Good morning. My name is Anthony Broccoli and I am a Professor of Atmospheric Science at Rutgers University, Chair of the Department of Environmental Sciences, and Co-Director of the Rutgers Climate Institute. Thank you for the opportunity to come here today to talk about the science of climate change and, more specifically, how the effects of climate change are being felt in New Jersey.

Global average temperature has risen by approximately 2°F since the late 19th century. In each of the last four decades—the 1970s, 1980s, 1990s, and 2000s—temperatures at the earth's surface have been warmer than the previous decade, and warmer than any decade since modern thermometer records began. And the 2010s are on track to continue this trend.

During the past twenty years, the great ice sheets that cover most of Greenland and Antarctica have been shrinking, as have almost all mountain glaciers throughout the world. Based on trends going back to 1880, global sea level has been rising at an average of just under 7 inches per century. But sea level rise is accelerating. If we look at just the past 25 years, the global rate of sea level rise has almost doubled to about 13 inches per century.

The causes of these dramatic changes in global climate are well-understood. Heat-trapping gases in the atmosphere have increased as a result of human activities. The most important of these gases is carbon dioxide, which is released into the atmosphere by the

combustion of fossil fuels. The atmospheric concentration of carbon dioxide has reached levels that are unprecedented in at least the past 800,000 years, and its current concentration is approximately 45% higher than it was prior to the Industrial Revolution. Carbon dioxide is being emitted into the atmosphere at a rate of nearly 40 billion tons per year.

The basic physics of how carbon dioxide and other heat-trapping gases affect climate have been understood for well over a century. To maintain a consistent global temperature, the earth must send energy back into space in an amount that balances the energy it receives from the sun. Heat-trapping gases act as a blanket that makes it more difficult for the earth to send energy back into space, thereby making the earth warmer than it would be otherwise. The continued increase of these gases will lead to a continuation of the global warming trend that has been observed. Without a stabilization of the amount of heat-trapping gases in the atmosphere, the changes in climate that the world has experienced are expected to continue and intensify.

As might be expected in a warming world, future climate will feature more frequent and longer heat waves and fewer cold temperature extremes. But other aspects of climate are also associated with rising temperatures. Heavy rain events over middle latitude continents such as North America are expected to become more intense and more frequent as the climate warms. Global wind patterns may change in ways that have the potential to affect air travel. And, perhaps most

important, the rate of global sea level rise will continue to increase during the 21st century.

What about climate change in New Jersey? Looking back, New Jersey's average temperature has risen at a rate of just under 3°F per century, or somewhat faster than the global average. The six warmest calendar years on record have occurred since 1998, with 2012 being the warmest year. Summers have been unusually warm, with the seven warmest summers on record taking place since 1998.

Looking at extremes on a monthly basis, we can define an unusually warm month as one that is among the five warmest for that calendar month, and an unusually cold month as one that is among the five coldest. In recent years, unusually warm months have been far more prevalent than unusually cold months, outnumbering them by 35 to 0 since 2000. The trend toward higher temperatures is expected to continue in the decades to come as the concentrations of heat-trapping gases continue to increase.

Annual precipitation in New Jersey has undergone an upward trend of just over 2 inches per century since statewide records began in 1895. This trend is small compared with the year-to-year variability of precipitation. But increases in the amount of precipitation falling in heavy rain events have been noted throughout the northeastern United States, including New Jersey. By one measure, the frequency of these events has doubled over the past two decades. There is reason to

expect this trend will continue, as heavy precipitation events are anticipated to become more intense and more frequent as temperature increases, with implications for the frequency of inland flooding along New Jersey's rivers and streams.

Sea level rise along the New Jersey coast has been more rapid than the global average because the land is sinking at the same time that water levels are rising. At Atlantic City, where records extend back to 1912, sea level has risen by an average rate of 1.5 inches per decade. As the ocean continues to warm and glaciers and ice sheets continue to melt, sea level rise is expected to accelerate. According to a recent report produced by a team of scientists under the auspices of the New Jersey Climate Adaptation Alliance, central (or “middle-of-the-road”) estimates of sea level rise on the New Jersey coast relative to the year 2000 are 10 inches by 2030, 17 inches by 2050, and 28 to 41 inches by end of this century, with the values in 2100 dependent on the magnitudes of future carbon dioxide emissions.

The evidence for changes in storm activity, including tropical storms and hurricanes, is mixed and remains an area of active research. Recent studies suggest that the global frequency of tropical cyclones will either decrease or change little in response to global warming. But their average intensity is likely to increase, in terms of both maximum wind speed and rainfall, and the frequency of the most intense hurricanes is expected to increase.

What we would really like to know is how the risks to New Jersey from hurricanes and other storms will change in the future. Unfortunately, we do not yet have great confidence in regional projections of future storm activity. But there is high confidence that the impacts of future storms in the form of coastal flooding are likely to be more frequent and more severe, as rising sea levels raise the baseline for coastal flooding events. For example, some of my colleagues at Rutgers have estimated that Hurricane Sandy flooded an area 27 square miles greater than it would have if it had occurred in 1880, increasing the number of people living in areas inundated by the storm tide by ~38,000 in New Jersey alone. The future rise in sea level will likewise increase the areas at risk of coastal flooding.

Many of our traditional strategies for planning for future weather and climate events assume that they will look a lot like the events that we have experienced in the past. Climate change invalidates this assumption, creating a need to prepare for and adapt to conditions that will likely be quite different from what we have seen in the past.

Because the primary driver of future climate change is the emission of carbon dioxide into the atmosphere, there is the potential to mitigate the impacts of future climate change through the development of alternative sources of energy and policies to discourage carbon dioxide emissions. But regardless of what policy direction we ultimately follow, we are already experiencing changes in climate, and there is no realistic scenario in which future changes can be completely avoided. Thus it will be necessary to adapt to the changes in climate that are already

"wired in," even if mitigation policies are implemented to reduce carbon emissions. A combination of mitigation and adaptation will be required; it is not an "either-or" proposition.

Finally, it is important that the decisions that we make, here in New Jersey and elsewhere, should be informed by the best available science. At Rutgers, faculty and students from many departments, schools, and campuses are engaged in research that will lead to a better understanding of climate change and the development of solutions for mitigating climate change and adapting to its unwanted effects.

The Rutgers Climate Institute was formed to facilitate collaboration among climate change scholars across a broad range of disciplines in the natural, social and policy sciences. Rutgers scientists study the changes in climate and sea level that have occurred in the past in an effort to better understand the mechanisms that drive them. They use computer models to study the processes that drive changes in the atmosphere and ocean. They monitor conditions on land and in the coastal waters, using automated weather stations, ocean gliders, radar, and satellites. They study the effects of climate change on fisheries and on the forests of the Pinelands. Other research topics include the vulnerability of our residents to climate change and the impacts of climate change on agriculture here in the Garden State.

The Rutgers Energy Institute promotes research on the production, storage, and use of energy, including the development of alternative

energy sources such as bioenergy, solar, wind, and water. Rutgers is engaged in research on battery technology, green buildings, and energy-efficient transportation and supply chain management, to name but a few examples. All of these efforts are motivated by a desire to address what is arguably the most important environmental issue of the 21st century.

You will hear from other expert witnesses today who will discuss in greater detail some of the topics I've mentioned. To the committee chairs and to the committee members, I thank you again for the opportunity to talk with you today and provide an overview of this important issue.