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before the
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Subcommittee on Environment
Sea Change: Impacts of Climate Change on Our Oceans and Coasts
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Madam Chair and Members of the Subcommittee, my name is Radley Horton. I am a Lamont Associate Research Professor at Columbia University's Lamont-Doherty Earth Observatory. Thank you very much for the opportunity to participate in this important hearing on the impact of climate change on our oceans and coasts. I have served as an author on the 3rd and 4th U.S. National Climate Assessments, and as a Lead Principal Investigator within NOAA's RISA Program. I speak to you today though in my personal capacity as a private citizen.

Primarily as a result of human activities including the burning of fossil fuels and land use change, carbon dioxide concentrations in the atmosphere have increased by more than 40 percent since the Industrial Revolution (Wuebbles et al. 2017). For most people, warming of the *atmosphere* is probably the first thing that comes to mind when they think about the climate changes that have resulted from these human activities. Indeed, based on records going back to the 19th century, surface air temperatures the last five years have been the five warmest on record, and the 20 warmest years have all occurred within the last 22 years (Climate Central, 2019).

It may come as a surprise therefore that since the middle of the 20th century, 93 percent of the excess heating associated with human activities has actually gone towards warming the *oceans* (Wuebbles et al. 2017). As a result, the surface of the ocean has warmed by well over 1°F on average since 1900. The enormous energy imbalance required to heat the upper oceans so rapidly can only be plausibly explained by human activities (Wuebbles et al. 2017).

This warming, in conjunction with related ocean acidification and deoxygenation, has directly affected all living organisms in the upper ocean, as other speakers today will describe. It is also affecting sea level, which will be the subject of the majority of my brief remarks today.

We have seen about 7-8 inches of sea level rise since 1900 (Wuebbles et al. 2017). Although there is a delay between carbon dioxide emissions and sea level change, acceleration of the rate of sea level rise has been observed during the past generation (Wuebbles et al. 2017). I'd now like to briefly discuss the causes, impacts observed to date, and where we could be headed later this century.

Globally, there are two predominant ways that climate change is causing sea levels to rise. First, as the ocean warms, it expands. Second, the ice sheets and glaciers that that sit on land are disgorging ice and water into the oceans, thereby adding mass. Although the first process had a bigger impact on sea level during the 20th century, it is thought that the second now rivals the first, and is set to surpass it this century. (Other drivers of sea level, of less importance globally, include 1) global storage of freshwater on land, 2) changes in local land height, and 3) regional variations in the change in ocean height due to factors ranging from ocean currents to the gravitational attraction of ice sheets (Sweet et al. 2017.)

But what about the future of sea level rise? It is often said that there is a lot of uncertainty about sea level rise, and in one sense, it is true. But it is asymmetric or 'high tail' uncertainty. According to Volume 1 of the Fourth National Climate Assessment (Wuebbles et al. 2017): "[Global mean sea level) is *very likely* to rise by…1.0–4.3 feet by 2100." There has been a lot of focus on whether the plausible worst-case scenario for 2100 is 4.3 feet, six feet, or even 8 feet of sea level rise. But I would like to highlight a less appreciated point. Even the most optimistic scenario imaginable--of one foot of sea level rise by 2100--would have direct and profound impacts. I am going to focus on the most obvious impacts, but there will be less direct ones as well.

Sea level rise means more frequent coastal flooding and more intense/higher magnitude coastal flooding (Wuebbles et al. 2017). Already we are seeing nuisance (also known as 'sunny-day') flooding happen far more often than it used to across the U.S. coastline, as shown in Figure 1. For some locations, the past two generations have seen a 5 to 10-fold increase in the number of days with nuisance flooding. (It should be noted that some of these places, including the Mid-Atlantic states, have had more sea level rise than the global average, but even for those states that have not, the trend towards more nuisance flooding is clear.) From Miami to Norfolk, this means for exmple: 1) more stores unable to open for normal business, with associated ripple effects on the economy; 2) people not able to drive home along their normal routes, leading to delays, and 3) more water in people's basements. These events perhaps deserve to be called a mere 'nuisance' when they only happen a few times per year—but at what point does it become something more than a nuisance?

Now lets look to the future of coastal flooding. And instead of looking at nuisance flooding, lets look at the big coastal floods—what are colloquially known as the '1 in 100 year' events—heights that flood insurance, and zoning decisions are made based upon (Figure 2). With just one foot of sea level rise, and even if coastal storms do not change at all, the 1 in 100 year high water levels of the past become events that for most of the U.S. coast will be experienced within the 30-year lifetime of the typical home mortgage. In some areas, these high water levels could happen every couple of years in the future. Rather than focusing on the exact numbers in any one location, I would encourage you to note how the statistics shift strongly across the entire U.S. And once again, this is a lower end sea level rise scenario of one foot, and one that includes no assumptions about coastal storms changing in the future. For hurricanes, this assumption is probably somewhat optimistic, since the balance of evidence suggests that major hurricanes will become more frequent and intense, in large part due to the warming of the upper oceans (Weubbles et al. 2017).

But sea level rise does more the just cause more frequent flooding. It means that when a coastal storm makes landfall, additional areas are flooded that would not have flooded before. And deeper floodwaters, which allow for greater wave penetration, cause more economic damage and loss of life. If the foot of sea level rise in the Greater New York/New Jersey Metropolitan Region since 1900 had somehow not occurred, 2012's Superstorm Sandy would have flooded the residences of 80,000 fewer people (Climate Central 2013; Miller et al. 2013). One recent study found that three feet of sea level rise would inundate 2 million American's homes (Hauer et al., 2016). Globally the number would be approximately two orders of magnitude larger.

The more frequent and intense coastal flooding brought on by sea level rise will impact all Americans. Along our coasts are assets worth trillions of dollars. From our homes, to critical service providers, to critical infrastructure including interstates like I-95, rail lines including Amtrak, airports including the 'big three' in the New York Metropolitan Region, and municipal water treatment plants.

And sea level rise is also a public health and safety issue. It means less time to evacuate from low lying areas in advance of a coastal storm, and greater risk of injury and death for those vulnerable members of our communities who are unable to evacuate. Sea level rise also mobilizes hazardous pollutants from our soils.

And just as all Americans suffer when the health and safety of any American is imperiled, so too will all Americans suffer the economic costs of sea level rise. It is after all U.S. taxpayers who bear much of the bill for coastal flood damages. And coasts are economic hubs for the entire nation. Our ports, which almost by definition are vulnerable to sea level rise, serve inland interstates and rail systems, as well as regional distribution centers. If ports are damaged or operating at reduced capacity, we therefore see supply chain implications, and economic disruption.

And then there are the national security implications. From NASA's Kennedy Space Center on Florida's Space Coast and Johnson Space Center outside Houston, to Norfolk's Naval Base and shipyards, what happens along U.S. coasts can have global implications. Recent coastal storm damages made worse by climate change have led to billions in damages at an Air Force base and a Marine Corps camp.

In my remarks, I have focused on a linear story—describing how *small* amounts of sea level rise profoundly increase the frequency of coastal flooding, and pointing primarily to relatively direct impacts of coastal flooding, like local damage. However, I feel an obligation to mention that the more greenhouse gases we emit into the atmosphere, the greater the potential for tipping points or 'surprises', such as sea level rise far in excess of the 4.3 feet described above. There is growing evidence from the ice sheets that further warming of the atmosphere and ocean could unleash positive feedbacks that lock us into more rapid ice sheet losses, and resultant high end sea level rise. Because extreme sea level rise of say 6 to 8 feet this century would be so difficult to adapt to, it follows that the further we increase greenhouse gas concentrations, the greater the odds of other impact/societal ‘surprises’ like conflict, which would presumably make it that much more difficult to reduce greenhouse gas emissions at the scale needed given the magnitude of the problem.

While I have focused my brief remarks here on how human activities lead to sea level rise and its impacts, it is important to remember that earth systems are connected. On land, the impacts of warming oceans extend far inland. Warming oceans are loading the dice towards 1) heavier rain events; 2) combinations of high heat and humidity that put the health of our vulnerable populations, as well as outdoor labor productivity, at risk; and 3) all other things being equal, stronger hurricanes. And of course, these changes interact. For example, for a low lying coastal city, even a small increase in rainfall intensity, combined with a small increase in a hurricane’s storm surge could lead to a large increase in flooding if accompanied by even modest sea level rise.

While my training is in climate science, during the past decade I have had the good fortune to learn a great deal from decision-makers (including large municipalities, federal agencies, small communities, the private sector, and NGOs) as they devise solutions to climate change. These experiences have convinced met that, although we are running out of time, a window still remains open for the ultimate tipping point/surprise—specifically, rapid societal action to reduce greenhouse gas emissions and make society more resilient in the face of growing climate risks.

Thank you for inviting me to testify, and I look forward to our discussion.

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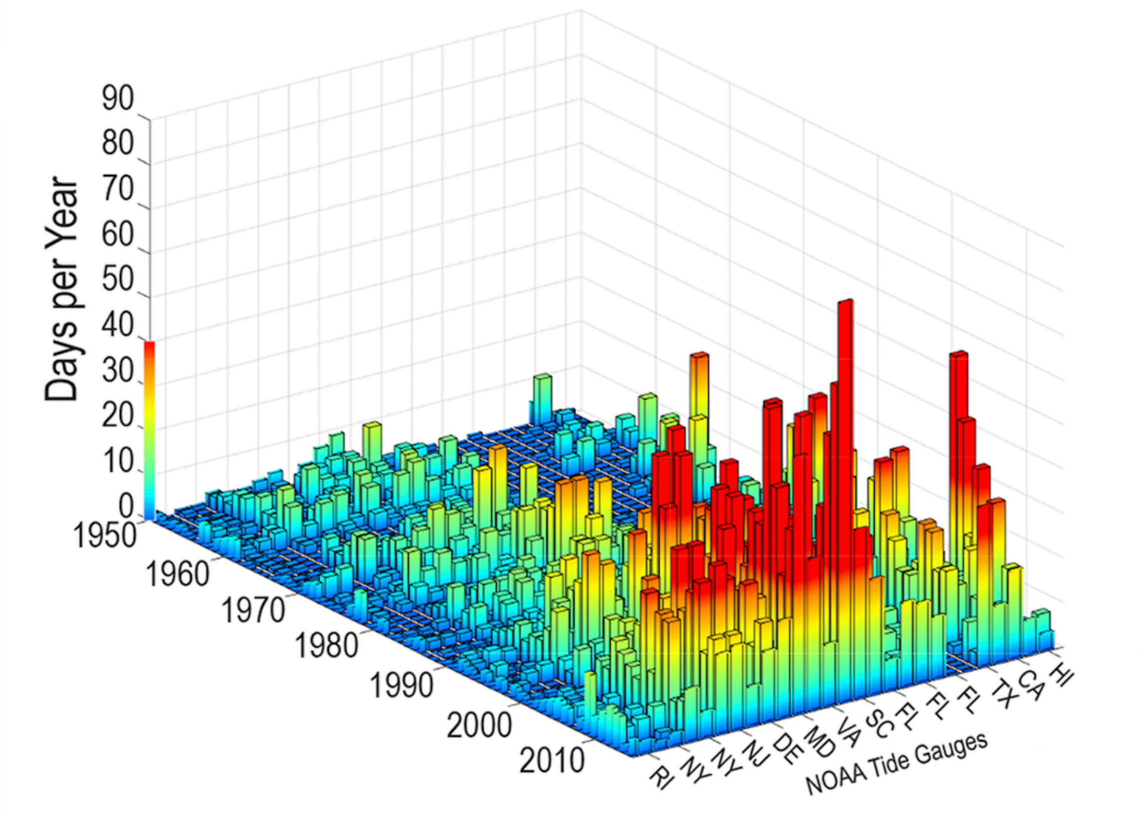

Figure 1. Tidal floods (days per year) exceeding NOAA thresholds for minor impacts at 28 NOAA tide gauges through 2015. Source: Sweet et al., 2017.

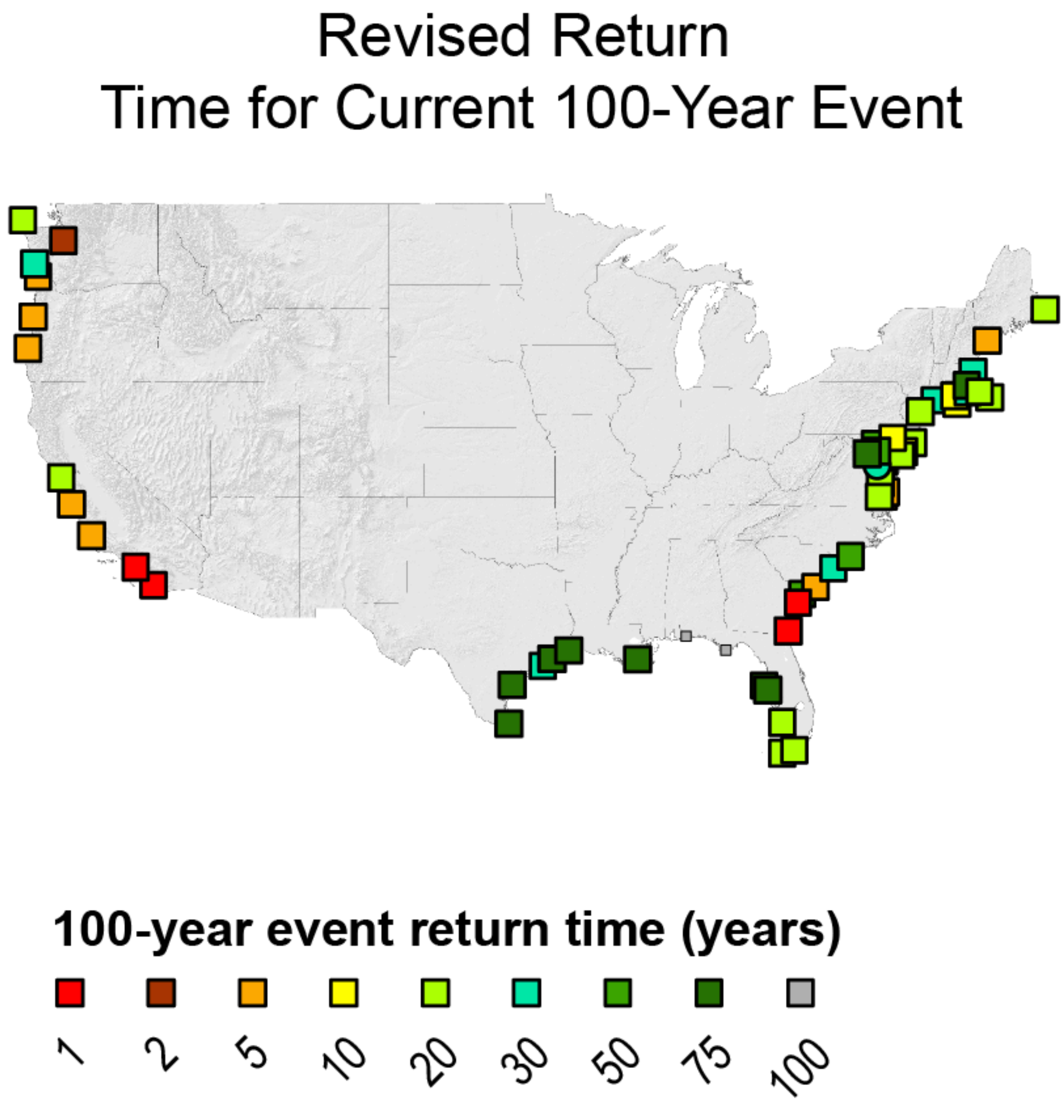

Figure 2. The amount of sea level rise (SLR) by 2050 will vary along different stretches of the U.S. coastline and under different SLR scenarios, mostly due to land subsidence or uplift. This figure shows how a 1.05-foot SLR by 2050 could cause the level of flooding that occurs during today's 100-year storm to occur more frequently by mid-century, in some regions as often as once a decade or even annually. All estimates include the effect of land subsidence. Source: Moser et al., 2014.