years of on-farm trials cannot reveal. Since the risk of crop failure and income loss resides in the tails of probability distributions, climate change requires scientists to develop tools capable of generating whole probability distributions of production outcomes.

Whole probability distribution cannot be generated by conducting trial-and-error experiments or by searching for crops in analogous environments. Whole probability distributions can only be generated by systems analysis and simulations using dynamic, process-based models. There are too many factors that influence means and variances of crop yield and profit, and there are insufficient resources and time to conduct experiments to explore even a fraction of the range of outcomes.

In the next three to four decades, the world must double production with a new kind of agriculture to feed, cloth and house a global population that will increase not only in size but in aspirations. It will be challenging enough just to double production, but we are now being asked to do so without compromising the stability and resiliency of the ecosystem, and to complicate matters even more, this increased production will now need to be achieved in the context of uncertain global climate change. It is not surprising then, that there is now widespread agreement that business as usual will not do and a new kind of agriculture will need to be created to meet the challenge of food security for all.

In 1983, the College of Tropical Agriculture and Human Resources of the University of Hawaii established a project called the International Benchmark Sites Network for Agrotechnology Technology Transfer (IBSNAT) project with Federal funds to produce a software called Decision Support System for Agrotechnology Transfer (DSSAT) capable of predicting the growth, development and yield of the major food cereal, grain legume and root crops anywhere in the world using historical weather data to drive the model.

DSSAT generates whole probability distributions of outcomes based on simulated crop yields taking into account daily, seasonal and annual weather variations over many decades. This ability to generate and display means and variances of production outcomes enables users to analyze risk and seek alternative crops and/or crop management strategies to maintain high yields and minimize risk. DSSAT not only generates information on crop yields, days to maturity, crop responses to rate and timing of inputs, but enables users to compute cost of production and perform economic analysis.

The capability of DSSAT is illustrated by the attached paper (Ogoshi *et al.,* 1998), which describes the authors' response to a request to assess the economic feasibility of producing soybean on land formerly used to grow sugar cane. To simulate performance in different locations of the land area, DSSAT needed input information on soil, weather and soybean varieties. Since no soybean study had been conducted in the area, DSSAT was asked to determine the best variety based on yields obtained at multiple locations, planted at 12 different date, at several different planting densities. A typical task DSSAT would be asked to perform might be to evaluate 4 varieties at 6 locations at 12 (monthly) planting dates and 4 population densities for 30 consecutive years. DSSAT can complete this task in a few hours, but a trial-and-error field experiment would involve installing 34,560 field plots over a 30 year period.

As powerful as DSSAT is today, climate change adds a new dimension to the task of matching crops to land and compels DSSAT to look for help to remain relevant and useful. DSSAT now operates on the assumption that historical weather data mimics means and variance of current weather. Climate change will invalidate this assumption.

DSSAT is a product of agricultural scientists and economists. It now needs the help of atmospheric scientists to develop climate models that can generate means and variances of weather conditions that apply to a given parcel of land. Our capacity to match crops to land will depend on the climate forecasting capability of atmospheric science.

References

USDA, Staff. 1999. Soil Taxonomy. A basic system of soil classification for making and interpreting soil surveys. 2nd ed. U.S. Government Printing Office, Washington, D.C. 20402.

Silva, J.A. ed. 1985. Soil-based Agrotechnology Transfer. Benchmark Soils Project, Department of Agronomy and Soil Science, Hawaii Institute of Tropical Agriculture and Human Resources, University of Hawaii. 292 pp.

Ogoshi, R.M., Tsuji, G.Y., G. Uehara, and N.P. Kefford. 1998. Simulation of Best Management Practices for Soybean Production in Hawaii. Cooperative Extension Service, College of Tropical Agriculture and Human Resources, University of Hawaii.

Soil and Crop Management—Oct. 1998—SCM–2—Cooperative Extension Service—College of Tropical Agriculture and Human Resources, University of Hawai'i at Mānoa

SIMULATION OF BEST MANAGEMENT PRACTICES FOR SOYBEAN PRODUCTION IN HAWAII

Ogoshi, R.M,[1] Tsuji, G.Y.,[1] G. Uehara,[1] and N.P. Kefford[2]

A method is presented that assesses economic profit, management practices, and risk involved with soybean production for three locations on the North Shore of Oahu, Hawaii, where soybean has not been planted before. Simulations of soybean growth and economic analysis using 768 combinations of cultivar, plant density, irrigation, and planting date over 20 seasons for each of three locations were made using the computer program Decision Support System for Agrotechnology Transfer (DSSAT. v. 3.0). Economic profit was calculated as the difference between revenue generated from grain yield and the total cost incurred from water, seed, labor, and other inputs. High economic profit and low variation of the profit from season to season were the criteria that identified the best management scheme out of the 768 for each location. Results from the simulations indicate profitable soybean production at each location is possible if a cultivar adapted to the mid-Atlantic states, "Bragg," is planted in the spring. In addition, high plant density and irrigation are necessary. Revenue from increased yield outweighed the costs accrued from extra seed and water. The expected economic profit ranged from $789 to $829 per hectare (2.47 acres; see conversions). Agronomic modeling with economic analysis was shown to be an effective tool for the rapid generation of knowledge necessary for decision-making on crop production based on expected economic profit and an assessment of risk. Such decisions are key to the timely selection of alternative crops and practices in areas previously planted to other crops.

Introduction

Two critical objectives in any agricultural enterprise are to minimize cost and maximize production. Economic feasibility of the enterprise depends on revenue being greater than cost. Other worthy objectives such as minimizing environmental impact or maintaining biodiversity may be included, but for this study, minimizing cost and maximizing revenue are the objectives.

Minimizing cost and maximizing production depend on the local environment where the crop is grown. An effective way to minimize cost is to match crop growth requirements to the biophysical environment, which includes soil fertility, rainfall, and temperature. With a good match, inputs and their associated costs are minimized. However, environments seldom match crop requirements perfectly. Irriga-

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[1] Department of Agronomy and Soil Science.
[2] Rural Economic Transition Assistance program.

tion, fertilization, and liming are often necessary to correct fertility or moisture deficiencies, or an alternative location must be used to fulfill temperature requirements. At each location, the combination of these interventions to correct mismatches is probably unique. Therefore, determination of the best management practices to produce crops will require information on the crop, weather, and soil; the effects of particular management practices; and their combined impact on yield.

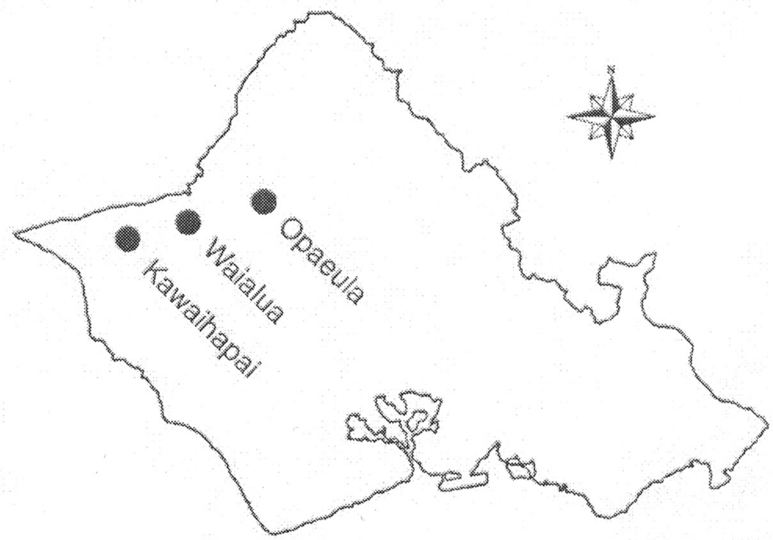
Information needed to manage environmental mismatches for crop production is generated in one of two ways: through trial-and-error field experimentation or systems simulation. The scope of the information generated in these two ways is different. In field experiments, the scope includes the specific responses of a crop to the environment as influenced by genetics, plant competition, and soil amendments at a particular time and place. Field experiments seldom integrate climate with crop response to soil and soil amendments because this involves multi-year and multi-location experiments, which are extremely expensive. Because field experiments can rarely be conducted over many years and locations, simulated outcomes of such experiments are useful. Crop simulation models are designed to imitate the behavior of real plants by integrating their known response to weather, soil, and amended conditions. Models can estimate crop production under many conditions to define precise differences that can occur from year-to-year or location-to-location, or as a consequence of finely graded management practices. Specific field experiments are still necessary to generate the new information on crop responses to factors that are not included or not well simulated in the model. Trial-and-error experiments and systems simulations generate information that are complementary. Field experiments produce new data that improves our understanding of plant and soil processes. Crop models integrate the improved understanding into new knowledge of crop performance.

The purpose of this study was to determine the agronomic and economic feasibility of soybean (*Glycine max* L. Merr.) production at selected sites on the North Shore, Oahu, Hawaii, as part of a rural stabilization program based on alternative crops for former sugarcane land. Feasibility will be appraised with projections from a soybean simulation model. Since large-scale soybean production has never been done on the North Shore, the model will be used to estimate yields that result from management decisions such as location, planting date, cultivar, plant density, and irrigation. With this information, the combination of management practices likely to give high, stable yield and economic profit will he determined.

Procedure

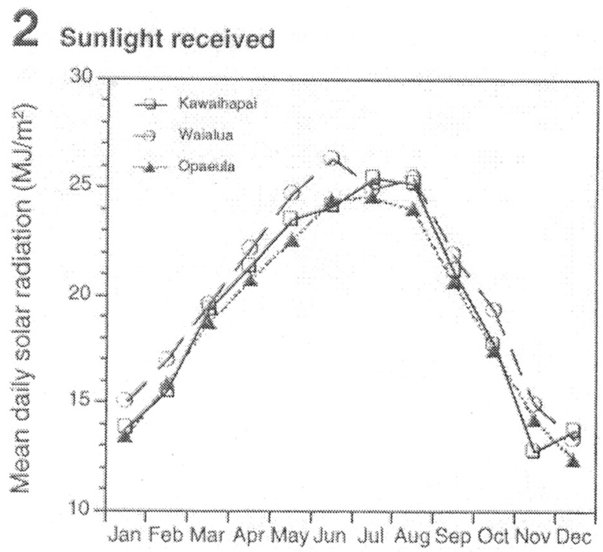
Predicting soybean yield requires a biophysical description of the sites to give the model information on the environmental factors that affect soybean growth. Kawaihapai, Waialua, and Opaeula, sites on the North Shore, were selected for simulating soybean growth and yield (Fig. 1). Based on experience with soybean production outside Hawaii, these three locations were assessed to contain the fewest constraints.

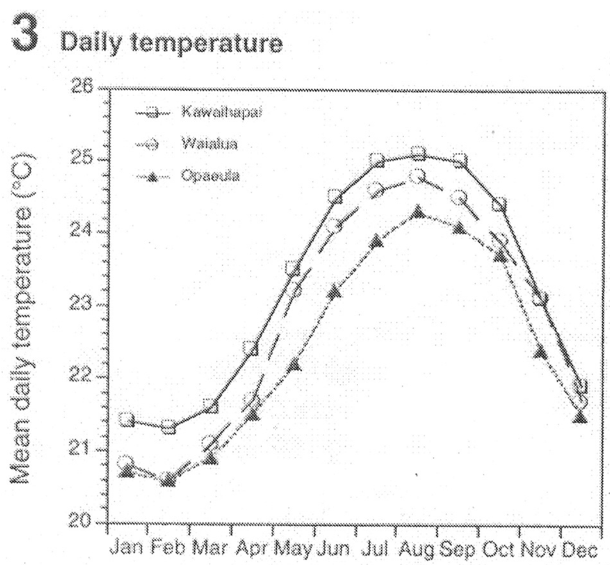
1 Three locations on Oahu, Hawaii, that provided data for simulations of soybean growth.



Records characterizing the unique weather and soil of each site were found in the archives of the Hawaii Agricultural Research Center (Osgood, personal communication) and Ikawa *et al.,* (1985). All sites have a weather pattern typical of low-elevation, leeward areas in Hawaii. Solar radiation and temperature are high in the summer months, and rainfall is high in the winter months. Annual solar radiation is highest at Waialua, while Kawaihapai and Opaeula have similar, lower values (Fig. 2). Mean daily temperature is highest at Kawaihapai and lowest at Opaeula throughout most of the year (Fig. 3). Opaeula receives the most rainfall, 1046 mm a year, while Kawaihapai and Waialua receive 880 and 846 mm, respectively. (Fig. 4). Soil texture, bulk density, pH. and organic carbon content determine the amount of water the soil can hold, water movement in the soil profile, and root penetration. These soil attributes are derived from soil physical and chemical characteristics in each layer of the soil profile at Kawaihapai (Ustollic Camborthid, fine, kaolinitic. isohyperthermic), Waialua (Vertic Haplustoll, very fine, kaolinitic, isohyperthermic), and Opaeula (Tropeptic Eutrustox, clayey, kaolinitic, isohyperthemic) (Table 1). Each combination of weather and soil characteristics establishes the environmental conditions in which soybean growth was simulated.

Climatic conditions at the three study sites.





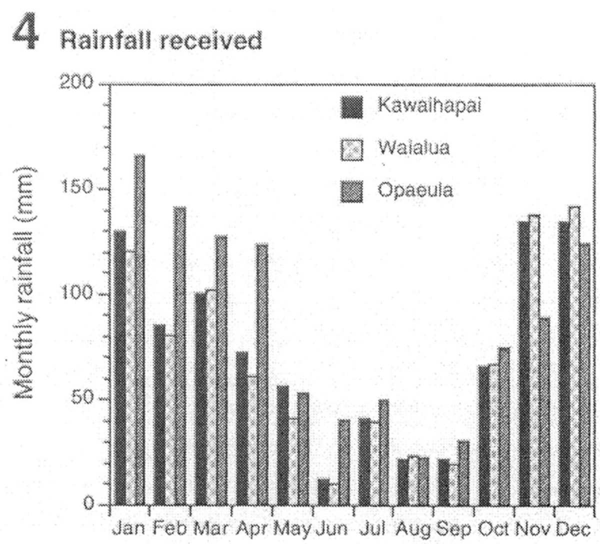


Table 1. Soil physical and chemical characteristics of the top layer of soils at the test sites.

	Site		
Soil characteristic	Kawaihapai [y]	Waialua [z]	Opaeula [z]
Clay %	n.a.	51.1	43.7
Silt %	n.a.	38.9	37.7
Sand %	n.a.	10.0	18.6
Bulk density (g/cm^3)	1.33	1.28	1.31
Organic carbon %	2.0	4.1	1.5
pH	7.7	7.2	5.2

[y] SCS 1976, [z] Ikawa *et al.,* 1965

After specifying the environmental conditions, management practices can he chosen to test how well soybean would yield under a prescribed set of practices. Options for management practices may include cultivar, plant density, irrigation regime, planting date, fertilization, row spacing, and organic residue application. For this study, cultivar, plant density, irrigation, and planting date were combined in the simulations to identify the best management scheme to grow soybean on the North Shore. Four cultivars (cvs. 'Evans', 'Clark', 'Bragg', and 'Jupiter'), four plant densities (150, 300, 450, and 600 thousand plants per hectare with rowspace 0.6 m), four irrigation regimes (no irrigation, 25 percent trigger, 50 percent trigger, and no stress), and 12 planting dates (the first day of every month) were combined for a total of 768 schemes (equal to $4 \times 4 \times 4 \times 12$). The four cultivars represent types that are grown in latitudes from Minnesota (cv. 'Evans') to Florida (cv. 'Jupiter'). The irrigation regimes of 25 percent trigger, 50 percent trigger, and no stress were implemented by allowing the soil water-holding capacity at a 20 cm depth dry down to 25 percent, 50 percent, and 99 percent of field capacity, then irrigation was applied to reach field capacity. The 99 percent trigger was used as a control treatment and will be referred to as "no stress." Soybean growth was simulated for each of the 768 possible schemes over 20 unique weather sequences.

Predicted soybean growth and yield were simulated using CROPGRO-soybean (Hoogenboom *et al.,* 1994a). CROPGRO-soybean simulates soybean progress through its life cycle at a daily time-step and is dependent on the cultivar, temperature, and daylength. Photosynthesis is simulated through the capture and conversion of sunlight and carbon dioxide to carbohydrate, the building material for plant tissue. Protein production is simulated from nitrogen uptake through the roots and biological nitrogen fixation. CROPGRO-soybean distributes the carbohydrate and protein among plant organs (roots, stems, leaves, pods, and seeds) as affected by the stage of its life cycle, water or nitrogen stress, daylength, and temperature. At the end of the simulated season, the final seed weight is designated to be the yield. CROPGRO-soybean was designed to mimic soybean behavior and has been successfully tested under a wide range of environments (AVRDC 1991, Egli and Bruening 1992, Hoogenboom *et al.,* 1994b, Swaney *et al.,* 1983).

Simulation of the 768 combinations of cultivar, plant density, irrigation, and planting date over 20 seasons was facilitated with the software package Decision Support System for Agrotechnology Transfer v3.0 (DSSAT v3) (Tsuji *et al.,* 1994).

To decide which management scheme was best, a mean-variance analysis was conducted for each location. This technique presumes that the two important factors in deciding which strategy is best are the amount of economic profit and its riskiness. Economic profit is simply the revenue generated from selling the grain minus the cost of its production. Since the alternative to producing soybean in Hawaii is shipping grain from Seattle, Washington, the price of soybean grain was assumed to be the market price of the grain on the U.S. mainland plus shipping, or $449 per metric ton of dry grain in March 1997. Local production cost scenario was based on a 300 hectare farm on leased land and equipment purchased with a loan (M. McLean, personal communication) (Table 2). The basic production cost for the non-irrigated and irrigated farm was $1,602 and $1,772 per hectare. The costs for irrigation water, irrigation application, and seed were $0.10 per 1,000 gallons, $1.30 per application, and $0.66 per kg, respectively (M. McLean, personal communication). The riskiness of a strategy is represented by the standard deviation of profit derived over the 20 years.

Table 2. Base production cost for producing irrigated soybean in Waialua on a 300-hectare farm.

Operating costs				
A. Pre-harvest costs	**units/ha**	**in units**	**$/unit**	**$ cost/ha**
1. Land preparation				
a. Labor to clear land	6.7	hours	20	134.00
b. Machinery to clear land	6.7	hours	35	234.50
2. Planting				
a. Labor to plant seed	3.7	hours	20	74.00
b. Machinery to plant seed	1.9	hours	35	66.50
3. Pest control				
a. Herbicide: Roundup	1.4	gallons	75	105.00
b. Labor to spray	2.47	hours	20	49.40
c. Sprayer operation	2.47	hours	35	86.45
4. Irrigation				
a. System setup costs	3	sprinkler	20	60.00
B. Harvest costs				
1. Harvesting				
a. Labor to harvest	1.2	hours	20	24.00
b. Combine operation	1.2	hours	35	42.00
2. Commission and excise tax	294,852	$ gross	0.0417	40.98
Ownership costs				
A. Management resource	**gross $**		**% gross**	
1. Management	294,852		5	49.14
2. Office overhead	294,852		2	19.66
B. Capital resources				
1. Depreciation (est.) on	**invested $**	**% depreciation**	**depreciation $**	
a. Machinery and equipment	270,000	14	37,800	126.00
b. Irrigation system	300,000	5	15,000	50.00
	loan $	**% interest**	**interest $**	
2. Interest expense on loan	270,000	10	27,000	90.00
	equity $	**% equity**	**opportunity $**	
3. Opportunity cost on equity	300,000	6	18,000	60.00
C. Land resource	**assessed $**	**% tax**	**tax**	
1. Property tax	300,000	1	30,000	100.00
	premium $			
2. Property insurance	16,000			53.33
	payment $			
3. Leasehold	92,000			306.67
Total				1771.63

With the mean profit and its standard deviation, the best strategy to produce soybean can he found based on a few assumptions. Mean-variance analysis assumes that most people prefer high profit and low risk, and most are willing to accept a lower profit if risk can he reduced to a "comfortable level." When the mean profit is plotted against the standard deviation, the best strategies are those with high mean and low standard deviation found in the upper left corner of the graph (*e.g.,* Fig. 9).

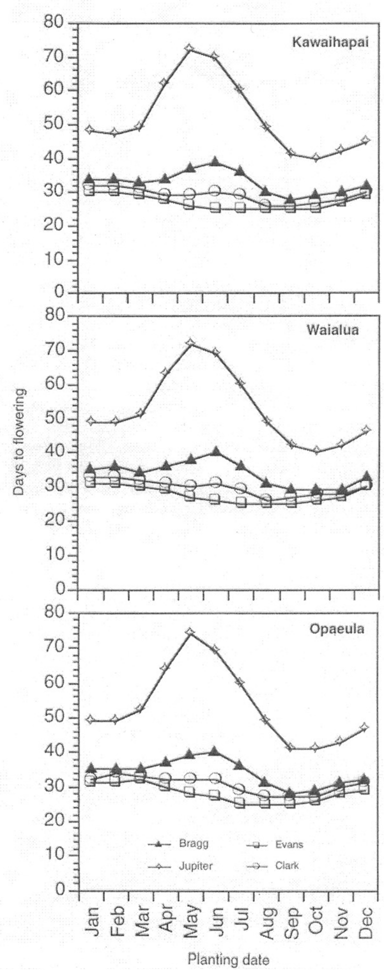
Further discrimination among the remaining strategies was done with stochastic dominance analysis (Thornton *et al.,* 1994). Ultimately, only one strategy was selected as best for each location.

Outcome

Results from the Simulation

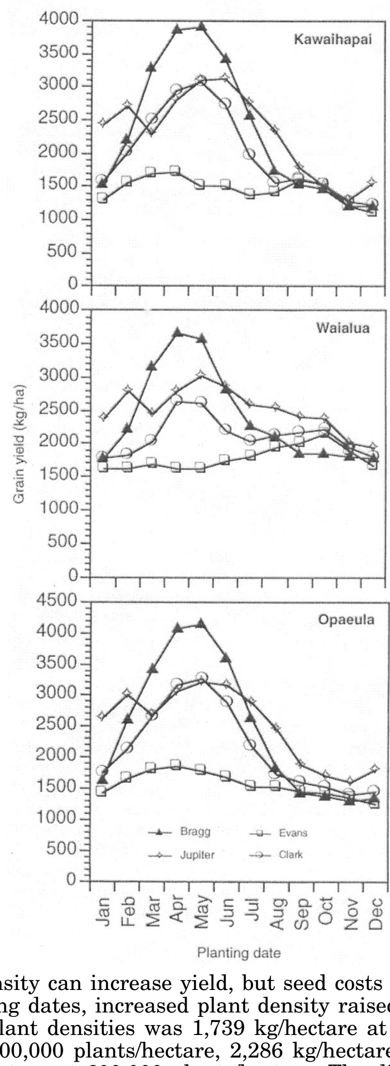
The simulation showed that differences in the daylength sensitivity of cultivars profoundly affected yield. The yield differences result from increases in the time from planting to flowering as daylength increases, *i.e.,* in spring (Fig. 5). This permits more leaf growth, which supports greater yield. 'Jupiter', the cultivar adapted to low latitudes, is the most daylength-sensitive cultivar as seen in its greatly prolonged time to flowering when planted in the summer months. The least daylength sensitive cultivar, 'Evans', had a relatively constant time to flowering regardless of planting date (Fig. 5).

5 Simulated days from planting to flowering for four soybean cultivars planted at monthly intervals at three sites on Oahu (values averaged over four irrigation regimes, four plant densities, and 20 seasons).



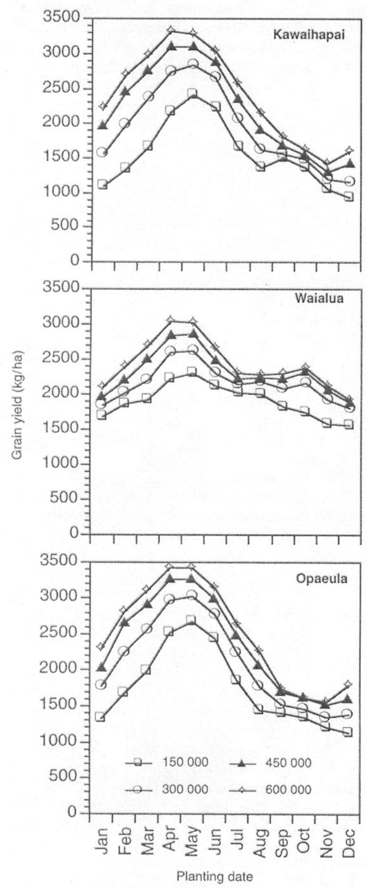
The greatest yield for the daylength-sensitive cultivars was obtained with spring planting dates, while the lowest was with fall planting dates (Fig. 6). Meanwhile, the daylength-insensitive cultivar 'Evans' had a relatively stable yield regardless of planting date. The close relation between yield and time to flowering suggest that yield depends on leaf area. However, yield differences among cultivars across planting dates were not completely dependent on leaf area differences. For any planting date, 'Jupiter' was a larger plant than 'Bragg' (data not shown), yet 'Bragg' had greater yield than 'Jupiter' in the spring plantings (Fig. 6). The yield reduction in the spring for 'Jupiter' resulted from nitrogen deficiency stress that may have been induced by excessive top growth. So, the best yielding cultivar changes with planting date: 'Bragg' had the highest yields when planted from March to June, while 'Jupiter' produced the highest yields for other planting dates.

6 Simulated grain yield (kg/ha) for the soybean cultivars at three sites on Oahu (values averaged over four irrigation regimes, four plant densities, and 20 seasons).



Increased plant density can increase yield, but seed costs make the yield gain expensive. At all planting dates, increased plant density raised soybean yield (Fig. 7). The mean yield for plant densities was 1,739 kg/hectare at 150,000 plants/hectare, 2,059 kg/hectare at 300,000 plants/hectare, 2,286 kg/hectare at 450,000 plants/hectare, and 2,437 kg/hectare at 600,000 plants/hectare. The diminishing gain in yield for each increase in plant density indicates that yield per plant was greatly lowered as plant density was raised. The reduced yield per plant resulted from increased competition among plants for water, sunlight, and nutrients.

7 Simulated soybean grain yield (kg/ha) at four plant densities when planted at monthly intervals at three sites on Oahu (yields averaged over four irrigation regimes, four cultivars, and 20 seasons).



While irrigation generally increased yield over raided soybean, efficient water use in soybean production depended on the planting date and location. Except for the fall plantings, which had virtually the same yield for all regimes, irrigation increased yield over rainfed crops for all planting dates (Fig. 8). The 25 percent trigger irrigation regime gave a larger yield than the rainfed crop, but smaller than the 50 percent trigger and no stress regimes. The 50 percent trigger irrigation regime generated yield nearly the same as the no stress regime, but was sometimes higher, probably due to waterlogged conditions in the no stress regime. The most water-use efficient irrigation regime to produce soybean can be calculated from irrigated yield minus rainfed yield, divided by the amount of irrigation water used (Table 3). With the ratios 8.23 and 8.40 kg/hectare per mm of water, the 25 percent trigger regime was most efficient for producing soybean grain at Kawaihapai and Opaeula. At Waialua, the 50 percent trigger irrigation regime was the most efficient at 7.90 kg/hectare per mm of water.

8 Simulated soybean grain yield under four irrigation regimes for soybeans planted at monthly intervals at three sites on Oahu (yields averaged over four irrigation regimes, four cultivars, and 20 seasons).

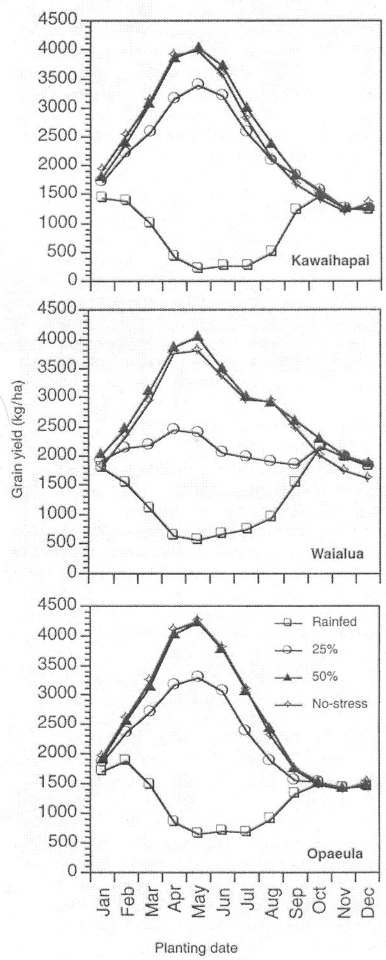


Table 3. Ratio of difference between irrigated soybean grain and rainfed yield (kg/ha) to irrigation water used (mm) for soybean grown at three sites on Oahu.

	Ratio (kg/ha per mm of water)[z]		
Location	25% trigger	50% trigger	No stress
Kawaihapai	8.23	7.74	4.57
Waialua	7.80	7.90	3.41
Opaeula	8.40	7.77	4.19

[z] Yields and irrigation water averaged over four cultivars, four plant densities, and 12 planting dates.

Agronomic Interpretation of the Simulation Results

In summary, simulated soybean yields varied with site and the management practices of cultivar, plant density, irrigation, and planting date.

Daylength sensitivity among the cultivars had the greatest effect on yield. Soybean flowers earlier in short days, and delays flowering in long days resulting in a larger plant with more leaves capable of supporting greater yield. However, too much vegetative mass can divert carbohydrate and protein resources away from grain growth. Hence, the cultivar of choice should be one that increases leaf area and supports greater yield, not one with vegetative growth that curbs yield.

Plant density must balance the beneficial effect of capturing the greatest amount of sunlight and the harmful effect of increased plant competition for water and nutrients.

Irrigation supplies essential moisture to plants, but in excess can create waterlogged conditions that inhibit root growth with increased water cost.

Because weather patterns proceed through annual cycles, changing the planting date alters the daylength, rainfall, solar radiation, and temperature the plant is exposed to. As previously discussed, seasonal daylength, in conjunction with the daylength sensitivity of the soybean cultivar, greatly affects plant size and yield potential.

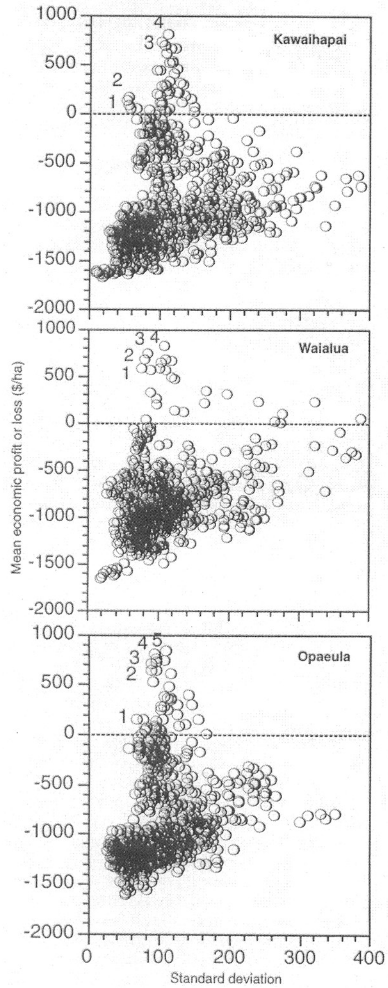
Cyclical rainfall governs soil moisture status that influences water stress and irrigation frequency as planting date changes. With an inverse relation to rainfall, solar radiation exhibits an annual cycle that affects yield as plants compete to intercept the sun's energy. Planting date has important implications on yield as affected by plant size, soil moisture, and plant competition.

Given the above information, estimates on profit can be based on the expected yield and the expected costs of seed, water, and "overhead." However, this information is inadequate to provide options to make a decision on the best production scheme since a trade-off exists between seed and water costs and revenue, and that tradeoff depends on weather that changes from year to year.

Selecting the Best Management Scheme

The better management schemes based on economic profit and riskiness show that generating more revenue can overcome the extra costs incurred to increase grain yield. For each location, the mean economic profit per hectare for each management scheme was plotted against its standard deviation for the 20 seasons (Fig. 9). The better schemes are those found along the outer edge of the upper left quadrant in the scatter. These schemes have high profit, low risk, or both. Generally, these better schemes result when fields are planted with 'Bragg' or 'Clark', are planted in April or May, and mostly irrigated when the soil moisture reaches 50 percent of field capacity. The plant density for the better schemes range from 300 to 600 thousand per hectare. While irrigation and high seeding rate increased the cost of production, the revenue generated from higher yield of irrigated crops planted in these 2 months offset the cost.

9 **Mean-variance analysis for finding best management practices to grow soybean on the North Shore, Oahu, based on CROPGRO-Soybean simulations.**



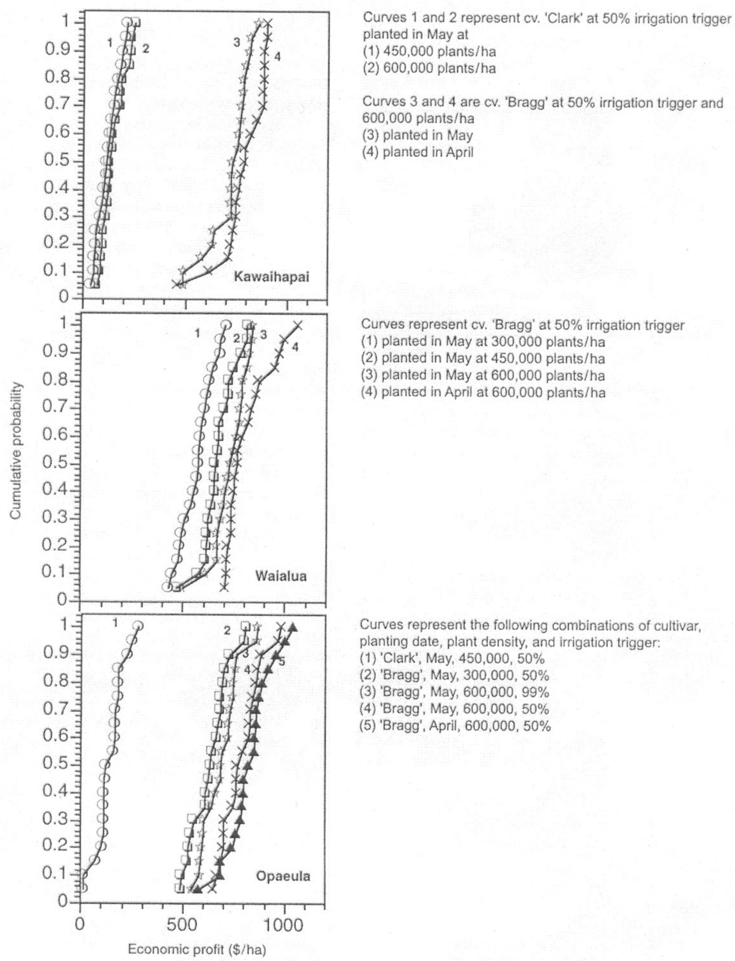
Kawaihapai:
1, 2. cv. 'Clark' planted in May with 50% trigger irrigation at (1) 450,000 plants per ha, and (2) 600,000 plants per ha.
3, 4. cv. 'Bragg' planted at 600,000 plants per ha with 50% trigger irrigation in (3) May and (4) April.

Waialua:
1 to 3. cv. 'Bragg' planted in May with 50% trigger irrigation at (1) 300,000 plants per ha, (2) 450,000 plants per ha, and (3) 600,000 plants per ha.
4. cv. 'Bragg' planted in April at 600,000 plants per ha with 50% trigger irrigation.

Opaeula:
1. cv. 'Clark' planted in May at 450,000 plants/ha with 50% trigger irrigation.
2. cv. 'Bragg' planted in May at 300,000 plants/ha with 50% trigger irrigation.
3. cv. 'Bragg' planted in May at 600,000 plants/ha with no stress irrigation.
4, 5. cv. 'Bragg' at 600,000 plants/ha with 50% trigger irrigation planted in (4) May and (5) April.

The best management scheme is the same for the three locations, but the expected profit is different. Stochastic dominance analysis was applied only to the better management schemes. The best management scheme is identified as the function furthest to the right that does not cross over other functions (Fig. 10). The best management scheme was 'Bragg' planted in April at 600, 000 plants per hectare with irrigation triggered when soil moisture reached 50 percent of field capacity. This management scheme was the best for all three locations. The expected profits for Kawaihapai, Waialua, and Opaeula were $789, $811, and $829 per hectare, respectively.

10 **Cumulative probability curves of simulated economic profit from soybean grown at three locations on the North Shore of Oahu.**



The worst schemes, in terms of mean economic profit, had several management practices in common. A negative mean economic profit resulted from schemes with any one of the following practices: cultivar 'Evans', a plant density of 150,000 plants per hectare, rainfed, or a planting date in January, February, July, August, September, October, November, or December. The cultivar 'Evans' had consistently lower yields, because of early flowering as discussed previously, that did not generate enough revenue from yield to compensate for the costs incurred for basic production. Planting at a density of 150,000 per hectare was too low to produce high yield. Rainfed crops lacked the moisture to produce adequate yield and planting from July to February either did not place the crop in favorable moisture or solar radiation conditions to yield well as previously discussed.

Conclusions

This study shows that an agronomic model and economic analysis are useful tools for agricultural decision-making. In Hawaii, the agricultural environment is complex due to the fact that crops can grow year-round and topographical influences on weather and the many soil types create many unique niches. Finding agricultural management practices to deal with this complexity has been difficult but is possible with careful extrapolation of results from field experiments. However, field experiments are time-consuming and do not quantify the variation in yield that can be expected from month to month and year to year. The soybean model coupled with economic analysis helps to overcome both of these problems.

In this study, crop models shortened the time needed to test and determine suitable management schemes to produce crops in specific locations. This analysis took approximately 1 week to complete. To achieve the same results, 768 field experiments would have had to be done over 20 years. The faster result is possible because the crop model has the ability to integrate weather, soil, and management information from a site and make realistic predictions on crop performance. With predicted yields, a fast economic analysis can be done to identify feasible management schemes based on profit and risk.

Predicting crop performance can have a profound impact on land-use decisions requiring this information. For this study, the question of whether soybean can be produced on the North Shore was answered from the viewpoint of an entrepreneur. Others who may benefit from this information include farmers who want to know whether alternative crops can be produced on their land, bankers who need to quantify the risk involved in an agricultural enterprise applying for a loan, and policymakers who need information on land capabilities. Armed with this information, decisions to commit a plot of land or investment capital to crop production are not answered with a simple yes or no but with estimates of economic profit, options for management practices to produce this profit, and an assessment of risk.

Acknowledgments

The authors extend their appreciation to Dr. PingSun Leung for his help with the economic analysis, Dr. Robert Osgood for making weather data available, Dr. Michael McLean for providing the cost-of-production spreadsheet, and Ms. Juvi Pagba for production assistance with this publication.

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References

AVRDC, 1991. 1990 Progress Report. Asian Vegetable Research and Development Center. Shanhua, Tainan, Republic of China.

Egli, D.B. and W. Bruening, 1992. Planting date and soybean yield: Evaluation of environmental effects with a crop simulation model: SOYGRO. Agricultural and Forest Meteorology 62:19–29.

Hoogenboom, G., J.W. Jones, P.W. Wilkens, W.D. Batchelor, W.T. Bowen, L.A. Hunt, N.B. Pickering, U. Singh, D.C. Godwin, B. Baer, K.J. Boote, J.T. Ritchie, and J.W. White. 1994a. Volume 2–2: Crop models. In: Tsuji *et al, op. cit.*

Hoogenboom, G., J.W. Jones, K.J. Boote, N.B. Pickering, W.T. Bowen, and W.D. Batchelor, 1994b. A new and improved soybean simulation model: CROPGRO-Soybean. World Soybean Research Conference V, Chiang Mai, Thailand, Feb. 20–27, 1994.

Ikawa, H., H.H. Sato, A.K.S. Chang, S. Nakamura, E. Robello, Jr., and S.P. Periaswamy, 1985. Soils of the Hawaii Agricultural Experiment Station, University of Hawaii: Soil survey, laboratory data, and soil descriptions. HITAHR Res. Ext. Series 022.

Soil Conservation Service, 1976. Soil survey laboratory data and descriptions for some soils of Hawaii. Soil Conservation Service, U.S. Dept. of Agriculture, Soil Survey Investigations Report No. 29, U.S. Government Printing Office 212–613.

Swaney, D.P., J.W. Jones, W.G. Boggess, G.G. Wilkerson, J.W. Mishoe, 1983. Real-time irrigation decision analysis using simulation. Trans. American Society of Agricultural Engineers 26:562–568.

Thornton, P.K., G. Hoogenboom, P.W. Wilkens, and J.W. Jones, 1994. Volume 3–1: Seasonal Analysis. In: Tsuji *et al., op. cit.*

Tsuji, G.Y., G. Uehara, and S. Balas (eds), 1994. DSSAT v3. University of Hawaii, Honolulu, Hawaii.

Conversions

1 kg = 2.2 lb
1 lb = 0.454 kg

1 hectare (ha) = 2.47 acre
1 acre = 0.405 hectare

$1.00/ha = $0.405/acre

1 kg/ha = 1.12 lb/acre
1 lb/acre = 0.89 kg/ha

1 mm = 4⁄100 inch
1 inch = 25.4 mm

20 °C = 70 °F, 25 °C = 77 °F

The CHAIRMAN. All right, thank you very much, Dr. Uehara. Your testimony has been most helpful.

I think I should point out a few facts of life in the Congress.

After about 30 years, I'm pleased to tell you that my Committee passed a fuel efficiency law. It was carried out with the opposition, powerful opposition, of automobile companies and such, but it's now part of the laws of the United States.

The Center that you spoke of, Dr. Kim, and the other programs, like the Tropical Agricultural Center on the Big Island, and the grants that you speak of, have been calculated, but they're all earmarks. I'm certain you've heard of that nasty word "earmark," and "add-ons."

As you know, I've been condemned because of my success in getting these earmarks, and I'm not embarrassed by them. If we didn't have the earmarks, you wouldn't have your Center, you won't have the Tropical Agricultural Center on the Big Island. So, it may interest you to know, although you're not involved in it, the very popular East-West Center is an earmark.

And so, you'll hear all of these politicians speaking about doing away with earmarks. I hope they'll look at the Constitution, because the Constitution says the Congress of the United States has a role to play.

Well, if these grants and earmarks were not provided, what would your operation be like, Dr. Kim if your Center wasn't there?

Dr. KIM. Well, the Center provides a tremendous opportunity to do things that we are doing right now, but to a much larger scale. In part, what we have is a tremendous amount of research, good research, outstanding, world-class research that's conducted at the University of Hawai'i. What's needed is to translate this research into effective policies, programs and training programs. And what's needed is some special sensitivities that, I believe, that we have at the University of Hawai'i, and in this region.

I mean, the first is our exposure to a broad range of natural hazards. The second issue that we have that makes us all the more important is our vulnerability—our remote location. It's the combination of these risks that we face, but also what would happen in the event that we have a very serious natural disaster occurring, and we've had so many recent disaster declarations that suggest this is a problem.

So, it's something just about improving our community, but by developing effective programs to prepare, respond and recover from these hazards, we can really serve as a model. We can avert the disaster which happened with Katrina, and in other places as well, too, because we have both the resources and the concentration of policymakers and decisionmakers and others, in this community, that's really unlike any other place in the world.

One of those things that I would like to point out, is I went to graduate school in Massachusetts, which has 351 cities and towns. As you're aware, in Hawaii, we have four units of local government. We have a tremendous degree of centralization, and good programs that have been developed at the local level, and a real opportunity to work closely with State, local, and Federal Government, and with the University of Hawai'i. I think that's unlike any other Center.

And when I've talked with my counterparts, they realize that we do have certain locational advantages, both in terms of the hazards that we face, the vulnerabilities, but also the opportunities to build a training program.

You know, I came from these meetings with the United Nations University, and there were many of our Pacific Island partners attending this meeting—from American Samoa, from Guam, from other parts of the flag territories, Vanuatu, Fiji, even places that are not part of the United States, but—and they really look to Hawaii for leadership, assistance, technical support, training in this area, and in other areas.

And so, I think we have a broad mission, in addition to addressing the needs of the Nation, as a whole, coastal communities, in particular, others exposed to the range of similar natural hazards from flooding to earthquakes to hurricanes—I think we also have a special obligation and responsibility for work in the region.

The CHAIRMAN. Well, I hope you'll speak up when someone says nasty things about earmarks.

Dr. KIM. Absolutely.

[Laughter.]

The CHAIRMAN. Well, I can assure you that your Congressional delegation is well aware of the importance of Hawaii in this battle to keep our planet viable.

We know, as Dr. Leong pointed out, 85 percent of the coral beds in the United States are found here. We also know that because of its isolation, Hawaii is the most dependent State on fossil fuels. As a result, we have been doing our best to bring in activities here that could make Hawaii a model, could make Hawaii a test lab.

For example, it may interest you to know that the first military hydrogen bus operated here in Hawaii. And I can assure you, the military didn't want to get involved with that, because they said, "It's none of our business," you know? The first electric bus was developed at the University of Hawai'i.

And so, we do get involved in activities of this nature, and if it weren't for the grants, I think that your research program would be nil.

Dr. KIM. That's correct.

The CHAIRMAN. And, I'd like to, if I may, because these questions would take much concern, can we submit to you, questions that you can respond to? They are highly technical in nature, I want to be able to present to my Committee, a full portfolio of issues, reactions, and what we can do about it.

So, with that, I'd like to thank you all for your testimony, it's been extremely helpful. And I can assure you that it won't be wasted.

Thank you very much.

[Whereupon, at 11:36 a.m., the hearing was adjourned.]

A P P E N D I X

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. DANIEL K. INOUYE TO FRED T. MACKENZIE, PH.D.

Question 1. NSF expects the impact of the FY08 cuts to be 1,000 fewer new research grants awarded, 230 fewer Graduate Research Fellows hired, and several major solicitations delayed for at least a year, including in the areas of computer science, cyber-infrastructure, and mathematics and physical sciences. Do you anticipate your programs experiencing repercussions from the lower than expected FY 2009 President's request?

Answer. Yes, our programs have not been keeping up over the years with grant needs of excellent scientists and a budget that only meets last fiscal year's will result in proposal success rates that are at even lower levels than 10–20 percent.

Question 2. Do you feel that more could or should be done to explicitly bolster education programs at the University of Hawaii and Hawai'i Pacific University?

Answer. Yes definitely, and especially in earth system and global environmental science. Every educated university undergraduate student should be required to take such a course, just like they take freshman English.

Question 3. Since 2004 the state has been making climate change mitigation and adaptation a priority through increased dedication and investment in the research and development of clean energy technologies. How has legislation passed in recent years benefited your research or commercial goals?

Answer. No direct benefit and I do not feel the state is making the effort needed to meet the challenges of peak oil, the fact that 90 percent of our energy comes from oil, mainly foreign, and is doing little to adapt to the global climate changes of the future. Mitigation is almost useless for Hawaii since we produce so little greenhouse gas relative to much of the rest of the world. We need to pay more attention to adaptation.

Question 4. Dr. Mackenzie, in your testimony, you indicated that regional climate models are not yet as robust as global climate models. What do we need to get to the point where the regional models are as useful as the global models?

Answer. I feel there are at least two major things we require—more regional data on climate variables like temperature, precipitation, and seawater CO_2 and carbon chemistry and development of new models for the influences of global climatic change on the regional scale ocean-atmosphere system and marine and terrestrial ecosystems. The model complexity needs to be on the order of the models that have been developed for El Niño-Southern Oscillation events. Data acquisition requires more use of satellite technology and *in situ* networks of instrumentation to measure the changes in the major physical variables of climate and the important physical, chemical and biological properties of the oceans on a regional scale.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. DANIEL K. INOUYE TO JO-ANN C. LEONG, PH.D.

Question 1. Have you found evidence of increasing ocean temperature around Hawaii's reefs and have you observed a correlation to bleaching events or disease?

Answer by Paul Jokiel, Research Professor, HIMB. HIMB scientists have been working on this question for the past 40 years. In the early 1970s studies on the impact of elevated temperature on coral reefs were initiated by Paul Jokiel and Steve Coles in order to understand the possible impact of a proposed Hawaiian Electric Co. power plant in Kaneohe Bay. Their reports show that a warming of one degree above summer maximum temperature will lead to bleaching of corals and high mortality (Jokel and Coles 1974, 1977). Field and laboratory studies at Kaneohe Bay and at Enewetak Atoll led to the generalization that corals in the tropics as well as the subtropics are living within 1 degree of bleaching during the summer months (Coles *et al.,* 1976). This generalization has been shown to be true throughout the world (Jokiel 2004). Jokiel and Coles (1990) also predicted that Hawaii would experience a major coral bleaching event with rising sea water temperature in a manner similar to locations throughout the tropics. The first major bleaching occurred in the main Hawaiian Islands in 1996 followed by bleaching in the Northwestern Hawaiian Islands in 2002. These events are documented in by Jokiel and Brown (2004), and they clearly link rising global temperature to the bleaching events. The history of Jokiel's involvement in this question is summarized in Fig.1.

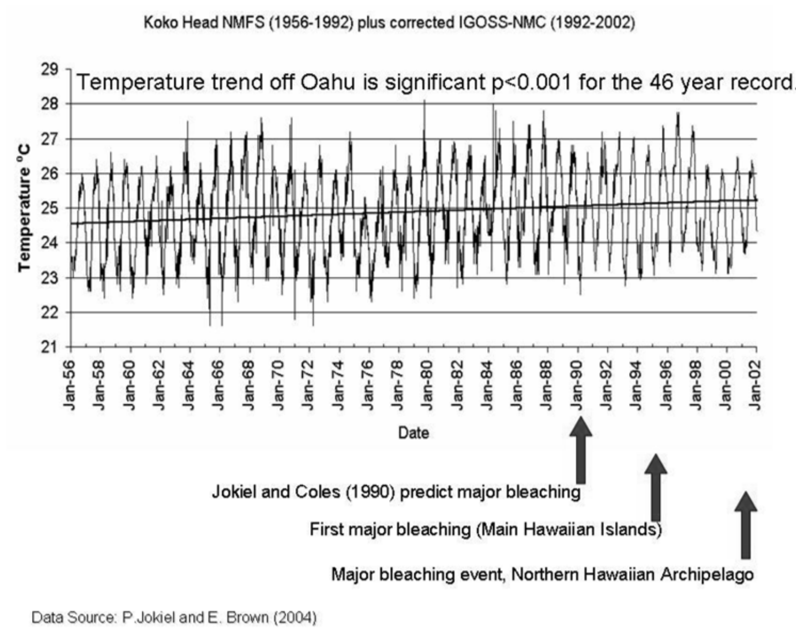


Fig. 1. Increasing temperature in Hawaiian waters, prediction of bleaching (1990) and bleaching event summary.

At the present time Paul Jokiel is continuing his global climate change studies in collaboration with Dr. Bob Buddemeier (Univ. Kansas) and others. They have produced a model that quantitatively describes the future changes on Hawaii coral reefs over the next century given various scenarios of carbon dioxide emissions (Buddemeier *et al.,* in press). Other studies by Jokiel and colleagues show that ocean acidification, expected to occur in this century as a result of anthropogenic carbon dioxide emissions, will have severe impact on coral reefs (Kuffner *et al.,* 2008, Jokiel *et al.,* 2008).

References

Jokiel, P.L., and S.L. Coles. 1974. Effects of heated effluent on hermatypic corals at Kahe Point, Oahu. Pac. Sci. 28(1):1–18.

Coles, S.L., P.L. Jokiel and C.R. Lewis. 1976. Thermal tolerance in tropical versus subtropical Pacific reef corals. Pac. Sci. 30:156–166.

Jokiel, P.L., and S.L. Coles. 1977. Effects of temperature on the mortality and growth of Hawaiian reef corals. Mar. Biol. 43:201–208.

Jokiel, P.L. 2004. Temperature Stress and Coral Bleaching. 2004. pp. 401–425 In Coral Health and Disease (E. Rosenberg and Y. Loya Eds.). Springer-Verlag, Heidelberg.

Jokiel, P.L. and Eric K. Brown. 2004. Global warming, regional trends and inshore environmental conditions influence coral bleaching in Hawaii. Global Change Biology 10:1627–1641.

Kuffner, Ilsa B., Andreas J. Andersson, Paul L. Jokiel, Ku'ulei S. Rodgers, and Fred T. Mackenzie (2008) Decreased abundance of crustose coralline algae due to ocean acidification. Nature Geoscience 1: 114–117.

Jokiel, Paul L., Ku'ulei S. Rodgers, Ilsa B. Kuffner, Andreas J. Andersson, Evelyn F. Cox, Fred T. Mackenzie (2008) Ocean acidification and calcifying reef organisms: a mesocosm investigation. Coral Reefs DOI 10.1007/s00338–008–0380–9.

Buddemeier, R.W., P.L. Jokiel, K.M. Zimmerman, D.R. Lane, J.M. Carey, G.C. Bohling, J.A. Martinich. (in press) A modeling tool to evaluate regional coral reef responses to changes in climate and ocean chemistry. Limnol Oceanogr.

Question 2. NSF expects the impact of the FY08 cuts to be 1,000 fewer new research grants awarded, 230 fewer Graduate Research Fellows hired, and several major solicitations delayed for at least a year, including in the areas of computer science, cyber-infrastructure, and mathematics and physical sciences. Do you anticipate your programs experiencing repercussions from the lower than expected FY 2009 President's request?

Answer by Steve Karl, Associate Research Professor at HIMB. An NSF Small Grant for Exploratory Research (SGER) funds our research on genetics and the health of coral reefs. These grants are ". . . recommended for innovative, smaller-scale research ideas that are high-risk/high-reward . . ." (NSF website). We were very fortunate to have received this award because the research that we proposed is on a spatial scale (micro—*i.e.,* meter and centimeter) commonly ignored but not known to be irrelevant and an idea that has never been tried (understanding the genetic relatedness of every coral colony on a reef). Through this research we hope to better understand the physical, ecological, and genetic spatial heterogeneity in a reef and its relationship to coral reef robustness, resilience, and health. With overall risk-adverse nature of the NSF and reduced funding, these types of grants are likely to be hardest hit. Although it will not directly effect our research, other high-risk proposals that also have the potential for high-reward will likely be strongly reduced.

We are in the process of writing a larger proposal to NSF that uses what we've learned to expand to the most exciting and rewarding areas our results support. Given that the NSF Biological Oceanography funding rate currently hovers around 10 percent, under the best of circumstances it is unlikely that we will be successful in our first submission. Currently, due to the number of worthy proposals exceeding the available funds, even worthy and well-founded research proposals are very unlikely to be granted in the first submission. Worthy proposals that were not accepted this year due to lack funds have a better chance if resubmitted and considered in subsequent years. Since we will be submitting for the first time, it is unlikely (regardless of the quality of the science) we will be funded. A smaller budget for NSF makes this more likely to happen this year and again next year when we resubmit. Unfortunately, some of the momentum that we have in the research simply won't last 2+ more years for funding to be approved. Since no other agency funds this type of fundamental research we likely will be forced to change the direction to applied questions that are more attractive to other funding sources (*e.g.,* Sea Grant). Experience has shown, however, the innovation frequently comes from basic research. Applied research is generally too narrowly focused to result in fundamentally new ideas. NSF is the only real source for basic, non-medical science.

Answer by Malia Rivera, Faculty Marine Education Coordinator at HIMB. In addition to research grants, NSF funds projects associated with education targets at various levels, including graduate, undergraduate and K–12 students (*e.g.,* REU, NSF GK–12, COSEE), as well as informal public audiences (*e.g.,* ISE and CRPA). Presumably, cuts in the overall NSF budget will impact not only research, but these types of important science education related programs as well. Marine science education programs associated with academic research institutes such as those at the Hawai'i Institute of Marine Biology are uniquely positioned to create and deliver educational opportunities that bridge and leverage real scientific research (which engages graduate and undergraduate students) with meaningful science education and scientific literacy at the K–12 and public audience levels. Certainly it would be expected that the projected cuts to the President's request would diminish the availability of these opportunities that otherwise would have served to contribute to the enhancement of science literacy in the public audiences and encouragement of the pursuit of higher education in science disciplines by local students.

Question 3. What resources are needed to carry out the proper level of monitoring and research of coral reefs?

Answer by Steve Karl, Associate Research Professor at HIMB. A considerable amount of funding is going to environmental sensing on global and broad regional scales such as NSF Ocean Research Interactive Observatory network (ORION). This view of the physical marine environment is useful for things like predicting the frequency and severity of hurricanes in the Atlantic, understanding how El Niño and La Niña contribute to changing climates, and assessing the role of elevated sea surface temperature in the 1997–1998 Indo-Pacific and 2005 Caribbean mass coral bleaching events. The success of an individual, however, is more strongly dependent on very small-scale processes that the individual experiences throughout its life. These small-scale processes likely are not reflected in the larger, more regional studies that are more common. Our research in Kaneohe Bay, Hawaii, however, is indicating that there is micro-spatial heterogeneity on coral reefs and that these differences are stable over time. We have been monitoring the water temperature at points 4 meters apart across a patch reef. We are finding that adjacent sites separated by 4 meters can be nearly a degree different in temperature. Even more surprising is that these differences are stable over time and not associated with the depth of the water. This is significant because other researchers have shown that coral bleaching occurs at a threshold temperature and temperatures even one-degree higher cause coral bleaching. Furthermore, if the temperature is sustained the coral colony is unlikely to recover and will die.

Currently, we are collecting the temperature data by using small temperature data loggers. These loggers record the temperature every 25 minutes and store it in memory. Within a month the memory is full and we retrieve the data loggers, download the data, clear the memory, and put them back out in the field. This is exceedingly time consuming. We would also like to collect other measurement (solar irradiance, salinity, water movement, etc.) but this is time prohibitive. What is urgently needed to further this sort of monitoring are wireless, underwater data loggers. Since we have over 100 temperature data loggers, it is untenable to have them wired to a central receiver. Currently, the technology for underwater wireless communication of data is lacking. The appropriate types of monitors would also need to be developed so that micro-spatial analyses were possible. In general, considerably more resources need to be directed to understanding the dynamics at all physical scales from the micro to an ocean basin.

Question 4. Do you feel that more could or should be done to explicitly bolster education programs at the University of Hawai'i and Hawaii Pacific University?

Answer by Judy Lemus, Faculty Academic Programs Specialist at HIMB. Undergraduate enrollment in science majors is declining all over the country and I think it would be helpful to look at that more closely, specifically within the context of Hawaii and develop objectives at UH that could help to reverse that trend. Certainly engaging more minority and underrepresented groups is needed as the demographics of universities move toward parity with the general population. But more broadly, I think it also has to do with changing our approach to teaching science in a way that keeps up with contemporary culture, is more enriching and engaging, and is better in tune with career opportunities. So this would require investments in revising curricula and also providing more resources for immersive and authentic science experiences for undergraduates. I think there is potentially a huge need for this at the University of Hawai'i.

Toward outreach education, the university functions within the continuum of a broader educational system and culture, including K–12 education and free-choice, life-long learning of adult citizens. As such, and as the pinnacle of the formal education system, the university should certainly be engaged in bolstering education throughout that continuum. For science in particular, if the academic science community disregards the education needs and interests of the public, it risks alienating that public audience and potentially eroding support for publicly funded science, and therefore diminishing our capcity in science and technology (two of the fastest growing sectors of the global economy). We have already seen how difficult it is to enage any disenfranchised sector of the public. For the University of Hawai'i, there needs to be better coordination of the many worthwhile outreach efforts that are happening.

Answer by Malia Rivera, Faculty Marine Education Coordinator at HIMB. In early 2007 the HIMB Education Program, with the help of the University of Hawai'i Office of Institutional Research, compiled statistics from the Fall 2006 semester on the number students at UH Mānoa (UHM) majoring in undergraduate degrees from majors associated with the School of Ocean and Earth Science and Technology (SOEST—of which HIMB is a part), in Zoology, and in Marine Biology (the latter two departments whose curricula are most closely associated with the mission of HIMB). Despite an overall student body at UHM made up of 60 percent undergraduate students that graduated from Hawaii high schools (that is, students presumably *from* the State of Hawaii), the proportion of students from Hawaii that have declared majors in SOEST was only 15 percent, in Zoology only 17 percent, and in Marine Biology only 27 percent. In other words, most of the undergraduates majoring in these disciplines do not enter UHM as residents from the state, but rather are from either the mainland or other countries. Given recent efforts by the state to encourage STEM education to help diversify Hawaii's future economy away from its reliance on tourism, there is a need to create more opportunities for our local students to pursue science and technology disciplines as a course of study and as an eventual career. To do this, pathways that help students journey through the sciences from the K–12 through the undergraduate and graduate levels of study, and eventually job placement, are critical. While the good news is that more and more programs like these are emerging, the numbers of our students enrolling in these types of majors are still markedly low. Cuts to funding at NSF that have supported these efforts would likely thwart the progress made thus far.

Question 5. Since 2004 the state has been making climate change mitigation and adaptation a priority through increased dedication and investment in the research and development of clean energy technologies. How has legislation passed in recent years benefited your research or commercial goals?

Answer by Jo-Ann Leong, Professor and Director of HIMB. The America COMPETES Act with the reauthorization of NSF has been instrumental in providing funding for many of the HIMB faculty. The importance of this funding is documented in the previous answers. As of May 2008, 10 of 15 HIMB faculty members have competitive research grants from NSF. The cumulative amount of this funding, *i.e.,* for multiyear grants, is $3,844,288. Some of that funding will end in 2008 and, like all faculty members in academic research units, are working very hard to renew their funding. Projected cuts will have a major impact on these efforts.

Question 6. What types of trends have you witnessed in regard to the erosion of corals here in Hawaii?

Answer by Charles Fletcher, Professor and Chairman, Dept. of Geology and Geophysics, School of Ocean and Earth Science and Technology, UH-Mānoa. "No trends have been witnessed in this regard . . . coral erosion is not a worry—bleaching and acidification are worries and perhaps they are referring to this. The reason no trends have been witnessed is that no one is watching. There are no moitoring programs set up to look for this effect, and the effect is not expected to be manifest for several decades in any case. Of far greater concern are coastal run-off, poor water quality in restricted circulation areas, and other human impacts."

Question 7. Have we seen an increase in the last decade of disease events on corals reefs? If so, do you believe this to be attributed to increasing ocean temperatures or another event?

Answer by Greta Aeby, Assistant Researcher, Hawai'i Institute of Marine Biology, OEST, UH-Mānoa. Dr. Greta Aeby, in her response to your question regarding research on corals' resistance to climate change, documents the evidence that suggests a correlation between bleaching and disease.

Question 8. Is HIMB conducting any long-term monitoring and research of threats to coral reefs such as coral bleaching?

Answer by Jo-Ann Leong, Professor and Director at HIMB. The Hawai'i Coral Reef Assessment and Monitoring Program (CRAMP) was created during 1997–98 by leading coral reef researchers, managers and educators in Hawaii . The initial task was to develop a state-wide network consisting of over 30 long-term coral reef monitoring sites and associated database. Upon completion of the monitoring network the focus was expanded to include rapid quantitative assessments and habitat mapping on a state-wide spatial scale. Today the emphasis is on using these tools to understand the ecology of Hawaiian coral reefs in relation to other geographic areas. Led by Paul Jokiel, Ku'ulei Rodgers, Eric Brown, and Alan Friedlander, CRAMP is housed at HIMB and the data gathered by the Hawaii CRAMP over the last 7-years from 32 sites across the Main Hawaiian Islands has been utilized by county, state and Federal managers in their efforts to manage the resources of Hawaii.

Question 9. What resources are needed to carry out the proper level of monitoring and research of coral reefs?

Answer by Florence Thomas, Associate Research Professor at HIMB. One of the major tasks facing ocean scientists in the 21st century is to unravel the complex interaction of physical, chemical, and biological processes that underlie the function of oceanic ecosystems. We are in an era of rapidly developing technology and are beginning to approach science in a cross disciplinary fashion which is providing a means to examine these complex interactions rather than focusing on single processes or disciplines. Thus we are poised to examine oceanic ecosystems in a way that has previously been impossible.

Over the past 10 years there has been considerable development of sensors capable of monitoring aspects of the environment at increasingly small scales and with accuracy that meets the level of biological responses. To fully understand how corals and coral associated organisms respond to a changing environment we need to invest in the deployment of small-scale sensor arrays in locations where corals and associated organisms can be continually monitored for responses using modern molecular and more traditional methods.

Many biological processes are influenced by the physical and chemical characteristics of the environment. For example, hydrodynamic regime can determine the rate at which chemicals are delivered to or from an organisms or community. This rate in turn can impact biological processes such as photosynthesis, nutrient uptake, coral bleaching, and algal productivity. Further changes in light and temperature may impact normal biological function. While we know from land-based experiments that these physical parameters can impact biology, little is known about the small-scale fluctuation in physical parameters in the field and how organisms in situ respond to naturally occurring changes. To date, we do not know which scales of environmental variation may be most important in driving changes in ecosystem function. By mapping measures of response at the gene, metabolism, and community scale onto shifts in environmental parameters taken continuously at scales relevant to organisms we can begin to determine the factors underlying such shifts. Knowing how organisms respond to large scale and long-term perturbations in environmental parameters singly is not enough. We need real-time, small scale monitoring of multiple environmental factors at the scale of the organism if we are to understand changes in coral reef ecosystems.

Question 10. Research has shown that some corals are able show a greater tolerance to climate change and coral bleaching than others due to the different species of algae that live within their tissues. What research has been done to explore resistance of Hawaiian corals to climate change?

Answer by Greta Aeby, Assistant Researcher, HIMB. Corals have a narrow range of thermal tolerance and so are extremely susceptible to temperature stress. Studies are now starting to show there is a link between coral disease and ocean warming. Several diseases show seasonal patterns where higher levels of disease are found during the warm water seasons. For example, Willis *et al.,* (2004) found a fifteen fold increase in acroporid disease on the GBR during the summer surveys as compared to winter surveys. Disease outbreaks have also been found to follow water temperature anomalies or bleaching events. On the GBR, Bruno *et al.,* (2007) found a significant relationship between frequency of warm temperature anomalies and the incidence of white syndrome and Miller *et al.,* (2006) found significant coral mortality (26–48 percent losses in coral cover) from coral disease on reefs in the U.S. Virgin Islands following an extensive bleaching event. High temperature anomalies may drive outbreaks of disease by hindering the corals' ability to fight infection and/or by increasing the pathogen's virulence (Harvell *et al.,* 2007).

In Hawaii, we are just now developing the capacity to determine whether ocean warming, is currently or will in the future, result in increases in coral diseases on the reefs of Hawaii. Within the past couple of years, baseline disease surveys have been completed and focused studies on diseases of concern initiated. So while we do not yet know whether water temperatures have affected coral disease levels on the reefs of Hawaii, disease outbreaks have already been documented in both the northwestern Hawaiian Islands (Aeby 2006) and in Kaneohe Bay, Oahu within the main Hawaiian Islands (Aeby *et al.,* unpub. data). The recent disease outbreaks in Hawaii are worrisome and raise concerns about Hawaii's reefs ability to tolerate conditions associated with global climate change. Research is desperately needed to understand coral disease processes in Hawaii and thus be able to predict the trajectory of the health of Hawaii's reefs in the face of increasing anthropogenic stressors and warming ocean temperatures.

Literature cited

Aeby, G.S. 2006. Outbreak of coral disease in the Northwestern Hawaiian Islands. *Coral Reefs* 24(3):481.

Bruno, J., Selig, E., Casey, K., Page, C., Willis, B., Harvell, D., Sweatman, H. and A. Melendy. 2007. Thermal Stress and coral cover as drivers of coral disease outbreaks. *PLoS Biology* 5(6):e124. Doi:10.1371/journal.pbio.0050124.

Harvell, D., Johdan-Dahlgren, E., Merkel, S., Rosenberg, E. Raymundo, L., Simth, G., Weil, E. and B. Willis. 2007. Coral disease, environmental drivers, and the balance between coral and microbial associates. *Oceanography* 20(1):59–81.

Miller, J., Waara, R., Muller, E. and C. Rogers. 2006. Coral bleaching and disease combine to cause extensive mortality of reefs in U.S. Virgin Islands. *Coral Reefs* 25:418.

Willis, B., Page, C. and E. Dinsdale 2004. Coral disease on the Great Barrier Reef. Pages 69–104 in E. Rosenberg and Y. Loya (eds). *Coral Health and Disease*. Springer-Verlag, Germany.

Question 11. I have heard that Hawaii is an ideal place for the establishment of carbon offset forestry. Does using forestry to offset Hawaii's CO_2 emissions seem like a viable option?

Answer by Jo-Ann Leong, Professor and Director of the Hawai'i Institute of Marine Biology. This is a very interesting question and should best be answered by an expert in Forest CO_2 sequestration. I have referred it to Boone Kauffman, Director, Institute of Pacific Islands Forestry, Pacific Southwest Research Station, USDA Forest Service, 60 Nowelo Street, Hilo, Hawaii 96720. Here are some factors that might help in the discussion:

1. Hawaii in 2005 was generating approximately 23.05 million metric tons of CO_2 (EPA, Comparison of EPA State Inventories and the Inventory of U.S. Greenhouse Gas Emissions and Sinks, last updated Feb. 25, 2008).

2. Hawaii's existing forests are already acting as a carbon sink for 108 million tons of CO_2 (EPA State Action Policies: Hawaii, at the following website: *http://yosemite.epa.gov/gw/statepolicyactions.nsf/uniqueKeyLookup/BMOE5P9LGZ?OpenDocument*).

3. The State of Hawai'i Action Plan (koa reforestation and longer rotation of high value forest plantations) indicates that reforestation has the potential to sequester an additional 26 million tons of carbon.

4. According to the DBEDT plan, the reforestation projection is economically viable as a carbon sequestration strategy.

Please note that these figures are just estimates. I was not able to verify the figure for Hawaii's forests as tons or metric tons.

Question 12. Scientific evidence has suggested that one potential impact of climate change will be the increased expansion of invasive species. Hawaii has already suffered as the result of more than 70 marine invasive species. What kinds of monitoring and research are being performed to address invasive species in the Hawaiian Islands and what do we need to do to prevent future invasions?

Answer by L. Scott Godwin, Research Specialist, Hawai'i Institute of Marine Biology, SOEST, UH-Mānoa. The native species of the marine and terrestrial environments of the Hawaiian Archipelago arrived as natural biological invasions through historical time, and through evolution and adaptation became the present communities associated with the ecosystem. The advent of modern history has created new human-mediated biological invasions through non-natural mechanisms. The natural species invasion process is measured in geologic time but the invasions attributed to human-mediated sources are occurring at greater frequency than by natural means.

Disturbance, both natural and man-made, can create a situation in which competition dynamics can be altered in coral reef habitats. Physical damage, whether by storms or anchor damage, can lead to gaps that can be exploited by both native and non-native species. Once this has begun it is nearly impossible to take measures that can halt the process. From the standpoint of non-native species invasions, measures to minimize the likelihood of exposure by new non-native species are the best approach for resource managers. These measures take the form of monitoring both the marine communities that can be affected and the mechanisms that can expose these communities to non-native species.

Monitoring of marine communities involves baseline surveys to determine what native and non-native species exist so that new introductions can be identified and the spread of established non-natives can be followed (and possibly prevented). The baseline survey of organisms in marine communities is a lengthy process and requires taxonomic expertise to identify both native and non-native species. This expertise is rarely centered in the location of the survey efforts and requires collaboration with institutions throughout the world.

Identifying the mechanisms of non-native species transport requires a "pathway analysis" that takes into account all present and future vectors that could affect a region. Most pathways are associated with the movement of commercial commodities via maritime and air shipping hubs but other means also exist. Activities of public and private sector research and conservation entities can also be responsible for transport.

In Hawaii, a variety of surveys conducted under the auspices of the Hawaii Biological Survey (*http://hbs.bishopmuseum.org/*) and the Hawai'i Institute of Marine Biology (HIMB) have identified marine non-native species throughout the archipelago and the common transport mechanisms. The majority of the species are associated with natural and man-made shorelines in conjunction with maritime shipping hubs but there are many species established in shallow and deep water coral reef habitats. Most species are found within the Main Hawaiian Islands but some have become established in the Pāpahanaumokuākea Marine National Monument (PMNM). Specific management focus on marine non-native species and transport mechanisms for the PMNM has been conducted by the Hawai'i Institute of Marine Biology (*http://cramp.wcc.hawaii.edu/Downloads/Publications/TR__Godwin__et__al%20__Invasives__Final%20Draft.pdf*). A pro-active management plan that requires surveys of all maritime vessels applying for permits for entry into the PMNM was developed in conjunction with HIMB and has been in place since 2006. Presently, HIMB is also conducting work in the PMNM involving the survey of established non-native species populations to determine if expansion is occurring and the level of transport associated with derelict fishing gear. Researchers are providing developing genetic techniques for early detection of marine non-native species and taxonomic expertise for surveys of native and non-native species.

Question 13. Warmer seas are believed to contribute to increased numbers of harmful algal blooms. These blooms produce toxins which can be passed onto humans through the seafood that we eat. Will it be necessary to increase seafood monitoring and testing to protect Hawaiians from shellfish poisoning?

Answer by Jo-Ann Leong, Professor and Director, Hawai'i Institute of Marine Biology. Senate Bill 2688: Commercial Seafood Consumer Protection Act, if enacted should provide much needed capacity for the FDA and NOAA to carry out "testing and other activities" to ensure seafood safety for the American public. Current data indicate that the spatial and temporal incidence of harmful algal blooms is increasing and despite the cause, warmer seas or increased pollution (phosphorus and/or nitrogen in the environment), Hawaii will have to increase its capacity to test for and make predictions regarding harmful algal blooms that might impact its seafood.

Question 14. There has been concern that climate change could result in increases in the prevalence of diseases, specifically dengue fever. Does Hawaii need to worry about potential increases of diseases that have not been historically abundant?

Answer by Jo-Ann Leong, Professor and Director, Hawai'i Institute of Marine Biology. The World Health Organization in its report on Climate Change and Human Health (2003) points to observations that mosquito-borne diseases like malaria increases around five-fold in the year after an El Niño event (Bouma and van der Kaay, 1998). The Environmental Protection Agency (EPA 236–F–98–007e, Sept. 1998) reports that warming and other climate changes may expand the habitant and infectivity of disease-carrying insects, increasing the potential for transmission of diseases such as malaria and dengue fever. Although dengue fever is currently uncommon in the United States, conditions exist in Hawai'i that make it vulnerable to the disease. Dengue outbreaks have also occurred in Hawaii. Warmer temperatures resulting from climate change could increase this risk.

Bouma, M. and H. van der Kaay, The El Niño Southern Oscillation and the historic malaria epidemics on the Indian subcontinent and Sri Lanka: an early warning system for future epidemics? *Tropical Medicine and International Health,* 1(1): p. 86–96. (1996).

Question 15. One of many effects of sea level rise will be salt water contamination of drinking water. What efforts are being taken to look into salt water purifying systems to ensure that Hawaiians will have fresh water to drink?

Answer by Charles Fletcher, Chairman and Professor, Geology and Geophysics, School of Ocean and Earth Science and Technology, University of Hawai'i at Mānoa. In reality we use no drinking water from the coastal plain—our drinking water comes from higher elevations above the reach of sealevel impacts. There *are* real threats to drinking water, *i.e.,* decreased rainfall in an El Niño type future (one of many model results), lowering water tables and rising chlorinity levels, but these are from over-use and sea level rise will not have an important impact. Hence, sea level rise is not a threat to drinking water. The low lying coastal plains are where we inject our waste water on all islands through thousands of injection wells . . . sea level rise may impact these, but the injection is already done into the salty ground water, so I don't think this is a major concern. There are potentially severe impacts from sea level rise you may want to consider: beach loss and accelerated coastal erosion, increased vulnerability to tsunami and storm surge, loss of coastal plain drainage into storm drains, stream flooding where they meet the ocean, increased frequency of wave overtopping on crucial highways . . . and others.

Question 16. Corals and other marine resources in Hawaii may be significantly impacted by both climate change and ocean acidification. Changes in temperature, salinity, and sea level would directly impact coral reefs and related fisheries. Corals are susceptible to small increases in temperature, which may result in deadly coral bleaching. Studies have also confirmed that our oceans are becoming more acidic due to increased levels of carbon dioxide in the atmosphere. These conditions are predicted to adversely impact coral growth, and may also be harmful to commercially important fish and shellfish larvae. Such organisms are also important food sources for other marine species. Approximately half of all federally-managed fisheries depend on coral reefs and related habitats for a portion of their life cycles. The National Marine Fisheries Service estimates that the annual dockside value of commercial U.S. fisheries from coral reefs exceeds $100 million. For Hawaii, however, the economic value of coral reefs is estimated at more than $360 million annually, when reef-related tourism and fishing are taken into account. Coral reefs in Hawaii are not just critical habitats for marine animals, they also support the economy through fishing and tourism. Which is the more pressing issue for the health of Hawaii's coral reefs, ocean acidification or the increasing sea surface temperatures? Why?

Answer by Jo-Ann Leong, Professor and Director, Hawai'i Institute of Marine Biology. Ocean acidification and increasing sea surface temperatures are considered the result of rising concentrations of CO_2 in the atmosphere. Thus, increased sea surface temperature and acidification are related phenomena. Many of us consider both to be important. In the case of sea surface temperatures, if the increase in temperatures happens rapidly (over decades rather than centuries) there will be bleaching and some corals and their symbionts will be unable to adapt to prolonged exposure to higher temperatures. There should be corals that survive the temperature increase, but we cannot predict what species will survive and how many of these species will remain. Measuring resilience of coral reefs is critically important to determine whether coral reefs will be available in the future to provide habitat for fisheries and to protect our coastline.

Ocean acidification may reduce the recruitment of coralline crustose algae, the "glue" that holds the reefs together and provides the signal for coral larvae to settle. Other studies have shown that stony corals will lose their calcareous skeleton and essentially look like soft corals under acidic conditions in the laboratory. Again, we don't have enough data to predict the effects of ocean acidification on coral reef ecosystems (not single coral pieces in aquaria). We are in need of research facilities in the United States with large mesocosms that house coral reef ecosystems where water temperatures and seawater acid pH balance can be manipulated.

Question 17. What role does Hawaii play in providing answers for the impact of climate change and ocean acidification on coral reefs?

Answer. The Hawaiian Archipelago is the most isolated archipelago in the world. It is a site where 70 percent of the Nation's reefs reside and these reefs are situated on sites that were derived from geological processes operating on a well established time line, 30+ mya (Kure Atoll) to less than 1 mya (Hawaii Island). The marine environment of the different high islands, atolls, and reefs in the Hawaiian Archipelago are microcosms of environmental diversity with exposure to anthropogenic stresses in the southern part of the chain (Main Hawaiian Islands) to the relatively pristine part of the chain (Northwestern Hawaiian Islands). Hawaii is also close to the northernmost latitude for shallow water coral reefs and thus, climate changes are predicted to reach this site rather early. The number of species in Hawaii's coral reefs is largely unknown but estimates place the number at 7,000 and approximately 20–25 percent of these species are found nowhere else in the world.

All of these characteristics make Hawaii the prime place for the study of climate change on coral reefs. Nowhere else are there similar reefs distributed along a gradient of anthropogenic stress, gradient of geologic age, a gradient along a North-South longitude, and isolation from the influence of large land masses. The Federal, state, and university research and management enterprises in Hawaii have made a major investment in hiring experts to study coral reefs. A "critical mass" of talent is available in Hawaii to conduct these studies. The proximity of coral reefs to modern, technologically equipped laboratories is also a major advantage. Moreover, Hawaii can play a role in providing research capabilities and education opportunities for the six jurisdictions that the U.S. maintains in the Pacific including American Samoa, Guam, the Commonwealth of Northern Mariana Islands, the Republic of Palau, the Republic of Marshall Islands, and the Federated States of Micronesia.

Question 18. What is the trend with regards to the erosion of corals here in Hawaii?

Answer by Charles Fletcher, Chairman and Professor, Geology and Geophysics, SOEST, UH-Mānoa. In Hawaii, sea-level rise resulting from global warming is a particular concern. Riding on the rising water are high waves, hurricanes, and tsunami that will be able to penetrate further inland with every fraction of rising tide. In addition, the coastal groundwater table is likely to crop out above ground level and lead to widespread flooding. The physical effects of sea-level rise fall into 5 categories. These are:

1. Marine inundation of low-lying developed areas including coastal roads,
2. Erosion of beaches and bluffs,
3. Salt intrusion into aquifers and surface ecosystems,
4. Higher water tables, and
5. Increased flooding and storm damage due to heavy rainfall.

Assessing the impact of these on Hawaii requires identifying a likely global sea-level scenario. Global sea level is principally the product to two phenomena: (1) melting ice on Antarctica, Greenland, and among alpine glaciers, and (2) thermal expansion of seawater due to surface warming. The first detailed observations of Antarctic ice reveal net melting; the melting rate on Greenland has increased 250 percent in the past decade; there is widespread retreat and thinning of mountain glaciers, and together these major ice sources contribute about 2.0 mm/yr to global sea-level rise. Thermal expansion is calculated from the amount of heat stored in the upper ocean as revealed by increased water temperature. While changes in water temperature over past decades have been difficult to measure, studies indicate that thermal expansion increased from an average rate of about 0.36 mm/yr in past decades, to 1.6 mm/yr in the most recent decade. The total contributions to global sea level (~3.6 mm/yr) agree remarkably well with the observed rate of rise (~3.4 mm/yr) as measured by satellites.

The Intergovernmental Panel on Climate Change has predicted future sea-level changes to the year 2100 in the range 18 to 58 cm. However, these projections do not include a component based on ice behavior, and hence, are widely considered to underestimate the potential for flooding. Two studies published in 2007, both by German climate researcher Stefan Rahmstorf and colleagues, indicate a more likely scenario of future climate change and sea-level rise. In one study, Rahmstorf compared projections of future atmospheric warming and sea-level rise made in 1990 by the IPCC to observations in 2006. Results indicate that the climate system, in particular sea level, may be responding to global warming more quickly than models specify. Observed temperature changes are in the upper part of the range projected by the IPCC and sea level has been rising faster than even the extreme scenarios projected by the models. Notably, Rahmstorf found that the rate of sea level rise for the past 20 years is 25 percent faster than the rate of rise in any 20-year period in the preceding 115 years. In his second paper of 2007, Rahmstorf estimates 21st century sea-level change on the empirical relationship between 20th century temperature changes and sea-level changes. The study establishes a proportionality constant of 3.3 cm of sea-level rise per decade per °C of global temperature warming. When applied to future warming scenarios of the Intergovernmental Panel on Climate Change, this relationship results in a projected sea-level rise in 2100 of 0.5 to 1.4 m above the 1990 level. On the basis of Rahmstorf's research, and the documented accelerations in melting of both the Greenland and Antarctic ice sheets, it seems highly likely that a sea level of approximately 1 m above present could be reached by the end of the 21st century.

In Hawaii, as the ocean continues to rise, natural flooding occurs in low-lying regions during rains because storm sewers back up with saltwater, coastal erosion accelerates on our precious beaches, and critical highways shut down due to marine flooding. The Mapunapuna industrial district of Honolulu adjacent to the airport is a good example. If heavy rains fall during monthly highest tides portions of the region flood waist deep because storm drains are backed up with high ocean water. The undercarriages of trucks suffer a rust problem because floodwaters become salty at high tide. Even when it does not rain, the area floods with salt water as it surges up the storm drain into the streets and local workers report seeing baby hammerhead sharks in the 2-foot deep pools.

Using sensitive topographic data collected by NOAA and the Army Corps of Engineers, it is possible to map the contour line marking 1 m above present day high tide. This "blue line" identifies the portion of our communities that fall below sea level when seas reach the 1 m mark later in the century. This dramatic map has roughly 30 cm accuracy. Those lands that are closer to the ocean are highly vulnerable to inundation by seawater during high waves, storms, tsunami, and extreme water levels. Hotel basements will flood, ground floors will be splashed by wave runup, and seawater will come out the storm drains on most of the streets in Waikiki and along Ala Moana Boulevard.

Don't think that waves will be rolling down the streets and reaching the blue line. More likely, lands lying below sea level in the future will be dry at low tide during arid summers. But they will have high water tables, standing pools of rainwater, and backed up storm drains when it rains and tides are high. Beaches will be mostly gone and we'll have built large seawalls lining most of our shores. Despite the wet conditions, most of the buildings will probably still be inhabited and residents will have to time their movement between the tides, just as they do today in Mapunapuna. Back up in the McCully and Makiki areas residents won't see any seawater, they will see the wetlands of the 19th century reemerging as the water table rises above ground level in some areas (not all areas). Under these conditions, when it rains, we will have a real problem. The runoff will raise the water table, the storm drains will be full of seawater except at the very lowest state of the tide, and standing pools of water will accumulate throughout the region without a place to drain. Travel will be limited and many lands will turn to wetlands, there may be some areas of permanently standing water.

References:

Rahmstorf, S., 2007, A semi-empirical approach to projecting sea level rise. *Science,* 315, 368–370.

Rahmstorf, S., *et al.,* 2007, Recent climate observations compared to projections. *Science,* 316, 709.

Figure 1. The blue line marks the contour of high tide when sea level is 1 m above present. Lands makai of the line are highly vulnerable to coastal hazards. These are targets for redevelopment to increase resiliency to natural hazards.

Question 19. Have we seen an increase in the last decade of disease events on corals reefs? If so, could this be attributed to increasing ocean temperatures or another event?

Answer by Jo-Ann Leong, Professor and Director, Hawai‘i Institute of Marine Biology. Surveys of coral reefs for disease status was not undertaken in Hawaii until 2002 and in the short period of time since then, there appears to be an increase in the incidence of disease events in coral reefs. We do not have sufficient data to attribute increasing ocean temperatures to coral disease incidence in Hawaii. A critical need we have identified is a quarantine facility that will enable researchers to conduct laboratory studies that would lead to the identification of pathogenic agents of coral disease and an understanding of the possible responses of coral to infection and physical insult. Please see Dr. Greta Aeby's response to Question 7 above.

Question 20. Invasive species cause damage by diminishing fisheries, fouling ships, clogging intake pipes, and spreading disease. The United States spends $120 million annually to control and repair damage from more than 800 invasive species. Hawaii has 73 known marine invasive species, 42 percent of which are considered harmful. I understand that climate change may contribute to an increase in the number of invasive species. Given that Hawaii is already affected by more than 70 marine invasive species, what kinds of monitoring and research are being conducted here to address this?

Answer by Jo-Ann Leong, Professor and Director, Hawai'i Institute of Marine Biology. CRAMP (Coral Reef Assessment and Monitoring Program), a program with partners in NOAA–PIFSC, HIMB at UH-Mānoa, Bishop Museum, and Hawaii Dept. of Land and Natural Resources, and the Hawai'i Biological Survey based at the Bishop Museum have been monitoring different reef ecosystem in the Main Hawaiian Islands for potentially invasive organisms on an annual basis and selected reef ecosystems in the Northwestern Hawaiian Islands once every 2 years. There is not enough funding or manpower to monitor the entire Hawaiian Archipelago as often as is needed. Ships that enter the Papahānaumokuākea Marine National Monument undergo hull inspections. There is certainly a need for more monitoring and research that targets the pathways for marine invasions, *i.e.,* hull fouling and ballast water, and provides methods to reduce or eliminate these pathways for marine invasions.

Question 21. What can we do to prevent future invasions?

Answer by Jo-Ann Leong, Professor and Director, Hawai'i Institute of Marine Biology. I would refer you to the report available at the CRAMP website by L. Scott Godwin: *http://cramp.wcc.hawaii.edu/Downloads/Publications/TR_Godwin_et_al%20_Invasives_Final%20Draft.pdf.*

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. DANIEL K. INOUYE TO RICHARD E. ROCHELEAU, PH.D.

Question 1. Historically, Hawaii has had some of the highest utility and fuel costs in the Nation. This is in large part due to Hawaii's isolated location, which makes it difficult to connect a power grid. In addition, over 90 percent of the state's energy production comes from costly imported fossil fuels.

In recent years, Hawaii has taken impressive strides to address these issues by investing in the research and development of clean renewable energy technologies. By becoming a test bed for clean energy technologies, Hawaii has positioned itself to attract investment and to cut the state's dependence on costly imported fossil fuels. What renewable technologies are best suited to the state?

Answer. Hawaii is blessed with a varied and substantial abundance of renewable energy resources such that nearly all commercial renewable technologies can contribute to Hawaii's energy mix. Unfortunately, not all technologies are at a state of technical readiness to contribute. Additionally, the small grid systems with no interconnections between islands impose a number of practical constraints on the use of many of the technologies that will require additional effort and investment in order to maximize their contribution.

Wind, solar, and geothermal technologies are well-suited to Hawaii but each has limitations to their deployment. Biofuels are also expected to play a significant role but water resources, cost, and competing land-use are significant issues that may limit their availability from local sources. In the future, ocean energy technologies and advanced bioenergy systems such as algae could play a significant role but they are as yet unproven at the commercial scale. Although not normally included in a discussion on renewable technologies, end-use energy efficiency and energy efficient buildings is an area that is critically important to Hawaii and all other states. Additional but brief comments on each of these technologies follow.

Wind: Without doubt, wind is one of the best technologies for use in Hawaii. Overall, Hawaii has an excellent wind resource and wind technology is very mature and cost effective. The islands of Hawaii and Maui already get a significant amount of their energy from wind and both have the resources and potential sites for substantially more. At high penetration levels wind can, however, have negative impacts on the operability of the grid. The intermittency and difficulty of forecasting also can limit the maximum amount that can be accepted. Storage can help mitigate these effects but storage at this scale remains costly. HNEI is working with GE Global Research Center and the utilities to address these issues to allow higher penetration. Oahu, whose energy use is many times that of the other islands, is limited by resource and by siting. Efforts to develop wind on Molokai and/or Lanai for export to Oahu are underway, but land use is an issue and cost/permitting for an interconnection cable of the needed size are significant issues.

Solar: Solar photovoltaics (PV) is another technology that is extremely well-suited to Hawaii. PV is proven albeit somewhat expensive technology. Applications include utility scale, commercial roof, or residential roof systems. Tax credits are very important to help mitigate the current high cost of PV. As is the case for wind, solar is an intermittent resource and so PV may be limited in the total penetration level that can be achieved before grid operability is affected.

Geothermal: Geothermal is a reliable and cost effective renewable energy technology in areas where the resource exists. The best resource is on the island of Hawaii. Undersea cabling from Hawaii to the other islands has been examined in the past. Water depth and resource issues make that a very complex issue to overcome. Hot spots also exist on other islands (*e.g.,* Maui) but technology to economically extract energy from these lower temperature resources remains unproven. Engineered Geothermal Systems (EGS) which extracts heat by creating a subsurface fracture system to which water can be added through injection wells is a technology currently under development that may be a candidate for Hawaii.

Biofuels: Solid (direct fired) and liquid biofuels have the potential to make significant contributions to both the electricity and transportation sectors. Historically, bioenergy in Hawaii took advantage of waste biomass from the various agricultural sectors (*e.g.,* bagasse from the sugar industry). This contribution has decreased in recent years as agriculture has decreased. Hawaii also has regulations requiring 10 percent ethanol in gasoline. This ethanol is currently imported from the national and international markets. Large scale local production of feedstock for biofuels is envisioned but will be complicated by a number of issues including availability of water, competing land uses, and social issues (*e.g.,* food vs. fuel). The State of Hawaii has contracted the Hawaii Natural Energy Institute to develop a comprehensive plan for the development of bioenergy systems in Hawaii. Significant effort will also be needed to identify the best crops and agricultural practices for these to be sustainable activities. Crop development must be coordinated with the availability of conversion technologies. The Federal Government continues to have active programs supporting the development of conversion technologies.

There has been substantial discussion recently about the potential for photosynthetic algae to be a significant contributor to the biofuels energy mix. If commercial economically viable algal systems can be developed, the high growth rates and the absence of competition for food crops would be significant advantages. However, there are both biological and process engineering questions that remain unanswered at this time. Certainly, given the potential and the many unanswered questions, continued support of this research area is warranted.

Ocean Energy: Ocean energy can include wave energy, current, and ocean thermal technologies. Hawaii has some of the Nation's best wave energy resources and has near-shore sites with temperature differentials that make ocean thermal energy conversion (OTEC) possible. Planning studies and/or pilot scale testing is underway in Hawaii in both these areas. While promising for the future, neither wave nor OTEC can be considered commercially available or economically viable at this time. Although energy from ocean currents is somewhat more developed than either wave or OTEC, Hawaii does not have a significant tidal range and only a very limited ocean current resource.

Question 2. The European Union (E.U.) has become a world leader in renewable energy technologies; it possesses half the world renewable market and its industry employs 300,000 people with annual revenues of $20 billion. The E.U. has committed to investing $1.5 billion in renewable technology and energy efficiency, a 40 percent increase over the previous commitments. How does the United States compare to others around the world in the renewable energy technologies industry?

Answer. REN21 estimates that $71 billion was invested in renewable energy capacity worldwide in 2007, up from $55 billion in 2006 and $40 billion in 2005. Almost all of this increased investment was in solar PV and wind power with much smaller amounts in solar hot water, hydropower, biomass, and geothermal. PV and wind then provide useful technologies to use for comparison of the U.S. to others around the world in the renewable energy technologies industry.

It is almost a cliché answer, but it is fair to say that in many instances the U.S. has led the world in the research and development of various renewable energy technologies only to see other countries adopt their use, develop manufacturing capability, and eventually surpass U.S. industry in the manufacture and sales of these technologies. This is most clearly the case for photovoltaics. The development of wind technology occurred among a more diverse mix of countries, but, while the U.S. is currently seeing some of the strongest growth in the installation of wind systems, U.S. industry is not gaining market share in this field. The attached charts show current installation and manufacturing specifications for these two technologies.

Figure 1 shows the annual installation of photovoltaic systems by country or region between 2000 and 2007. The substantial increase of PV installations in Germany is a direct result of the large subsidy for PV in that country. The same was true for Japan. More relevant to this question is Figure 2 which shows annual PV production worldwide. The U.S. was the largest producer in the world through 1998 before falling behind Japan. By 2007, the U.S. was only the 4th largest producer, behind Japan, Europe, China, and Taiwan.

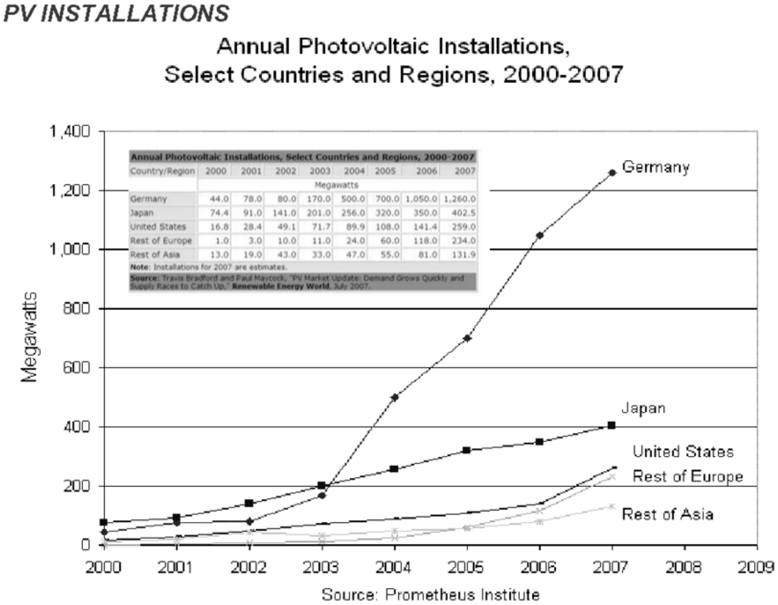
China, which almost tripled production in 2006 and then doubled it again in 2007 is poised to gain an ever larger share of the worldwide market. Although a late entry to the marketplace, China's Suntech is now the 3rd single largest producer of PV modules.

The picture for wind, while somewhat different than PV in that installation of wind turbines in the U.S. is keeping pace with installations in other countries (see Fig. 3) shows similar troubling trends in turbine manufacturer. While GE, the only U.S. turbine manufacturer in the top 10 worldwide in 2007 retained its ranking as the 3rd largest manufacturer worldwide, its market share slipped, from 17.5 to 15.5 percent in 2007, behind Vestas (Denmark) and Gamesa (Spain). Merrill Lynch reports that "GE will face fierce competition for market share from new entrants to its markets and without a high level of vertical integration, it also looks disadvantaged in the near-medium term" Enercon (Germany) and Suzlon (India) have both seen increased market share during this period. Currently, there are no Chinese companies exporting turbines. However, many recent reports indicate that two Chinese companies, Goldwind and Sinovel, have big export plans with others not far behind. The Chinese companies are expected to present a formidable challenge to existing turbine companies.

Question 3. Do you think we are at risk of falling behind others in research and development? Is it conceivable that if we don't make the proper investments, we may end up importing this technology from other countries in the future, just as we are importing oil today?

Answer. The U.S. has long been a leader in research and development of renewable energy technologies. It is imperative that industry, state, and Federal Government continue to invest in renewable energy R&D, especially in the emerging technologies such as future generation photovoltaics, biofuels, ocean energy technologies, and advanced end-use efficiency technologies. However, using PV and wind as examples, it seems apparent that investment in R&D is not sufficient to ensure that the U.S. will not become an energy technology importer as it is today for oil. There must be sufficient support to validate emerging technologies so that end-users (*e.g.,* utilities and large scale energy users) will accept them and to assist companies to move promising technology beyond the demonstration phase and into the marketplace. These are complicated issues that go beyond the support of research that has been typical of U.S. energy programs.

PV INSTALLATIONS



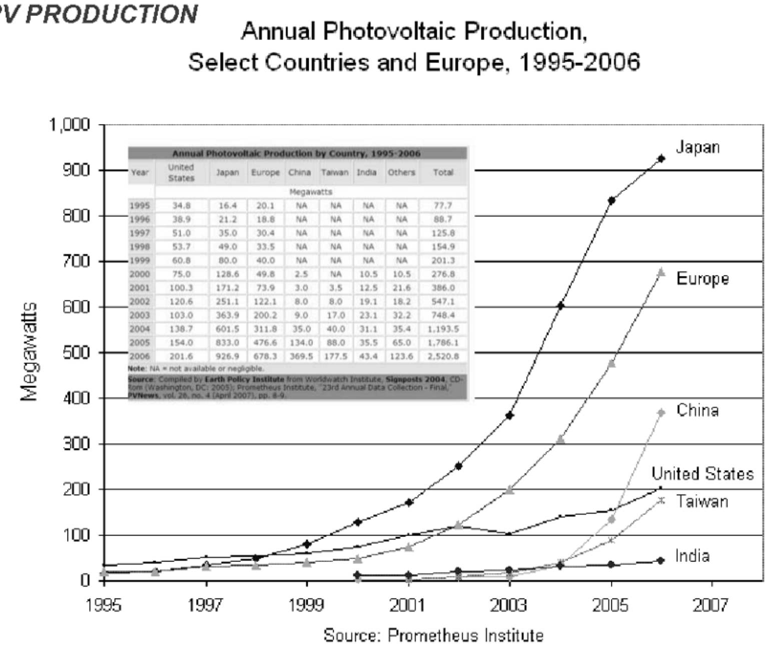
Annual Photovoltaic Installations, Select Countries and Regions, 2000-2007								
Country/Region	2000	2001	2002	2003	2004	2005	2006	2007
	Megawatts							
Germany	44.0	78.0	80.0	170.0	500.0	700.0	1,050.0	1,260.0
Japan	74.4	91.0	141.0	201.0	256.0	320.0	350.0	402.5
United States	16.8	28.4	49.1	71.7	89.9	108.0	141.4	259.0
Rest of Europe	1.0	3.0	10.0	11.0	24.0	60.0	118.0	234.0
Rest of Asia	13.0	19.0	43.0	33.0	47.0	55.0	81.0	131.9

Note: Installations for 2007 are estimates.

Source: Travis Bradford and Paul Maycock, "PV Market Update: Demand Grows Quickly and Supply Races to Catch Up," **Renewable Energy World**, July 2007.

Figure 1: PV Installation

PV PRODUCTION



Annual Photovoltaic Production by Country, 1995-2006

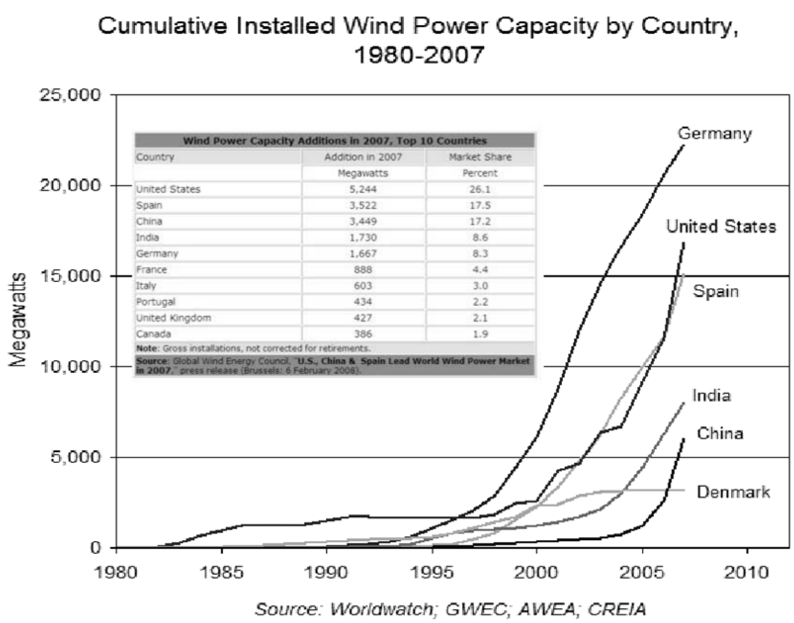
Year	United States	Japan	Europe	China	Taiwan	India	Others	Total
	Megawatts							
1995	34.8	16.4	20.1	NA	NA	NA	NA	77.7
1996	38.9	21.2	18.8	NA	NA	NA	NA	88.7
1997	51.0	35.0	30.4	NA	NA	NA	NA	125.8
1998	53.7	49.0	33.5	NA	NA	NA	NA	154.9
1999	60.8	80.0	40.0	NA	NA	NA	NA	201.3
2000	75.0	128.6	49.8	2.5	NA	10.5	10.5	276.8
2001	100.3	171.2	73.9	3.0	3.5	12.5	21.6	386.0
2002	120.6	251.1	122.1	8.0	8.0	19.1	18.2	547.1
2003	103.0	363.9	200.2	9.0	17.0	23.1	32.2	748.4
2004	138.7	601.5	311.8	35.0	40.0	31.1	35.4	1,193.5
2005	154.0	833.0	476.6	134.0	88.0	35.5	65.0	1,786.1
2006	201.6	926.9	678.3	369.5	177.5	43.4	123.6	2,520.8

Note: NA = not available or negligible.

Source: Compiled by **Earth Policy Institute** from Worldwatch Institute, **Signposts 2004**, CD-Rom (Washington, DC: 2005); Prometheus Institute, "23rd Annual Data Collection - Final," **PVNews**, vol. 26, no. 4 (April 2007), pp. 8-9.

Figure 2: PV Production

WIND POWER CAPACITY



Wind Power Capacity Additions in 2007, Top 10 Countries

Country	Addition in 2007	Market Share
	Megawatts	Percent
United States	5,244	26.1
Spain	3,522	17.5
China	3,449	17.2
India	1,730	8.6
Germany	1,667	8.3
France	888	4.4
Italy	603	3.0
Portugal	434	2.2
United Kingdom	427	2.1
Canada	386	1.9

Note: Gross installations, not corrected for retirements.

Source: Global Wind Energy Council, "**U.S., China & Spain Lead World Wind Power Market in 2007**," press release (Brussels: 6 February 2008).

Figure 3. Wind Installation

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. DANIEL K. INOUYE TO DR. GORO UEHARA

Question 1. While the many conversations about climate change revolve around carbon dioxide, other gases such as nitrous oxide and methane also contribute to climate change. What impact are these gases having on Hawaii's climate?

Answer. Agriculture clearly contributes to NO_X and methane emissions, but carbon dioxide from burning of imported fossils fuels is clearly the dominant green house gas in Hawaii. NO_X and methane are primarily generated in our taro fields and wetlands, but taro production in Hawaii is declining so human generated NO_X is most likely not a major factor in climate change for Hawaii. We need to be aware of other green house gas emissions, but out main efforts at this point should be focused on carbon dioxide.

Question 2. The Hawaii Climate Change Action Plan presents several options to utilize abandoned sugarcane and pineapple farmlands for forest cultivation. Is forestry something we should consider as a way to absorb carbon dioxide?

Answer. Farmland formerly in sugarcane and pineapple is too valuable for growing trees to absorb carbon dioxide. Hawaii has a great opportunity to show the tropical world how the state's agriculture and economy can be transformed from a fossil to a fiber based clean, energy future by using its land for energy crops production. Plant fiber consists mainly of cellulose, hemicellulose and lignin which can be converted into biofuels through biochemical or thermal conversion processes. Each ton of fiber can be converted into 70 gallons of ethanol by biochemical mean and/or 110 gallons of ethanol by thermal conversion processes. In tropical Hawaii, where we enjoy year long climate for crop production, each acre of land can produce from 20 to 40 tons of fiber annually or 2,200 to 4,400 gallons of ethanol from each acre of land each year. Hawaii needs to be ready for the day when commercial scale cellulosic conversion technology becomes a reality.

Hawaii has a huge potential for taking advantage of carbon trading based on a carbon offset market. This will, however, depend on the price of offset carbon and what is permitted as offset carbon. This is especially true in Hawaii, where 90 percent of our energy needs is now based on fossil fuels.

Question 3. In many of our island communities, we rely on fossil fuels for electricity. To what extent can agriculture contribute to carbon capture to mitigate the effects of centralized power plants of the type we have in Hawaii?

Answer. Renewable energy in the form of solar, wind, and geothermal is probably better suited to replace fossil fuel for power and heat generation in Hawaii than bioenergy from agriculture. Agriculture's can play a more important role in replacing gasoline and diesel for transportation fuel with biodiesel and ethanol in Hawaii.

Question 4. In the longer term is it possible to establish decentralized or distributed electric generating system and, if so, can agriculture play a role in carbon capture at these distributed systems?

Answer. Bioenergy is ideally suited for developing a distributed electric energy systems in isolated rural communities such as those that exits in the outer island. Biomass is bulky and transporting it over long distances to a central location defeats the purpose of lowering energy costs. Small, compact gasification units that convert biomass into syngas for power generation can provide electricity for farms and small communities and even generate income by returning excess power to the grid. With households on outer island currently paying as much as 40 cents per kilowatt hour, distributed power generation systems need to be evaluated for outer island communities. Feedstock for operating such systems can be agricultural waste, invasive plants and high yielding energy crops specifically cultivated for conversion into biofuels or electricity.

Question 5. If agriculture provides carbon capture opportunities, will the "revenue streams" from carbon capture be sufficient to justify agricultural production? Or, will multiple product systems of the type "sugar, molasses, bagasse, electricity" be required to justify a long term investment in agriculture in our island communities?

Answer. Historically, agriculture was practiced to produce food, feed and fiber. In the coming century, agriculture's new challenge is to add clean, renewable energy to the list of items it produces. Our ancestors depended on fiber (wood) for heating and cooking. We now need to use fiber to produce transportation fuel. Today, each acre of pineapple after the last fruit is harvested is burned or plowed to clear the land of biomass. In the future, we can convert the 30 tons of pineapple fiber that is now burned into 3,000 gallons of ethanol or ten tons of charcoal. Charcoal can be used to substitute for potting material imported by the plant nursery industry, as a metal reductant (*e.g.,* for producing silicon for photovoltaics), and as a soil amendment. We are currently testing charcoal as a soil amendment to rejuvenate degraded soils as was done centuries ago in the Terra Preta soils of the Amazon jungles by natives living there.

Charcoal has a half life of more than an thousand years so it can replace compost as a permanent means to improve soils quality. We are just beginning to appreciate the potential of biomass not only for energy, but for its potential to produce new bioproducts and biochemicals.

In the long term, a sustainable bioenergy and bioproduct producing agroecosystem must have four characteristics. First it must be highly productive and profitable; second, it must be stable and be free from "feast to famine" fluctuations in productivity; third, it must be highly resilient and be able to recover quickly from perturbations and stresses imposed on it such as climate change, and fourth, it must be highly equitable so that there is equal sharing of the benefits derived from the system.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. DANIEL K. INOUYE TO BILL THOMAS

Question 1. Hawaii has positioned itself as a leader on many fronts addressing the impacts of climate change. What do you see as the big questions that we need to focus on answering now for the impacts of climate change on island communities?

Answer. A broad set of potential climate change impacts have been identified; these include deteriorating coastal conditions, increased severity of coastal hazards, storm surge and erosion, shifts in regional water supplies, increased energy demand, greater public health threats, enhanced probability of flooding, and ecological changes. Potential climate impacts on Pacific Island coastal communities are highlighted here because of the likelihood that coastal communities will be more negatively affected by climate change than inland communities. For example, coastal communities face higher risk of coastal flooding and greater exposure of residents, their property, and coastal wetlands to inundation from sea level rise. The transportation infrastructure is also vulnerable to potentially hazardous flooding events. The possible costs associated with damages and losses to coastal communities, environments, and infrastructure in the Pacific Islands are extremely large.

In order to address these regional impacts, NOAA's Pacific Region has developed several programs that use an integrated approach to dealing with issues of climate change in the Pacific. These programs—the Pacific Risk Management *'Ohana,* the Pacific ENSO (El Niño Southern Oscillation) Application Center, the Pacific Climate Information System, the Pacific Islands Regional Integrated Science and Assessment, and the Pacific Region Integrated Coastal Climatology Program—have provided innovative approaches and a governance structure to address the ever-increasing need for information, products and services. These Pacific Regional programs work in concert with the public and private sector, as well as non-governmental organizations, to collaboratively address these issues of mutual concern.

The following highlights the major questions these groups have focused on, to address the impacts of changing climate conditions on our island communities:

1. *How do changing climate conditions affect individual island groupings and communities in the Pacific?* In order to understand this, improvements in the regional resolution of climate models, better documentation of current conditions and trends through enhanced observing systems as well as general improvements in our ability to document, model and assess the impacts of changing climate conditions on ecosystems and natural resources in the Pacific region is required. This also requires research on the local impacts of climate change on ecosystems, communities and businesses in the region as well as support for vulnerability assessment programs that support a collaborative, participatory process through which scientists, decision-makers and other public leaders can explore effective options for climate change mitigation and adaptation.

2. *How do changing climate conditions affect extreme events such as hurricanes, strong wind and high wave events, droughts in the Pacific?* NOAA is working toward improvements in models, as well as enhanced understanding of how climate change will affect the intensity, frequency and tracks of hurricanes and other storm events. This also involves the analysis of the historical context for extreme events. A related question involves developing an improved understanding and ability to model/predict how climate change will alter patterns of El Niño/La Niña events which are the primary drivers of changes in rainfall, temperature and tropical cyclones in the Pacific on a year-to-year basis.

3. *How does climate change affect sea level and patterns of coastal storms?* In most Pacific islands, the people, agricultural land, tourist resorts and infra-

structure (including roads and airports) are concentrated in the coastal zones, and are thus especially vulnerable to any rise in sea level. Determining how severe this problem is, or might be, is complicated by natural shifts in sea level associated with the recurring ice ages. Increased global temperatures are causing a rise in sea level from thermal expansion as the sea warms up and from melting of the planet's ice caps. However, while most recent data have shown that changes in sea level are related to many variables, accurate forecasting of these changes is years away. Thus, NOAA is engaged in activities to understand long-term sea level rise and how sea level rise combines with changing patterns of strong winds, high seas and heavy rains to produce coastal flooding along with a vulnerability assessment program to support the development of effective adaptation measures and policies.

4. *How does ocean acidification affect coral reefs and other critical coastal and marine resources?* Ocean acidification is an emerging issue that may have long-term implications for the global carbon cycle and climate, although the range and magnitude of biogeochemical and biological effects and their socio-economic impacts are currently too uncertain to accurately quantify. However, such impacts are likely to be substantial. Consequently, especially important in this context will be understanding the combined effects of rising temperatures, sea level rise and lower pH on coral reefs. NOAA has a burgeoning ocean acidification research program.

5. *What are public agencies in the region doing to develop adaptations to a changing climate?* Some public agencies in the Pacific region, especially in Hawaii, have begun planning to help the region adapt to climate change impacts. This includes considering the environmental, human health, water management, and infrastructure issues associated with a changing regional climate. Public agencies at all levels (national, regional, state, county, metropolitan, and city) have begun to investigate plans or actions for adaptation to climate change. Much of what is happening now is focused on research and risk assessment. The research deals with a range of topics including human health, water management, and protection of the built and natural environment. NOAA's Office of Oceanic and Atmospheric Research has invested in a long-term grant that looks at many of these issues through the Pacific Islands Regional Integrated Science and Assessment. This grant will be recompeted in Fiscal Year 2009.

6. *What role can the private sector play in adapting to climate change?* Many in the private sector, especially multinational corporations and regionally-based business coalitions have begun to address the issue of adaptation to climate change. Although many private sector activities are focused on reducing greenhouse gas emissions through energy efficiency, such activities improve the region's capacity to deal with warming in general and heat waves in particular.

7. *What are the impacts of climate change on the cultural resilience (i.e., cultural identity, traditional knowledge, and customary practices) of island economies?* Over the next 100 years, a major concern will be the potential loss of cultural identity and connection as a result of mitigation efforts. For example, relocating indigenous coastal communities out of flood zones or after major storms; further loss/erosion of ancestral land connections due to sea level rise and coastal inundation; loss of traditional knowledge in impacted areas; shifts in artisinal and customary resource use patterns; and occupational shifts due to loss of livelihoods.

In island communities that are prepared for such impacts and ready to respond and adapt to climate impacts, cultural resilience will be higher and socio-economic impacts to the islands will be reduced (*e.g.,* meeting basic dietary/protein needs of human populations following major natural hazard events thanks to resilience in the fishing community). NOAA's National Integrated Drought Information System and Regional Integrated Sciences and Assessments (RISA) program have been funding a pilot program since 2007 to look at Local and Indigenous knowledge networks in climate and drought. This is a collaboration between the Pacific, Southwest and Alaska RISAs to build expertise in strategies for coping with drought and increasing climate resilience.

Question 2. Where is the greatest gap or deficiency in scientific research and information?

Answer. NOAA agrees with the scientific findings of the 2007 Fourth Assessment Intergovernmental Panel on Climate Change's (IPCC–AR4). IPCC–AR4 states that small island communities, like those in the Pacific, are particularly vulnerable to climate variability and change. The IPCC–AR4 identified several key uncertainties and research gaps with respect to climate science and small islands:

- *Observations:* Ongoing observations are required to monitor the rate and magnitude of changes and impacts, over different spatial and temporal scales. For example, *in situ* observations of sea level help to understand relative sea level change on regional and local scales. Two examples of regional observing networks are: the Pacific Islands Global Climate Observing System and the Intergovernmental Oceanographic Commission Sub-Commission for the Caribbean and Adjacent Regions Global Ocean Observing System;
- *Improved Models:* Projections for changes in precipitation, tropical cyclones, and wind direction/strength are critical for small islands, and are currently limited by climate model resolution. Projections based on outputs at finer resolution are needed to inform the development of reliable climate change scenarios for small islands (*e.g.,* regional climate models and statistical downscaling techniques). Further, hydrological conditions, water supply, and water usage on small islands pose different research problems from those in continental situations. These need to be investigated and modeled over the range of island types (different geology, topography and land cover).

In addition to the climate science gaps identified above, the IPCC–AR4 identified several key gaps in contemporary research on the impacts of climate change on small islands. These include:

- The role of coastal ecosystem (mangroves, coral reefs, beaches) in providing natural defenses against sea-level rise and storms;
- Establishing the response of terrestrial upland and inland ecosystems (including woodlands, grasslands, wetlands) to changes in mean temperature and rainfall extremes;
- Considering how commercial agriculture, forestry, and fisheries will be impacted by the combination of climate change and non-climate-related forces;
- Expanding knowledge of climate-sensitive diseases in small islands through national and regional research (vector-borne as well as skin, respiratory, and water-borne diseases);
- Identifying the most vulnerable island sectors and systems; and
- Increasing understanding of climate in decision-support, including how to translate climate information into tools and products that are easily accessible and interpreted by decision-makers.

Question 3. What impacts should we be most concerned about? Over what time scales?

Answer. NOAA agrees with the scientific findings of the 2007 Intergovernmental Panel on Climate Change's IPCC–AR4, which contains updated projections of changing climate conditions (*i.e.,* temperature, rainfall, sea level, and extreme events) and the impacts for Pacific Islands and other small island states. IPCC–AR4 confirms the vulnerabilities identified in the 2001 Pacific Islands regional assessment, and provides insights into climate-related challenges such as ocean acidification. The time scale for these impacts varies broadly, ranging from decades to multidecadal.

The IPCC–AR4 and similar climate assessment reports state that small island communities, like those in the Pacific, are particularly vulnerable to climate variability and change. Small island impacts include:

- Deterioration of coastal conditions is expected to affect local resources and reduce their value as tourist destinations (*e.g.,* the combined effect of increased ocean temperatures and ocean acidification on coral reef resources);
- Sea level rise is expected to exacerbate coastal hazards such as inundation, storm surge and erosion as well as reduction of freshwater availability due to saltwater intrusion, especially in low-lying islands;
- Climate change is projected to reduce water resources in many small islands (Pacific and Caribbean) to the point where, by mid-century, resources may be insufficient to meet demand during low rainfall periods;
- Invasion of non-native species is expected to occur with rising temperatures; and
- Climate change will exacerbate other existing human influences on fisheries and marine ecosystems such as over-fishing, habitat destruction, pollution, and excess nutrients.

Question 4. What are the top three actions we should take now to improve our ability to mitigate and adapt to the impacts of climate change?

Answer. NOAA is committed to expanding climate services for all user communities and enhancing climate research. The FY 2009 President's budget request identifies three key, specific climate-related activities for which NOAA has requested increases: developing the National Integrated Drought Information System; investigation into ocean current circulation and its relationship to abrupt climate change; and the development of satellite climate sensors. Combined with continued support for NOAA's existing climate-related projects, these activities will improve our ability to mitigate and adapt to climate change.

In addition to the key climate-related research activities highlighted in the FY 2009 President's Budget Request, NOAA's Pacific Region is engaged in a number of ways to help the Pacific Islands plan for, mitigate against, and adapt to climate change (please see response to Question 6 for a detailed list of activities). NOAA's Pacific Region will continue to work with our island communities to develop tools, products, and services to move toward realizing NOAA's vision of, "an informed society that uses a comprehensive understanding of the role of the oceans, coasts and atmosphere in the global ecosystem to make the best social and economic decisions."

Question 5. In recent weeks, articles have been circulated among Members of the Congress that suggest the climate change issue is overstated, and that what is actually happening is a natural phenomenon. What do you think about this suggestion?

Answer. NOAA agrees with the scientific findings of the 2007 Intergovernmental Panel on Climate Change's (IPCC–AR4) that warming of the climate system is unequivocal, and most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in greenhouse gases caused by humans. The IPCC–AR4 also pointed out that uncertainties remain, such as the rate of warming, including the potential for abrupt and extreme changes, as well as region-specific climate variation and change.

NOAA's responsibility is to provide critical information on the amount of greenhouse gases in the atmosphere and their impact on climate, so that policymakers can make informed decisions about what is best for our Nation.

Question 6. The 2007 Intergovernmental Panel on Climate Change Assessment reports that global temperature has increased substantially over the last 100 years, due in large part to the burning of fossil fuels. Increases in carbon dioxide (CO_2) in the atmosphere lead to increased ocean temperatures, which threaten coral reef ecosystems through more frequent and severe coral bleaching, rising sea levels, and possibly storm activity. What future programs or products is NOAA planning for the Pacific to monitor the oceans' response to growing carbon dioxide levels? What information will be provided for decision-makers for guidance on mitigation options?

Answer. NOAA's Pacific Region is engaged in a number of ways to help the Pacific Islands plan for, mitigate against, and adapt to climate change. NOAA's Pacific Region will continue to work with our island communities to develop tools, products, and services to move toward realizing NOAA's vision of, "An informed society that uses a comprehensive understanding of the role of the oceans, coasts and atmosphere in the global ecosystem to make the best social and economic decisions." Highlighted below are some prominent efforts:

The Pacific Risk Management 'Ohana

The Pacific Risk Management *'Ohana* (PRiMO) is a network of partners and stakeholders involved in the development and delivery of risk management-related information, products, and services in the Pacific, and is led by the NOAA Pacific Services Center. Established in 2003, this multi-agency, multi-organizational, multinational group brings together representatives from agencies, institutions, and organizations involved in Pacific risk management-related projects and activities with the overall goal of enhancing communication, coordination, and collaboration among the *'Ohana* (family) of partners and stakeholders involved in this work. As a result of this collaboration, several ideas that emerged over the years have led to the development of decision-support and community planning tools that aid a cross section from managers to the general public in better understanding risks and in making the best possible socio-economic decisions. Examples of these collaborations include:

Decision Support Tools

- Hazard Assessment Tools have been developed in partnership with NOAA's Pacific Region, local governments in American Samoa, Guam, and Hawaii (County of Kauai). These tools use Geographic Information Systems maps to integrate hazard risk information, such as sea level rise projections, along with local information on infrastructure, natural resources, and administrative boundaries to improve both short and long term decisionmaking.

- The Hazard Education and Awareness Tool is a template which allows any organization the ability to create a simple website which provides public access to local hazard maps for their community. Additional information on appropriate response and preparedness actions are also included.
- The Nonpoint Source Pollution and Erosion Comparison Tool is a decision support tool which allows coastal managers to compare potential water quality impacts of land cover change that may occur from changes in climate.

Data

- The Coastal Change Analysis Program (C–CAP) is a nationally standardized database of land cover and land change information, developed using remotely sensed imagery, for the coastal regions of the United States. C–CAP products inventory coastal intertidal areas, wetlands, and adjacent uplands with the goal of monitoring these habitats by updating the land cover maps every 5 years. Its primary objective is to improve scientific understanding of the linkages between coastal wetland habitats, adjacent uplands, and living marine resources. Land cover data from C–CAP has been developed for Hawaii from satellite images acquired in both 2000 and 2005. High resolution elevation data for Hawaii was collected in 2005 using Interferometric Synthetic Aperture Radar. This elevation data provides resource managers with the highest resolution elevation data currently available for Hawaii. This data is invaluable for determining potential impacts of changes in climate, such as sea level rise, in areas where higher resolution data may not be available.

Community Planning Tools

- The Coastal Community Resilience Guide presents a framework for assessing resilience of communities to coastal hazards. The work was the result of a partnership funded through the Indian Ocean Tsunami Warning System Program and is being piloted for application in Hawaii. The framework, developed in concert with over 140 international partners, encourages integration of coastal resource management, community development, and disaster management for enhancing resilience to hazards, including those that may occur as a result of climate change.

The Pacific ENSO Application Center

Pacific Island communities continually deal with dramatic seasonal and year-to-year changes in rainfall, temperature, water levels and tropical cyclone patterns associated with the El Niño Southern Oscillation (ENSO) cycle in the Pacific. This dynamic system involving the Pacific Ocean and the atmosphere above it can bring droughts, floods, landslides, and changes in exposure to tropical storms. Fourteen years ago, NOAA joined forces with the University of Hawai'i, the University of Guam, and the Pacific Basin Development Council to begin a small research pilot project designed to develop, deliver, and use forecasts of El Niño-based changes in temperature, rainfall, and storms to support decisionmaking in the American Flag and U.S.-Affiliated Pacific Islands. That pilot project—the Pacific ENSO Applications Center (PEAC)—continues its work today as part of the operational National Weather Service programs in the Pacific. The PEAC experience has demonstrated the practical value of climate information for water resource management, disaster management, coastal resource planning, agriculture, and public health.

The Pacific Climate Information System

The experience gained from PEAC and the Pacific RISA has helped inform the emergence of a comprehensive Pacific Climate Information System (PaCIS). As an integrated organization that brings together NOAA's regional assets as well as those of its partners, PaCIS provides, on a regional scale, a programmatic framework to integrate ongoing and future climate observations, operational forecasting services, and climate projections, research, assessment, data management, communication, outreach and education that will address the needs of American Flag and U.S.-Affiliated Pacific Islands. Within this structure, PaCIS will also serve as a United States' contribution to the World Meteorological Organization's Regional Climate Centre for Oceania and represents the first integrated, regional climate service in the context of emerging planning for a National Climate Service.

Scientists and decision-makers in Pacific Island communities are now engaged in individual and collaborative efforts to understand the nature of the climate change impacts described in IPCC–AR4 and explore our options for both mitigation and adaptation. This shared effort involves NOAA, other Federal programs, state agencies, university scientists, community leaders and nongovernmental organizations. Together these groups are focusing their unique insights and capabilities on a number of critical climate programs and activities including: contributions to global and regional climate and ocean observing systems; operational forecasts of seasonal-to-inter-annual climate variability; development and analysis of improved models that provide long-term projections of climate change; multi-disciplinary assessments of climate vulnerability, climate data stewardship, the development of new products and services to support adaptation and mitigation in the Pacific; and education and outreach programs to increase the climate (and environmental literacy) of Pacific Island communities, governments, and businesses.

Future planning for a number of climate programs in the Pacific will be organized in the context of PaCIS including building upon the PEAC, the Pacific Islands Regional Integrated Science and Assessment (Pacific) program and other related climate activities in the region. In addition to meeting the specific needs of U.S. affiliated jurisdictions in the Pacific, PaCIS will also provide a venue in which to discuss the role of U.S. contributions to other climate-related activities in the Pacific including, for example, observing system programs in the region, such as the Pacific Islands Global Climate Observing System (PI–GCOS) and the Pacific Islands Global Ocean Observing System, as part of an integrated climate information system.

In order to further define the roles and capabilities of PaCIS, a steering committee has been established, made up of representatives of institutions and programs working in the fields of climate observations, science, assessment, and services in the Pacific (including PEAC, the Pacific RISA, PI–GCOS, and the National Weather Service), as well as selected individuals with expertise in similar regional climate science and service programs in other regions. The PaCIS Steering Committee will provide a forum for sharing knowledge and experience and guide the development and implementation of this integrated, regional climate information program.

The Pacific Region Integrated Coastal Climatology Program

Over the past decade, discussions with disaster management agencies and coastal managers in the Pacific Islands have highlighted concerns about sea level rise, and the associated coastal inundation, as one of the most significant climate-related issues facing coastal communities in the Pacific. In light of this need, NOAA, through its IDEA Center, with support from the Pacific Services Center, and working with colleagues throughout NOAA, the U.S. Army Corps of Engineers, U.S. Geological Survey and university scientists in Hawaii, Guam, Alaska, and Oregon, initiated the Pacific Region Integrated Coastal Climatology Program (PRICIP). PRICIP recognizes that coastal storms and the strong winds, heavy rains, and high seas that accompany them pose a threat to the lives and livelihoods of the people of the Pacific. To reduce their vulnerability, decision-makers in Pacific Island governments, communities, and businesses need timely access to accurate information that affords them an opportunity to plan and respond accordingly. The PRICIP project is helping to improve our understanding of patterns and trends of storm frequency and intensity within the Pacific Region, and develop a suite of integrated information products that can be used by emergency managers, mitigation planners, government agencies, and decision-makers in key sectors including water and natural resource management, agriculture, fisheries, transportation, communications, recreation, and tourism.

As part of the initial build-out, a PRICIP web portal is serving a set of historical storm "event anatomies." These event anatomies include a summary of sector-specific socio-economic impacts associated with a particular extreme event as well as its historical context climatologically. The intent is to convey the impacts associated with extreme events and the causes of them in a way that enables users to easily understand them. The event anatomies are also intended to familiarize users with *in situ* and remotely-sensed products typically employed to track and forecast weather and climate.

Hawaiian Archipelagic Marine Ecosystem Research

The Hawaiian Archipelagic Marine Ecosystem Research Plan is a collaborative planning process to develop sustainable conservation and management throughout Hawaii's marine ecosystem through improved understanding of the unique physical and biological attributes of the Hawaiian archipelagic marine ecosystem, their interconnected dynamics, and their interactions with human beings. By using Hawaii as a large-scale archipelagic laboratory for the investigation of biophysical processes, comparing the protected Northwestern Hawaiian Islands to the heavily used Main Hawaiian Islands and integrating socioeconomic information, Hawaii and comparable marine ecosystems worldwide should realize improvements in resource management and community response to changes in climate.

While this project is in its formative stages, the information generated by this projected 10-year multi-agency, collaborative program will:

- Fill critical and important research gaps in the underlying science of marine ecosystem dynamics;
- Complement national, international, and state ecosystem research initiatives;
- Improve understanding of the behavior of humans in a marine ecosystem approach to conservation and management;
- Formulate predictive theory of ecosystem dynamics relative to physical and biological variables; and

Generate useful information for conservation managers.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. DANIEL K. INOUYE TO KARL KIM, PH.D.

Question 1. Climate change experts have forecasted changes in the worldwide climate that will impact forest productivity, ecosystems, agriculture, water resources, and energy. Among these impacts is sea level rise, increased and intensified flooding, and higher storm surges along vulnerable coasts. A combination of these possibilities could pose a threat for Hawaii in the form of intensified storms and other natural disasters.

In the 9/11 bill, the Committee authorized the creation of the National Disaster Preparedness Training Center. This purpose of the center is to develop plans to prepare for, mitigate, and respond to disasters in Hawaii. The Center would serve as a databank, develop scientific models and tools for monitoring natural disasters, and evaluate potential risks to urban populations. As an island community, Hawaii must be proactive in preparing for varied natural threats, as well as manmade. Can you tell us about the potential for adverse impacts from sea level rise on the population centers of the Central and Western Pacific, particularly with respect to port and road infrastructure, coastal habitats, living marine resources, and vulnerability of towns and villages to extreme coastal events like tsunami?

Answer. There are a wide range of adverse consequences now being predicted with increasing levels of probability for Hawaii, the Central and Western Pacific, and Pacific region generally. The State of Hawaii, in its 2007 Multi-Hazard Mitigation Plan, utilizes the Fourth Assessment of the Intergovernmental Panel on Climate Change as a source for information about impacts and vulnerabilities, and researchers at the University of Hawaiʻi are also generating useful primary data and modeling tools to assess the potential effects of sea level rise. Some consensus points on expected impacts include:

> Coastal areas are projected to be exposed to increasing risks of coastal erosion, and this will be exacerbated by population pressures in the coastal areas.
>
> Flooding will increase in coastal areas, particularly the low-lying areas, and the increase is expected to accelerate over the coming decades.
>
> Salt water incursion into water tables will increase, with particularly severe consequences for small island communities with already tenuous water supplies.
>
> Low-lying zones are heavily correlated with population density and urbanization throughout the Pacific region, compounding the vulnerability of these zones to other hazards, such as tropical storms and localized coastal erosion and subsidence.
>
> Coastal and low-lying zones are also heavily correlated with structural infrastructure, *i.e.,* roads, ports, business districts, airports, fuel depots, and communications networks. Sea level rise and related increased levels of inundation, storm surge and coastal erosion pose heightened threats to vital infrastructure.

These infrastructural vulnerabilities will have direct adverse effects on livelihoods and island economies. Deterioration of coral resources due to sea rise-related thermal changes may impact fisheries, and loss of beaches and related natural resources will have detrimental effects on tourism, a major economic activity on island communities. To illustrate the potential impact, a one meter rise in sea level would inundate most of Honolulu's Waikiki district, essentially eliminating a major component of the state's economic activity.

Question 2. Where are the most vulnerable areas, and how are they kept informed and prepared?

Answer. Vulnerability is widespread in the Pacific region, and differs based upon considerations such as geography, geology, bathymetry, atmospheric conditions and other environmental variables. Along with environmental science based parameters, vulnerability has a distinct social character, with variability based upon income, access to education and communications technologies, experience with recent disasters and development of coping skills, and the level of local government proactivity, as examples.

Vulnerability mapping models are being developed to provide improved understanding of the location of vulnerable populations, and these technologies are also useful in disaster response planning and implementation, improving situational awareness at all stages of the disaster management process. Despite these advances, remote areas and localized concentrations of persons disadvantaged due to socio-economic factors, linguistic minorities, persons with disabilities and other issues continue to present challenges to effective messaging about, and preparation for, disasters.

Question 3. What is the current state of Hawaii's disaster preparedness and is it adequate to address Hawaii's unique and varying threats?

Answer. Following the devastation of Hurricane Iniki in 1992, the State of Hawaii has made disaster preparedness a priority. State and local Civil Defense operates at a high level of professionalism, and local first responders have been sensitized to the need to be prepared for the wide variety of natural disasters which may occur in Hawaii. Numerous state and Federal agencies are working individually and collectively to identify and mitigate hazards in Hawaii and the region. However, funding constraints, gaps in training and educational resources, and the twin challenges of rapidly accelerating hazard and disaster threats and rapidly expanding populations in hazardous areas illustrate the need for a significant increase in preparedness at all levels.

As one example, Hawaii State Civil Defense has effectively promoted the development of tsunami inundation maps, and disseminated these widely through placement in all telephone books in the state, improving public awareness of hazard zones and evacuation procedures. With newly developed modeling methods, significantly improved maps are now possible which will greatly improve the utility of these maps, but creating them will require new commitment of funding, engineering and information management skills and talents. In other words, risk levels continue to rise, and mitigation technologies are improving, but demands on resources often outstrip local capacity.

The indelible lesson of Hurricane Iniki, reinforced by recent natural disasters in other tropical coastal areas, is that given the vulnerability of Hawaii's tropical island location, the remoteness of any feasible outside relief assets, and the difficulties inherent in inter-island transport in a crisis, island communities must develop a high level of local resilience, or remain vulnerable to catastrophic loss when extreme events occur.

Question 4. How would the National Disaster Preparedness Training Center fill any gaps in Hawaii's current disaster preparedness program?

Answer. The NDPTC, as part of the National Domestic Preparedness Consortium, will aim at addressing disaster preparedness in Hawai'i and the U.S. Pacific Islands on the one hand, and sharing the experience of training for disaster in one of the most hazard vulnerable regions with our collaborating centers and the national disaster community as a whole on the other. These are mutually reinforcing roles, and will aid in addressing gaps in disaster preparedness both locally and nationally.

Based at the University of Hawai'i, the central focus of this center is to address knowledge gaps in the natural disaster management system. Universities have a unique and increasingly critical contribution to make in disaster risk reduction research as well as in institutional capacity building for disaster response. Universities house the basic scientific research and applied technology development relevant to disaster risks, and train future professionals in vital constituent disciplines. The University of Hawai'i has particular strengths in Ocean and Earth Sciences, Civil, Ocean and Environmental Engineering, Urban and Regional Planning, Architecture, Tropical Agriculture and Natural Resource Management, Medicine and Public Health, and Law that are highly relevant to disaster risk management.

The NDPTC will address the knowledge gap by adapting leading edge findings from academic sources and the best practice experience of our dynamic community of disaster management organizations to create training and education products for every level of practitioner. The need to broaden understanding of the technical nature of hazards and increase familiarity with the latest tools, models and methods used in mitigating their impacts, extends from first responders right up through management and planning to policy and decision-making. Increasing the level of knowledge held in common across disciplinary, agency and community boundaries will have a direct effect in improving the coherence of disaster planning, and the promotion of community resilience.

The training and education products developed at the NDPTC will substantially improve readiness in Hawaii and the U.S. Pacific Island jurisdictions. However, these same products will be made available for training programs throughout the U.S. As the first of the National Domestic Preparedness Consortium institutions to focus specifically on natural disasters, the NDPTC will also contribute to the effort to assure that all hazards are addressed, and that preparation incorporates a broad view of the nature of hazard.

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