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OVERSIGHT HEARING ON WILDLIFE AND OCEANS IN A CHANGING CLIMATE

BEFORE THE
COMMITTEE ON NATURAL RESOURCES
SUBCOMMITTEE ON FISHERIES, WILDLIFE, AND OCEANS
U.S. HOUSE OF REPRESENTATIVES

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Introduction

Good morning Madam Chairwoman and Members of the Committee. My name is Mark Eakin, and I am the Coordinator of the Coral Reef Watch program within the National Environmental Satellite, Data, and Information Service of the National Oceanic and Atmospheric Administration (NOAA), in the Department of Commerce. This program is a component of the NOAA Coral Reef Conservation Program (CRCP), for which I also serve as the climate lead. The CRCP coordinates NOAA's many coral reef activities across its various offices. Thank you for inviting me to discuss the effects of climate change on coral reefs, an important resource to many coastal and island communities. Among NOAA's diverse missions, our tasks include understanding and predicting changes in the Earth's environment and acting as the nation's principal steward of coastal and marine resources critical to our nation's economic, social and environmental needs.

I will focus my remarks on how climate change is impacting coral reef ecosystems and local communities. NOAA's work on climate change and marine ecosystems relevant to this hearing includes observations of the physical environment and biota, research to understand the changes in the environment and the broader ecosystem, and incorporating projected effects of climate change into NOAA's conservation and management of living marine resources and ecosystems. Climate change is one of a complex set of factors that influence marine ecosystems, including natural climate cycles, overfishing, atmospheric pollution, pesticide and fertilizer use, land use changes, inadequate storm water management, and discharge of untreated sewage. NOAA is committed to an ecosystem approach to resource management that addresses the many simultaneous pressures affecting ecosystems.

Changing climate is potentially one of the most significant long-term influences on the structure and function of marine ecosystems and must therefore be accounted for in

NOAA's management and stewardship goals to ensure healthy and productive ocean environments. Changes and variations in climate may directly or indirectly affect marine ecosystems. This includes changes and variations of sea-surface temperature, ocean heat content, sea level, sea ice extent, freshwater inflow and salinity, oceanic circulation and currents, pH, and carbon inventories.

Analyses of NOAA data show that the Earth's oceans have warmed almost 1 degree Fahrenheit over the 20th century average (Figure 1). These data, along with findings from the recent Intergovernmental Panel on Climate Change (IPCC) assessments of 2001 and 2007 show that not only have the atmosphere and oceans warmed, they will continue to do so during the 21st century, at least in part due to increased greenhouse gases in the atmosphere. The 2007 IPCC Working Group II report stated: "Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases."

NOAA's Roles in Climate and Ecosystem Sciences

Within the climate science community, NOAA is a recognized leader both nationally and internationally. Our scientists actively participate in many important national and international climate working groups and assessment activities. One of NOAA's mission goals is to understand climate variability and change to enhance society's ability to plan and respond. NOAA is the only federal agency that provides operational climate forecasts and information services (nationally and internationally). NOAA is the leader in implementing the Global Ocean Observing System (NOAA contributes 51 percent of the world-wide observations to GOOS, not including satellite observations). NOAA also provides scientific leadership for the IPCC Working Group I and the interagency Climate Change Science Program. To better serve the nation, NOAA created a Climate Program Office to provide enhanced services and information for better management of climate sensitive sectors, such as energy, agriculture, water, and living marine resources, through observations, analyses and predictions, and sustained user interaction. Services include assessments and predictions of climate change and variability on timescales ranging from weeks to decades.

Within the ecosystem community, NOAA's ecosystem researchers have been at the forefront of establishing links between ocean variability and impacts on marine ecosystems. NOAA has funded some research programs specifically dedicated to evaluating impacts of changes in the physical environment on marine resources, as well as many observing programs established to aid in the management of fisheries, protected species, marine sanctuaries, corals and other specific agency mandates.

These data, primarily collected in support of NOAA's ecosystem stewardship authorities, provide a wealth of information for interpreting climate impacts when combined with NOAA's climate, oceanographic and weather information. Results of these analyses have been widely disseminated and NOAA's contributions to the emerging science of ecosystem impacts of climate change have been significant. However, a greater understanding of the full range of climate induced effects on ecosystems will require us to increase our observation of ecosystems in relation to variable climate forcing and focus our research on the mechanisms through which ecosystems are affected. In this way we can develop quantitative assessments and projections of climate's ecological impacts, including impacts on the resources on which human communities rely.

Current and Projected Impacts of Climate Change on Coral Reef Ecosystems

Coral reef ecosystems are among the most diverse and biologically complex ecosystems on Earth and provide resources and services worth billions of dollars each year to the United States economy and economies worldwide. Coral reefs have been estimated to house several million different species. They house more than one third of all described marine species — more species per unit area than any other marine environment — including about 4,000 known species of fish and 800 species of hard coral. Approximately half of all federally-managed fish species depend on coral reefs and related habitats for a portion of their life cycles. NOAA's National Marine Fisheries Service estimates the annual commercial value of U.S. fisheries from coral reefs is over $100 million per year. Local economies also receive billions of dollars from visitors to reefs through diving tours, recreational fishing trips, hotels, restaurants, and other businesses based near reef ecosystems. In the Florida Keys, for example, coral reefs attract more than $1.2 billion annually from tourism. In addition, coral reef structures buffer shorelines against waves, storms and floods, helping to prevent loss of life, property damage and erosion.

Coral reefs are under stress from many different sources, including increased sea-surface temperatures, pollution, overfishing, destructive fishing practices, coastal uses, invasive species, and extreme events (e.g. hurricanes and coastal flooding). Climate change, in particular, increases in global air and ocean temperatures, threatens coral reef ecosystems through increased occurrence and severity of coral bleaching and disease events, sea level rise, and storm activity. Increased absorption of atmospheric carbon dioxide into the oceans also leads to ocean acidification that may reduce calcification rates in reef-building organisms, as declining seawater pH reduces the availability of carbonate ions. Reduction in calcification rates directly affects the growth of individual corals and the reef's ability to maintain itself against forces that cause reef erosion, potentially compounding the 'drowning' of reefs caused by sea level rise.

Ocean Acidification

The oceans are the largest natural long-term reservoir for carbon dioxide, absorbing approximately one-third of the carbon dioxide added to the atmosphere by human activities each year. Over the past 200 years the oceans have absorbed 525 billion tons of carbon dioxide from the atmosphere, or nearly half of the fossil fuel carbon emissions over this period. Because the rate of emissions has increased faster than oceanic uptake and mixing, the percentage of anthropogenic CO_2 in the oceans requires time to catch up with atmospheric increases and terrestrial uptake. Ultimately, oceanic and geologic processes acting over very long time-scales will redistribute much of the anthropogenic CO_2 into the deeper ocean waters. Over tens of millennia, the global oceans are expected to absorb approximately 90 percent of the carbon dioxide emitted to the atmosphere (Archer *et al*., 1998; Kleypas *et al*., 2006).

For over 20 years, NOAA has participated in decadal surveys of the world oceans, documenting the ocean's response to increasing amounts of carbon dioxide being emitted to the atmosphere by human activities. These surveys confirm that oceans are absorbing increasing amounts of carbon dioxide. Estimates of future atmospheric carbon dioxide concentrations, based on the IPCC emission scenarios and general circulation models, indicate that by the middle of this century atmospheric carbon dioxide levels could reach more than 500 parts per million (ppm), and near the end of the century they could be over 800 ppm. This increase in atmospheric CO_2 to 800 ppm would result in a surface water pH decrease of approximately 0.4 pH units as the ocean becomes more acidic, and the carbonate ion concentration would decrease almost 50 percent by the end of the century. To put this in historical perspective, this surface ocean pH decrease would result in a pH that is lower than it has been for more than 20 million years (Feely *et al*., 2004).

Recent studies indicate that such changes in water chemistry would have effects on marine life, such as corals and plankton (Orr *et al*., 2005). The carbonate chemistry of seawater has a direct impact on the dissolution rates of calcifying organisms (coral reefs and marine plankton). As the pH of the oceans decreases and becomes more acidic, some species of marine algae and plankton will have a reduced ability to produce protective calcium carbonate shells. This makes it more difficult for organisms that utilize calcium carbonate in their skeletons (e.g. corals, Langdon *et al*., 2000) or shells to build and maintain their structures. Decreased calcification may also compromise the fitness or success of these organisms and could shift the competitive advantage towards organisms not dependent on calcium carbonate. Carbonate structures are likely to be weaker and more susceptible to dissolution and erosion. In fact, a recent study showed that the projected increase in acidity is sufficient to dissolve the calcium carbonate skeletons of some coral species (Fine and Tchernov, 2007, using CO_2 projection from Caldeira & Wickett, 2003). Ongoing NOAA research is showing that decreasing pH may also have deleterious effects on commercially important fish and shellfish larvae.

Coral Bleaching Events

As global temperatures have risen over the past 30 years, there has been a corresponding increase in the frequency of extremely high sea-surface temperatures and coral bleaching events in many tropical regions (Brown, 1997; Hoegh-Guldberg, 1999). Coral bleaching is a response of corals to unusual levels of stress primarily thought to be associated with high light and unusually high sea-surface temperatures. Bleaching occurs when a coral expels the symbiotic algae that live in its tissues and give the coral its coloration. Loss of the symbiotic algae leaves the coral tissue pale to clear and, in extreme cases, causes a bleached appearance. Corals often recover from mild bleaching. However, if the stress is prolonged and/or intense, the corals may weaken, causing them to be more susceptible to disease and other stressors, or die from direct thermal stress.

Coral bleaching has occurred in both small, localized events and at larger scales. Although many stressors can cause bleaching, large-scale, mass bleaching events have exclusively been linked to unusually high sea-surface temperatures (Glynn & D'Croz 1990; Brown, 1997; Hoegh-Guldberg, 1999). There is still much that we do not know about the effects of bleaching-associated mass coral mortality on the functioning of coral reef ecosystems and associated ecosystem services, such as fisheries, coastal protection, recreation, and tourism industries.

Through satellite and *in situ* monitoring of sea-surface temperatures, NOAA tracks the sea-surface temperature conditions that could lead to coral bleaching. NOAA provides access to all of its data and products, including sea-surface temperature anomalies, bleaching HotSpot anomalies, Degree Heating Weeks, and Tropical Ocean Coral Bleaching Indices. This work builds on, and complements, NOAA's efforts to monitor temperatures on coral reefs in both the Atlantic and Pacific Oceans, using instruments deployed throughout U.S. coral reefs. These systems are designed to provide local managers and scientists with the information they need to make informed decisions. When the data show that conditions are conducive to bleaching, NOAA provides watches, warnings, and alerts via e-mail to users throughout the globe through NOAA's Coral Reef Watch program and Integrated Coral Observing Network. Coral bleaching alerts allow managers and scientists to deploy monitoring efforts that can document the severity and impacts of the bleaching to improve our understanding of the causes and consequences of coral bleaching. The alerts also allow managers to take actions to reduce local stress, such as water quality and recreational abuse, that further threaten corals already under stress from bleaching.

Large scale or mass bleaching events were first documented in the eastern Pacific in the early 1980's in association with warming during the El Niño Southern Oscillation (Glynn, 1984). In 1997-98, coral bleaching became a global problem when a strong El Niño (period of warmer than average water temperature in the central tropical Pacific), followed by a La Niña (which warmed some western Pacific regions) caused unprecedented coral bleaching and mortality worldwide (Wilkinson, 2000; Wilkinson, 2002). In 1998, reefs in parts of the southern Indian Ocean and East Asia lost more than 80 percent of their corals. Parts of Palau lost up to 50 percent of their hard corals and 75 percent of their soft corals.

Coral bleaching events are not only tied to the El Niño/La Niña phenomena. In 2005, a year lacking El Niño or La Niña climate patterns, record high sea-surface temperatures were recorded in the tropical North Atlantic, Caribbean, and Gulf of Mexico. NOAA climate records show that in 2005, the eastern Caribbean experienced the warmest September water temperatures in over 100 years (Figure 2; Smith and Reynolds, 2004). Satellite records showed that the thermal stress experienced by corals in the Caribbean region 2005 was the largest and most intense event on record (Figure 3), with an average stress for the Caribbean region almost twice any level previously observed (Figure 4; Eakin *et al.*, in prep.). NOAA's ability to assess the extent and severity of this event was the result of investments in the development and operational implementation of satellite remote-sensing products. NOAA's ability to provide synoptic views of the global oceans in near-real-time and the ability to monitor reef areas have become a key tool for coral reef managers and scientists.

While the thermal stress in the Caribbean has increased over the last 20 years, 2005 was unusually high. As a result of NOAA satellite and *in situ* monitoring, NOAA alerted managers and scientists to this event as it developed. The unusually high sea-surface temperatures gave rise to the most intense coral bleaching event ever observed in the Caribbean. In 2005, many reefs, including those in the U.S. Virgin Islands, suffered bleaching of over 90 percent of their corals. *In situ* monitoring of reefs at the Virgin Islands National Park (NPS and USGS data) indicated a loss of 50 percent of the corals due to bleaching and disease outbreaks related to the prolonged high temperatures.

To respond to and assess the massive coral bleaching event in the Caribbean region in 2005, an interagency effort led by NOAA and the Department of Interior (DOI) was convened under the U.S. Coral Reef Task Force. This effort engaged many government and non-government partners from across the region, including local partners in Florida, Puerto Rico, the U.S. Virgin Islands, and Caribbean island nations, to assess the impacts of the 2005 mass bleaching event and make recommendations on how to prepare for and address future events. NOAA, DOI's National Park Service (NPS) and U.S. Geological Survey (USGS), and the National Aeronautics and Space Administration (NASA) employed detailed monitoring and new instrumentation to investigate the response of reefs and individual colonies to this record-breaking coral bleaching event. NPS and USGS research has been especially vital in identifying the effects that the unusually warm waters have on both bleaching and disease outbreaks (Miller et al, 2006). Some of this research will hopefully answer the question of why some corals survived while others perished. NOAA, NPS, and USGS, along with many partner agencies are analyzing the effect of this bleaching event on already vulnerable elkhorn and staghorn coral species. These two species were listed as "threatened" under the *Endangered Species Act* in May of 2006. It is clear that mass bleaching is a serious concern to the communities that depend upon these resources.

Even if greenhouse gases are kept at year 2000 levels, the 2007 IPCC Working Group I report concluded that global temperatures are expected to warm at almost 0.2 degrees Fahrenheit per decade. Based on current emissions, the anticipated increase in ocean temperatures over the coming decades is expected to increase the incidence of coral bleaching events (Donner *et al*., 2005). The 2007 IPCC Working Group II report concluded: "Corals are vulnerable to thermal stress and have low adaptive capacity. Increases in sea surface temperature of about 1 to 3°C are projected to result in more frequent coral bleaching events and widespread mortality, unless there is thermal adaptation or acclimatisation by corals." This means that marine resource management needs to plan for frequent and severe coral bleaching events in the future (Marshall and Schuttenberg, 2006).

The Value of Coral Reefs to Island and Coastal Communities

In its recent report *In the Front Line: Shoreline Protection and Other Ecosystem Services* *from Mangroves and Coral Reefs,* the United Nations Environment Programme (UNEP) estimated the value of coral reefs to be between $100,000-600,000 per square kilometer. This makes coral reefs among the most valuable resources of island and coastal communities. As part of their evaluation, they considered the loss to local economies if the ecosystem services of coral reefs were lost. UNEP predicted that "over a 20-year period, blast fishing, overfishing and sedimentation in Indonesia and the Philippines could lead to a net economic loss of $2.6 billion and $2.5 billion respectively." Further, in an extensive economic evaluation, the World Resources Institute estimated that coral reef degradation continuing through 2050 could reduce benefits from fisheries, dive tourism and shore protection by a predicted total of $350 million to $870 million in the Caribbean (Burke and Maidens, 2004).

Coral reef ecosystems also provide non-economic value to island and coastal communities, which are harder to quantify. Field teams evaluating the 2004 Indian Ocean tsunami suggested that the presence of healthy coral reefs significantly reduced wave damage to some communities in Sri Lanka (Fernando and McCulley, 2005). Modeling at NOAA's Geophysical Fluid Dynamics Laboratory and Princeton University also suggests that healthy reefs can provide protection and reduce damage from tsunamis (Kunkel et al., 2006).

Unfortunately, the value of ecosystem services provided by coral reefs has been poorly quantified for many locations. Accordingly, the cost of climate change effects to coastal communities is poorly known. NOAA's Coral Reef Conservation Program intends to begin research to quantify the effects that climate change may have on socioeconomic systems in the Florida Keys, similar to a study conducted for Australia's Great Barrier Reef (Hoegh-Guldberg, and Hoegh-Guldberg, 2004). Even without strict monetary valuations, island and coastal communities have recognized the tremendous economic and cultural values that reefs provide. Because coral reefs are such valuable resources, during the 16th U.S. Coral Reef Task Force Meeting in November 2006, Governor Togiola Tulafono of American Samoa gave a statement in which he recognized the threat and implored the U.S. Coral Reef Task Force to address climate change and its impacts on coral reefs to a greater extent than it has in the past. In his statement, Governor Tulafono said: "As a small island our way of life, a primary source of our food and a growing percentage of our economy depends heavily on a healthy coral reef. Under the present circumstances I can implement all the best management practices and still a single climate change event could devastate the majority of coral in the Territory…As the available data and scientific consensus become more persuasive and compelling on the present trends and projected impacts of global climate change, especially to the small islands dependent upon coral reefs and related resources, a set of proactive and responsive policies need to be developed along with realistic implementation strategies." This request was further echoed by delegations from other Pacific Island territories and the Freely Associated States at the 17th U.S. Coral Reef Task Force meeting in March 2007.

What Can Be Done?

As a steward of marine resources for the benefit of the nation, NOAA is working to improve its products to alert users of bleaching events through satellite and *in situ* observations, forecasts, and warning systems. NOAA is also working with local and regional managers to quantify the effect that increasing ocean temperatures have on coral reefs and ecosystem services, and to determine ways in which local managers can mitigate the impact of climate change on coral reefs.

The only practical way that we know of to eliminate the threat of coral bleaching is to stop or reverse the rise in ocean temperatures that has occurred over the last century. Such a reversal will very likely require reductions in greenhouse gas emissions, however, the policies to accomplish such a reduction fall outside the mandate of NOAA and beyond the reach of local managers in coastal and island communities. Recent work indicates that corals in the 21st century will have to adapt to temperature increases of at least 0.4 degrees Fahrenheit per decade to survive the increasing frequency and intensity of bleaching that we have seen. Unfortunately, ongoing studies have not found that corals have an ability to make physiological or evolutionary changes at that rate. Small latitudinal expansion of coral distributions is possible and may be occurring in one case (Precht & Aronson 2006). However, corals in higher latitudes are likely to encounter lower pH waters where skeletal growth may be depressed (Guinotte *et al*., 2003). This leads us to the question of what local managers can do to protect valuable coral reef resources in light of rising ocean temperatures and ocean acidification.

Indeed, what can be done for coral reefs in response to a changing climate? The U.S. Coral Reef Task Force posed this question when climate change was identified as one of the seven threats to reefs in *The National Plan to Conserve Coral Reefs*. As world leaders in coral reef management, NOAA and Australia's Great Barrier Reef Marine Park Authority, the Environmental Protection Agency, and the IUCN (The World Conservation Union), convened an expert workshop in 2003 to address what can be done. In 2006, we released *A Reef Manager's Guide to Coral Bleaching*.

The *Reef Manager's Guide* includes contributions from over 50 experts in coral bleaching and coral reef management from 30 organizations. The guide identifies three key actions reef managers can take to help reefs survive and recover from mass bleaching events:

(1) Increase observations of reef condition before, during and after bleaching to increase information and understanding of impacts and areas that may be especially resistant to bleaching.
(2) Reduce stressors (e.g., pollution, human use) on reefs during severe bleaching events to help corals survive the event.
(3) Design and implement reef management strategies to support reef recovery and resilience, including reducing land-based pollution and protecting coral areas that may resist bleaching and serve as sources of coral larvae for "reseeding" reefs.

The *Reef Manager's Guide* provides information on the causes and consequences of coral bleaching, and management strategies to help local and regional reef managers reduce this threat to coral reef ecosystems.

The *Reef Manager's Guide* reviews management actions that can help restore and maintain coral reef ecosystems. This review draws on a growing body of research on ways to support the ability of coral reef ecosystems to survive and recover from bleaching events. It also includes specific guidance and case studies on how to prepare bleaching response plans, assess impacts from bleaching, engage the public, manage activities that may affect reefs during bleaching events, identify resilient reef areas, and incorporate information regarding reef resilience into marine protected area design.

A key message from NOAA and its partners in the *Reef Manager's Guide* is the important role that resource managers play by taking all practical actions to control local threats to reefs. The 2007 IPCC Working Group II report addressed this issue stating that "Non-climate stresses can increase vulnerability to climate change by reducing resilience and can also reduce adaptive capacity because of resource deployment to competing needs." There are multiple sources of stress to coral reefs and reducing other stresses can help corals survive the stress of bleaching. Research has shown that improved local management, which reduces key threats such as overfishing, provides reefs with the greatest chance of surviving and recovering from climate change (Wooldridge *et al.*, 2005; Hughes *et al.*, 2007). In its recently released *Coral Reef Ecosystem Research Plan*, NOAA describes the need to further (1) improve our understanding of the relationships between the severity of bleaching events and mortality, including what makes coral reefs resilient; (2) assess the extent and impact of bleaching on coral reefs during bleaching events; and (3) developing models to predict the long-term impacts to coral reef ecosystems from climate change. The plan can be viewed at http://coris.noaa.gov/activities/coral_research_plan/.

Conclusion

To summarize, sea-surface temperatures have risen, increasing the frequency and intensity of coral bleaching, disease, and mortality. As humans continue to add CO_2 to the atmosphere, it is very likely that this will bring further increases in sea-surface temperatures and bleaching. Increased atmospheric CO_2 threatens coral reefs that are important resources to our nation and to island and coastal communities throughout the world, doing harm to ecosystems, ecosystem services, and the people that depend on them. To protect coral reefs against rising temperatures and ocean acidification, we must take all practical actions to protect coral reefs from local stressors and manage marine resources, including planning marine protected areas, with rising temperatures in mind. NOAA looks forward to working with this Committee to ensure we have the tools and resources available to conserve, manage, and protect our coral reefs.

Madam Chairman, I thank you for inviting me to help inform the Committee on this topic. I would be pleased to answer any questions.

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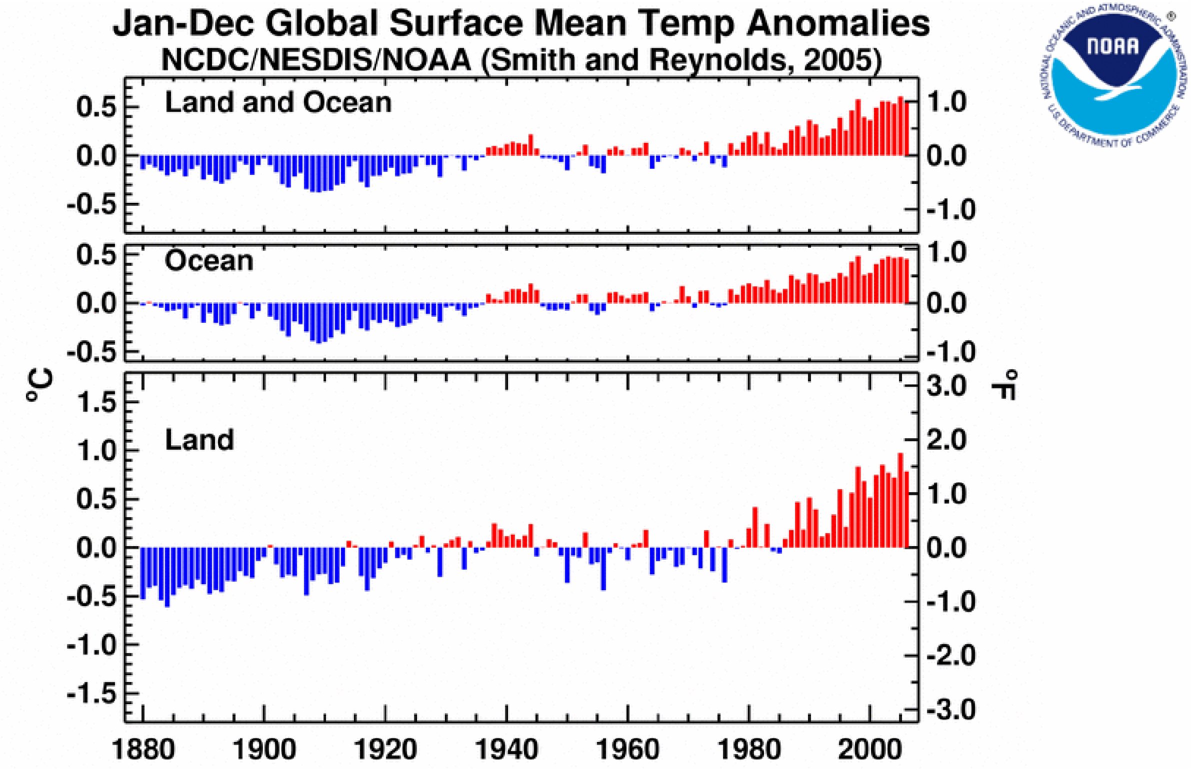

Figure 1: NOAA National Climatic Data Center data show us that the Earth's oceans have warmed almost 1 degree Fahrenheit over the 20th century average. Source: NCDC 2007. The Climate of 2006. Handout from the AMS meeting in San Antonio, TX: January 2007, http://www.ncdc.noaa.gov/oa/climate/research/2006/ann/ann06.html

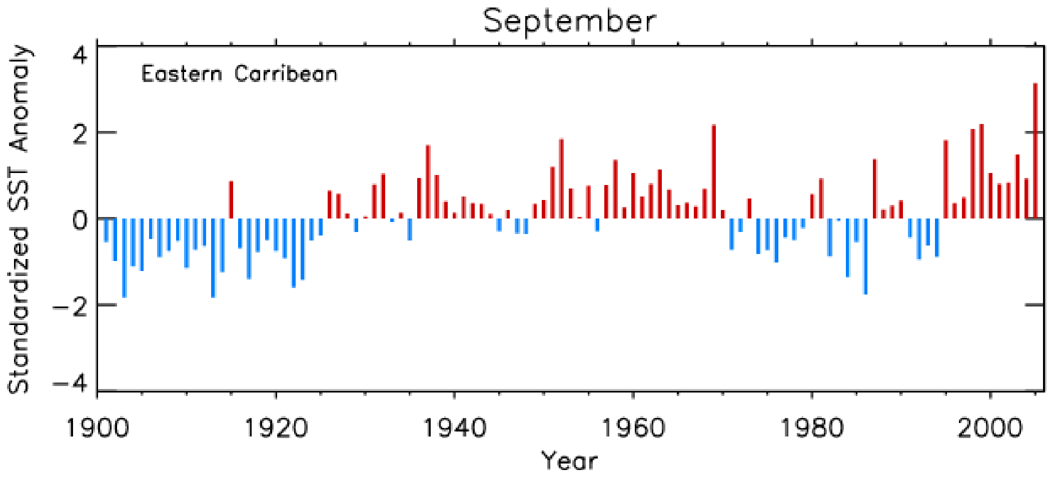

Figure 2: NOAA Extended Record of Sea Surface Temperature data showed that average ocean temperatures during June for the Western Caribbean and for September for the Eastern Caribbean exceeded temperatures seen at any time during the past 100 years. Source: Smith T. M., Reynolds R. W., 2004, *Improved extended reconstruction of SST* (1854-1997). Journal of Climate 17: 2466-2477, and data from NOAA's Earth System Research Laboratory, http://cdc.noaa.gov.

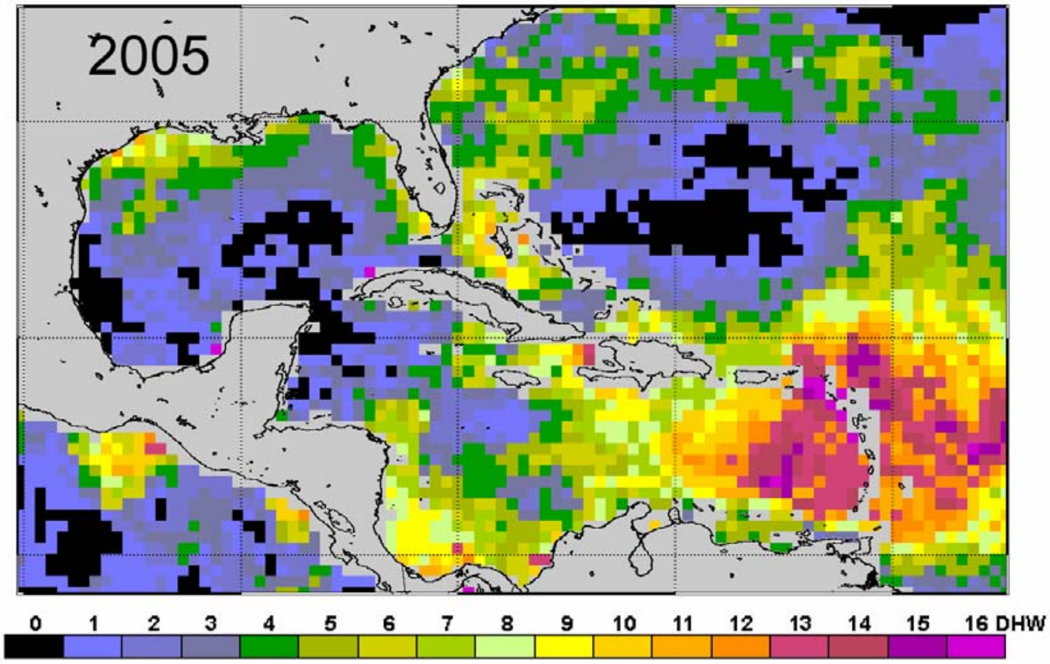

Figure 3: Map of 2005 maximum thermal stress (NOAA Coral Reef Watch Degree Heating Week values, or DHW) showing the maximum thermal stress across the Caribbean during 2005. Source: Eakin, C. M. et al., 2007, *Caribbean Corals in Hot Water: Record-Setting Thermal Stress, Coral Bleaching and Mortality in 2005*, intended for Nature, in preparation.

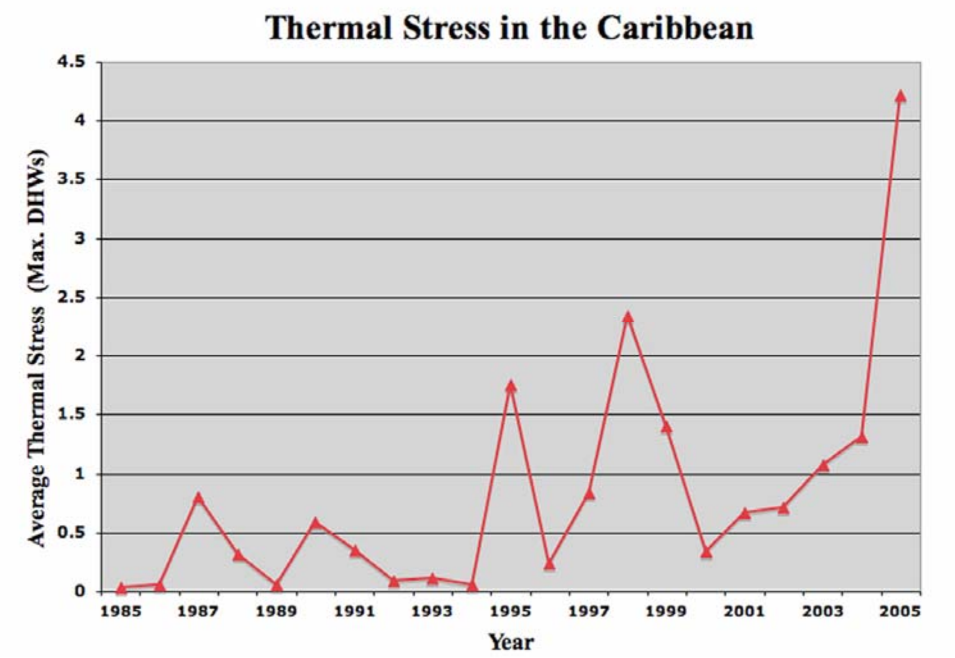

Figure 4. Graph of annual maximum thermal stress (NOAA Coral Reef Watch Degree Heating Week values, or DHW) in the Caribbean region during 1985-2005. Significant coral bleaching was reported in the Caribbean in years when thermal stress rose above 0.5, and was especially widespread in 1995, during the 1997-98 El Niño and 2005. Source: Eakin, C. M. et al., 2007, *Caribbean Corals in Hot Water: Record-Setting Thermal Stress, Coral Bleaching and Mortality in 2005*, intended for Nature, in preparation.