TESTIMONY

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to the

U.S. Senate Committee on Environment and Public Works Field Briefing
on
The Implications of Global Warming for Narragansett Bay

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Introduction

Good morning Senator Whitehouse and other distinguished members of the Committee. It is a pleasure to appear before you today as a citizen and member of the scientific and engineering communities. On behalf of University of Rhode Island President Robert Carothers and the Graduate School of Oceanography's Dean David Farmer, we thank you for hosting this briefing here at the University's Narragansett Bay Campus and we applaud your focus on this critically important issue for Rhode Island and other coastal states.

I am a Professor at the University of Rhode Island with a joint appointment in the Graduate School of Oceanography and the Department of Ocean Engineering. The information I present today is from work conducted by researchers at the University of Rhode Island, many of whom are attending the briefing today, and published in international, peer-reviewed journals. The importance of this topic is also clearly demonstrated by the participation at this briefing of state and national leaders: the Executive Director of the Coastal Resources Management Council, Grover Fugate, Rhode Island's state Geologist, Prof. Jon Boothroyd, the Director of Conservation Science at The Nature Conservancy, Caroly Shumway, and Save the Bay's Baykeeper, John Torgan.

Climate change studies are conducted by teams of individuals who bring together a wide variety of expertise to strive to understand the complex Earth system. My own research, in this arena, has focused on uncovering the past climate of the Arctic Ocean–an area of the planet that has significant control on the climate and is currently suffering from a greater impact from climate change than almost any other place on the planet.

The major role of the Arctic and polar regions in the climate puzzle cannot be overstated. Attending the briefing today is Dr. John Farrell, the Executive Director of the U.S. Arctic Research Commission, an independent federal agency with presidentially appointed commissioners. This Commission recommends science policy for the U.S. in the Arctic and he is here today because of the strong link between the Arctic and its climate impact on U.S. coastal areas.

Thank you for the opportunity to present on climate change and its impact on the state of Rhode Island, and specifically Narragansett Bay.

Testimony Content

Scientific evidence (IPCC, 2007a) has shown that the earth's climate is changing and unequivocally, these changes are anthropogenic. In other words, the human race is the cause of global change. On this point the greater, international scientific community is in agreement.

The impact of global climate change on Narragansett Bay is, to a large extent, controlled by the larger global changes. Trends seen here on our Bay are the result of events and drivers that are only partially controlled by our local actions. It is because of this that the State and Federal response to our local climate change requires a holistic picture of global climate change.

Today, I speak to you on this global picture, to put into context the serious changes that have already impacted coastal Rhode Island, to anticipate near-term changes to the Bay, and to consider the long-term changes that we may still have an opportunity to mitigate.

I will highlight the global change issues in terms of the scientific **observations**, future **predictions**, and the **uncertainties** in some of these predictions. There are a wide range of global impacts, but, I focus here on those related to the ocean and where the ocean and land meet which is of the greatest concern to the residents of Rhode Island.

Observations

Temperature

The greenhouse effect is a well-known natural phenomenon that maintains the planet at habitable temperatures (Kiehl and Trenberth, 1997). The effect is controlled by greenhouse gases in the atmosphere, such as carbon dioxide and methane. When the concentrations of these gases increases, the planet warms. Four data sets (Fig. 1) show the measured increases in greenhouse gases from the year 1000 to the turn of the recent century.

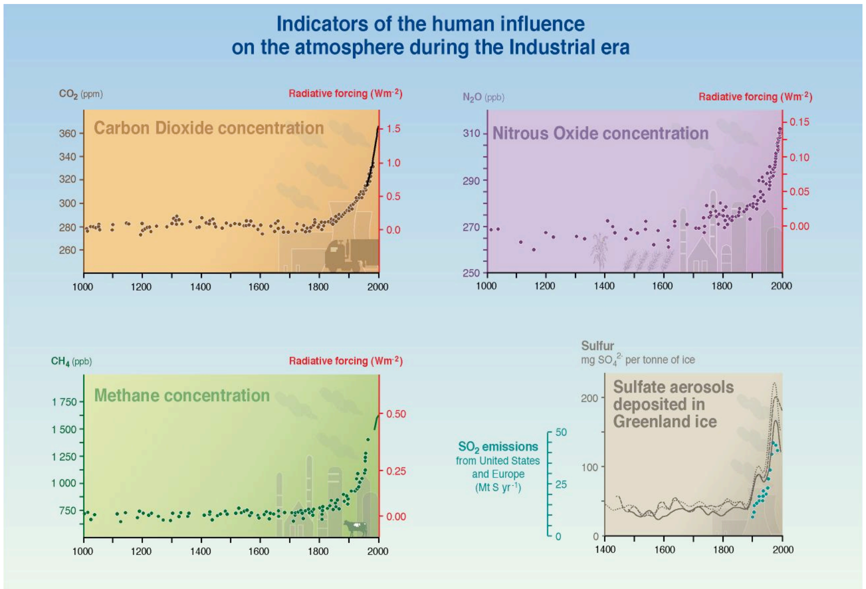

Figure 1. Measurements of greenhouse gases from the year 1000 to 2000 (IPCC 2007b).

Each of these data sets clearly document measured increases in greenhouse gases that are caused by burning of fossil fuels, industrial uses of agricultural fertilizers, domesticated animal food production, among other impacts. These increases enhance the greenhouse effect and dramatically warm the planet, which, in turn, can cause mass extinctions, extreme climate changes, and sea level rise, for example.

The warming of our planet is demonstrated by globally averaged measurements (Fig. 2) that indicate a ~1° C increase over the past 150 years–which, despite being a small number, is a large rise in a short amount of time.

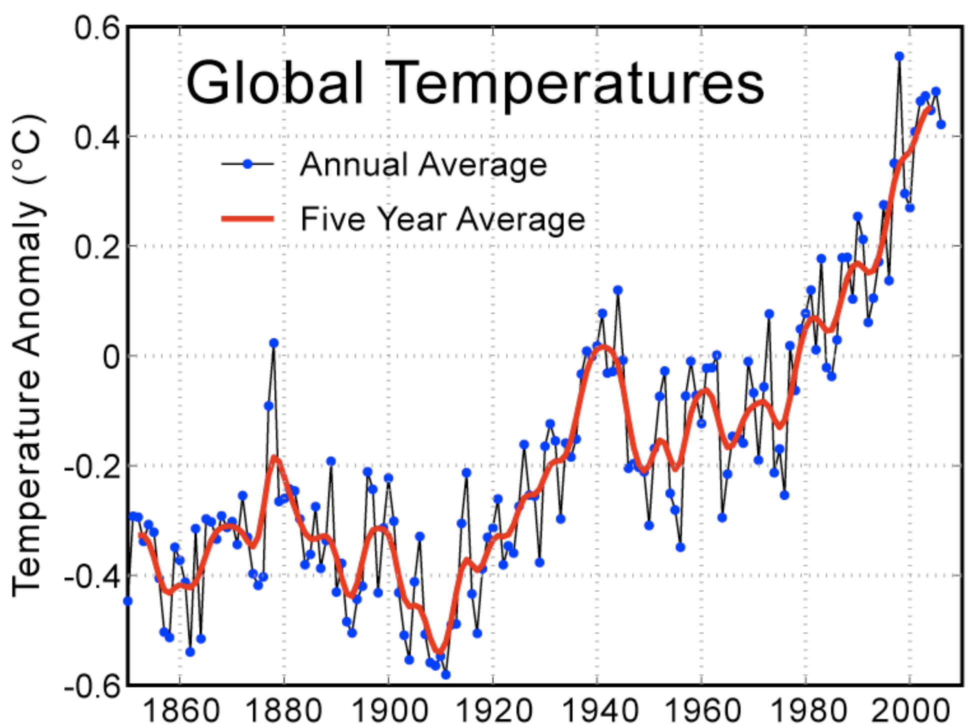

Figure 2. Measurements of global average temperatures as compiled by the Climatic Research Unit, UK Meteorological Office (Brohan et al. 2006). Zero temperature is the mean temperature from 1961-1990.

Closer to home in Rhode Island, we are fortunate that measurements (dubbed long term time series by the science community) of the surface water temperatures in Narragansett Bay were started by insightful scientists more than 50 years ago. I cannot emphasize enough the importance of sustained funding for these long-term measurements. This record shows a trend of increased temperature in the Bay (Fig. 3), with a warming rate of approximately 0.3° Celsius (0.5° F) per decade. University scientists have attributed this increase to human-induced atmospheric gases.

Consequences on coastal ecosystems in New England are large and have included changes in the number of fish in the Bay (Jeffries 2002), changes in phytoplankton blooms that can impact human health (Oviatt et al. 2002), increases in predatory jellyfish (ctenophore) populations (Sullivan et al. 2001), and the northern extension of oyster disease (Cook et al. 1998). All of these consequences are ecologically significant, but they also impact the local fisheries, tourism (in the case of harmful algal blooms) and, thus, the economy of Rhode Island.

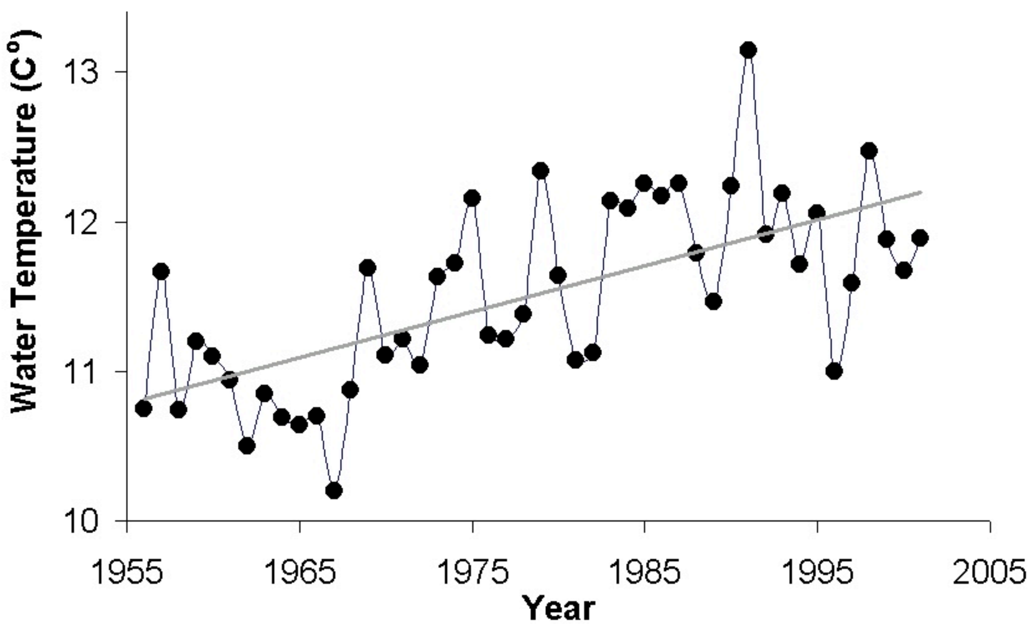

Figure 3. Mean annual surface water temperature in the lower reaches of Narragansett Bay south of Prudence Island. Sources of Data: 1956–1994 National Oceanic and Atmospheric Administration Newport Station; 1995–2001 University of Rhode Island Graduate School of Oceanography Fish Trawl Survey, Fox Island Station.

Sea Level

Sea level is rising globally (Fig. 4) primarily due to two major effects: expansion of sea water as it warms and melting of ice on land. Local sea level increases are also influenced by other factors that

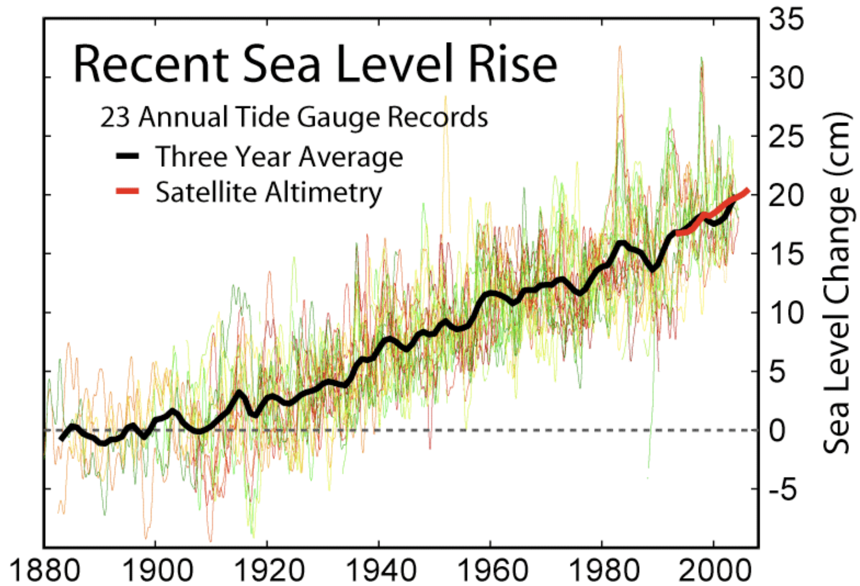

Figure 4. Annually averaged sea level from tide gauge measurements (Douglas,1997). The solid black line is a three-year average and the annually averaged satellite altimetry data are shown as a solid red line.

may be addressed by others today.) A sea level record for southern New England over the past ~700 years (Fig. 5; Donnelly et al. 2004) shows that the average rate of sea level rise was ~1 mm/year from 1300 to 1850 and a three-fold increase in this rate occurred since the mid 1800s, which is coincident with early industrialization. They conclude that the increase in the rate of sea level rise is associated with "recent warming of the global climate."

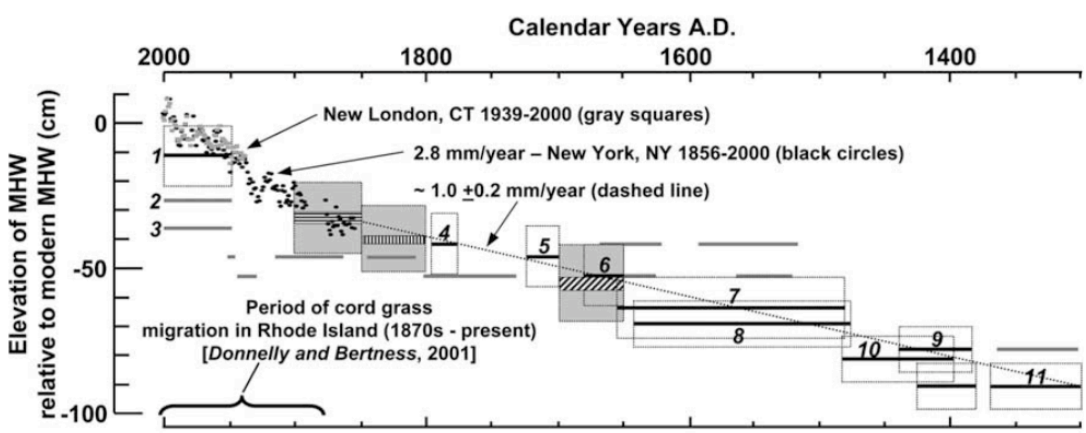

Figure 5. Mean high water (MHW), an estimate of sea level measurements over the past 700 years for southern New England and New York (figure taken directly from Donnelly et al. 2004). Note the tripling of the rate of sea level rise since ~1850.

Loss of Sea Ice - One of the Planet's Natural Air Conditioners

On the top of our planet lies the Arctic Ocean that has, for a long time, been covered year round by a cap of floating sea ice. The public and the press have been increasingly focused on the plight of the polar bear when reporting on the observations that the Arctic Ocean's sea ice is rapidly shrinking. This charismatic mammal lives in and on the sea ice and the loss of this habitat will certainly be devastating for polar bears (e.g. Pennisi 2007). However, another aspect of the Arctic Ocean's sea ice loss is not as well publicized, but has broader implications, even to us in Rhode Island.

This aspect is related to an effect called albedo. The albedo of any material on Earth is its ability to reflect sunlight. Albedo is defined as the ratio of outgoing, or reflected, solar radiation, to that of incoming radiation. Sea ice has a high albedo and effectively reflects incoming sunlight, thus keeping the planet cool and acting as a natural air conditioner. When the ice melts, the exposed seawater, which has a lower albedo, absorbs a greater percentage of sunlight, allowing the planet to warm. Research that colleagues and I have conducted suggests that a cap of Arctic sea ice has been in place, year-round, for perhaps as long as 13 million years (Moran et al. 2006; Backman and Moran 2008). Recently, however, sea ice has been shrinking at a rate that is significantly faster than that previously observed, and the shrinkage (in both thickness and areal extent) during the summer of 2007 was the greatest since synoptic measurements began (Fig. 6; Stroeve et al. 2007). Scientists are currently betting on when the Arctic Ocean will be ice free in the summer, and the dates are sooner verses later. When the sea ice that keeps the planet cool decreases, increased warming occurs and this change is considered to be one of the so-called "tipping points." Thus, if this point is "tipped", the result will likely be increased sea surface temperatures and a dramatic loss of sea ice in the summer. Predictions for this summer's sea ice are not good (see www.arcus.org/search/seaiceoutlook/index.php), and current observations indicate significantly less ice than average, but the final results will be seen by mid to late September 2008.

Figure 6. Areal extent of summer sea ice measured from satellite data comparing 1982 to 2007. Note the large loss in sea ice over this time period. Images from the National Snow and Ice Data Center 2007.

Other Observations

The IPCC (2007a) summarizes peer-reviewed studies that document other global change observations that I do not present here. These include:

- Tropospheric temperatures increasing
- Atmospheric water vapor content increasing
- Greenland and Antarctic Ice Sheets losing mass
- Glaciers and snow cover decreasing
- Area of seasonally frozen ground decreasing
- Mid-latitude wind patterns/ storm tracks shifting poleward
- More intense and longer droughts
- Frequency of heavy precipitation events increasing
- Extreme temperatures increasing
- Tropical cyclone intensity increasing

Taken together, the IPCC concludes that these changes are **unequivocally** linked to human-induced activities.

Ocean-related Predictions

Sea Level

The predictions for sea level rise (shown as blue range in Fig. 7) from the IPCC (2007a) include three effects: water expands when it gets warm (thermal expansion); melting mountain glaciers and ice caps, excluding Greenland and Antarctic; and ice sheet surface mass balance and dynamical imbalance. Thermal expansion estimated from climate models that include ocean circulation is considered robust. Sea level rise from glaciers and ice caps is based on observations from glaciologists who studied these features over the period of 1963 to 2003. Since glaciers are clearly disappearing, their contribution would add no more than ~40 cm of sea level rise. The contributions from Greenland and Antarctica are estimated by subtracting the melt of surface ice from snowfall, and by including the long-term average amount of ice lost to the ocean by the formation of icebergs.

These predictions do not, however, include major changes in ice dynamics from Antarctica and Greenland, such as those observed recently. I will return to this topic later when describing uncertainties. These estimates that do not include ice dynamics suggest about a 1 foot global sea level rise by 2050.

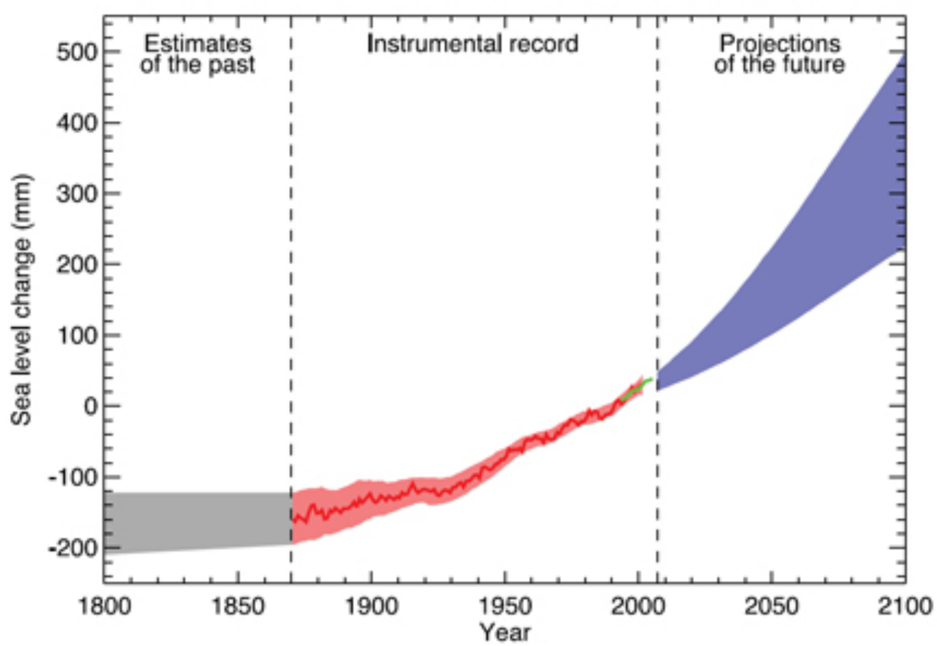

Figure 7. A sea level rise compilation including pre-instrumental estimates (grey), the range of measurements from instruments (red) and their average (solid red line); and the range of predictions derived from IPCC (2007a) shown in blue.

Hurricanes

Warm ocean water is the fuel that feeds hurricanes. A hurricane expert here at the Graduate School of Oceanography, Professor Isaac Ginis, has incorporated this fuel effect into computer models that are used by the National Oceanographic and Atmospheric Administration (NOAA) for real-time predictions of hurricane intensity and tracks (Falkovich, Ginis & Lord, 2005). These improved models significantly increased the accuracy of the predicted tracks of Hurricanes Katrina and Rita and more recent storms, as well.

This link between temperature and hurricanes suggests that with warming ocean waters, hurricanes could become more frequent or more intense. Some studies (e.g., Emanuel 1987) predict that there may be an increase in hurricane development, intensity and behavior. Recent predictions suggest otherwise, but the jury is still out. Knutson et al. (2008) found that hurricane frequencies in the Atlantic could be reduced under global warming scenarios, but storm rainfall rates would increase significantly. Yet other recent studies (Semmler et al. 2008) indicate an increase in the number of strong hurricanes and extratropical cyclones. They also predict changes in hurricane tracks. These research studies are not yet conclusive, but additional efforts must be supported in an effort to better understand and predict a phenomenon that has a tremendous impact on society. Comprehensive records of hurricanes have only been available since the advent of satellites where have we been able to observe all of the hurricanes that form in any year. Despite that, who in Rhode Island doesn't know of the hurricane of '38, which flooded downtown Providence?

Seawater Changes

Predictions consistently show that the ocean will continue to warm off our coast (IPCC 2007a). Model predictions show a ~2-3^{o} C increase by the end of this century (Fig. 8). As observations have shown, warming changes the ecosystem and, thus, these changes will impact fisheries, tourism, and the economy.

And what about ocean acidification that we've been hearing about? Carbon dioxide not only warms the planet, but it also sours the ocean. Atmospheric carbon dioxide is absorbed by the oceans, increasing it's acidity. This negatively impacts the ability of sea creatures, such as scallops, juvenile king crabs, and the less well-known plankton called pteropods, to create protective shells. In the Pacific, pteropods are a major food source for salmon, and the demise of the pteropods negatively impacts our renewable fisheries resource.

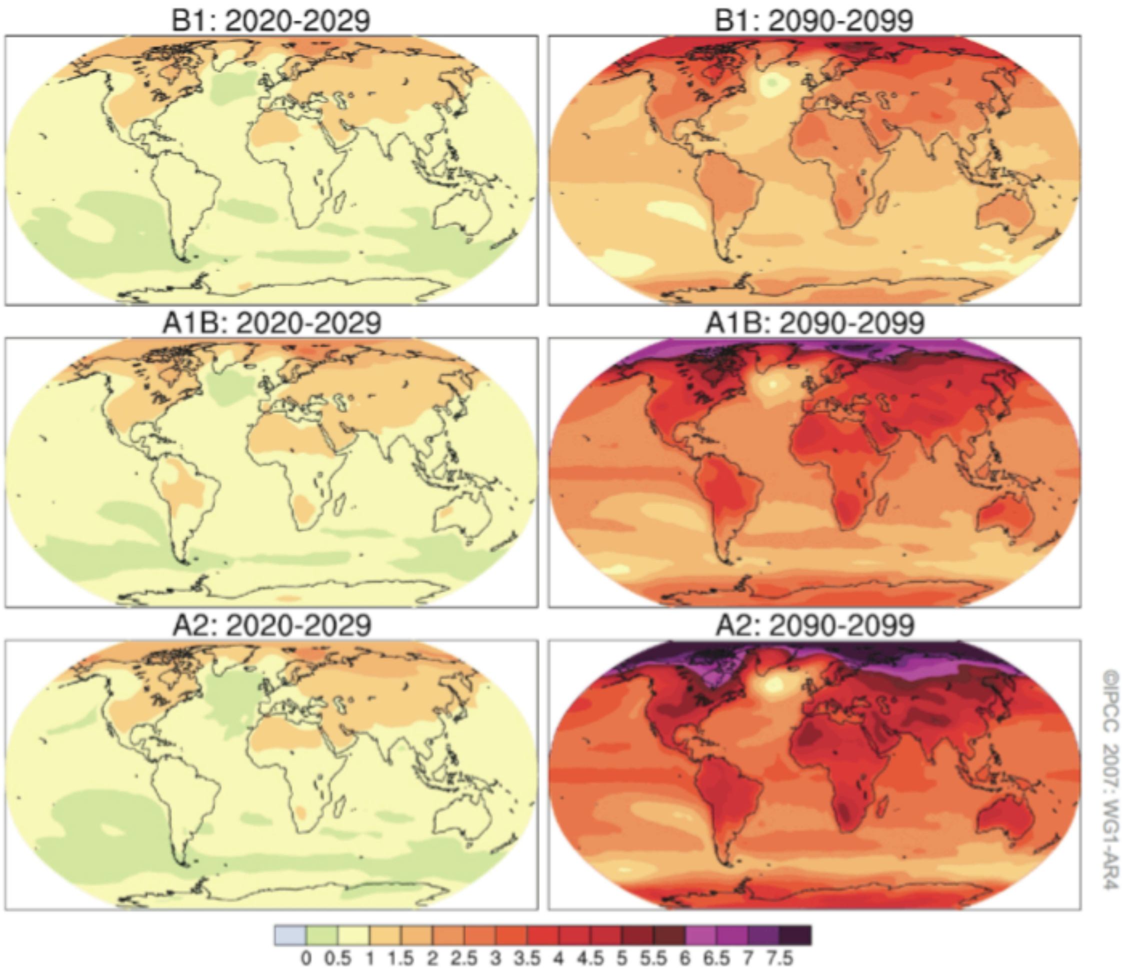

Figure 8. Computer-predicted surface temperature changes for the early (left) and late 21st century (right) compared to the average of the period 1980–1999 for different emission scenarios (IPCC 2007a).

Since the 1800's, the oceans have absorbed ~130 billion tons of carbon, which is about 1/3 of all human-induced emissions (Feely et al. 2008). Measurements have documented that absorption of carbon dioxide has increased ocean acidity by ~0.1 units (out of a total range of 14). Acidification is predicted to continue and has the potential to negatively impact the surface and deep ocean ecosystems. Although the Pacific Ocean is a more corrosive body of water and would be impacted first by this affect, especially in the northern Pacific, and off Alaska, Orr et al. (2005) suggest that widespread detrimental conditions could occur over the next few decades and that Atlantic impacts may be seen by mid century (Fig. 9).

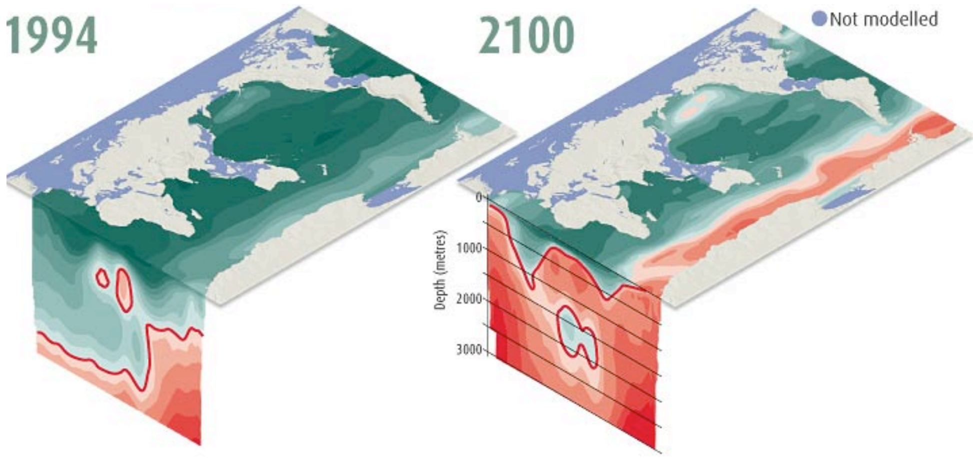

Figure 9. Predicted changes in ocean acidification between 1994 (left) and 2100 (right). Deep ocean waters are not corrosive (red) and will inhibit the sea life to form carbonate shells (image developed by New Scientist from Orr, 2005).

Uncertainties

I touched on the uncertainty that scientists are currently struggling with concerning hurricanes, but there is another uncertainty that is also of critical importance to Rhode Island. And this is sea level rise. I am proud to report that Rhode Island's Coastal Resource Management Council (CRMC) is taking a strong leadership role by integrating our current understanding of climate change, including sea level rise uncertainties, in their adaptation plans and regulatory updates. Clearly, these approaches should be adopted by other coastal states.

As introduced earlier, the IPCC (2007a) sea level rise estimates do not include major changes in the earth's large ice sheets on Greenland and Antarctica. Scientists have recently documented major changes in the melting characteristics of the Greenland and Antarctic ice sheets (Shepard and Wingham, 2008).

As with hurricane research, relatively new satellite measurements have allowed us to observe changes in these two large ice masses that show relatively rapid change. The balance between growth and loss in these ice sheets was initially thought to be relatively balanced. New data show that Antarctica and Greenland are losing ice and, thereby increasing sea level above the most recent IPCC (2007a) estimates. The current rate (0.35 mm/yr.) measured in this study is ~10% of today's total sea-level rise and is increasing.

Based on other observations (Howat et al., 2007), ice loss into to the ocean has accelerated over the past decade and this acceleration will continue, if not increase. This team studied two places in

Greenland where ice moves from the continent to the ocean (outlet glaciers). They found that the rate of ice movement to the ocean doubled in less than a year in 2004. NASA's gravity satellite "GRACE" shows that both ice sheets (Chen et al. 2006; Velicogna & Wahr 2006) are losing ice rapidly and at a rate that is double of only a few years ago. When compared with the fact that less than a dozen years ago, the ice sheets were in equilibrium, these changes are striking. Therefore, our estimates of sea level rise must be adjusted upwards to take into account the new studies that are focused on this little-understood, but critical component of sea level rise.

Summary

In summary, Narragansett Bay is already seeing the affects of climate change. Sea level rise will occur, but we must monitor this closely because both the timing and magnitude are still uncertain. Water temperatures will continue to increase and impact the coastal and Bay ecosystems. Ocean acidification may impact the Bay over the next century, but the timing and level of impact is not yet well understood. Hurricanes and tropical storms trends have the potential to inflict great damage, and coupled with increased sea level, we should be taking a precautionary approach so that coastal communities become resilient to the possible impacts.

Finally, we are the cause of these drastic changes to our planet, Rhode Island and Narragansett Bay and we must act **now** to alter this climate collision course.

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