Written Testimony of
Dr. Paula S. Bontempi
Dean, Graduate School of Oceanography
The University of Rhode Island

Hearing on "The Science Behind Impacts of the Climate Crisis"

before the

Committee on Science, Space, and Technology
U.S. House of Representatives

Chairwoman Johnson, Ranking Member Lucas, Members of the Committee, thank you for the opportunity to discuss the state of the science regarding Earth's climate crisis. Today I will highlight the ocean's role in Earth's climate, and the major impacts that climate variability and change have on our oceans and coasts from local to global scales. I will also highlight needed investments and opportunities for the U.S. in marine research and technology.

I deliver this testimony from Narragansett, Rhode Island, the traditional land of the Narragansett Tribal Nation. I deliver this testimony to the U.S. Government centered in Washington, D.C., the homeland of the Nacotchtank, or Anacostan, people. I honor their histories and ancestors, as well as their perseverance in our communities today, as our country was built on Indigenous land. We acknowledge the Indigenous people and honor their history and stewardship of the land, sea, and resources that they hold sacred.

The Fourth National Climate Assessment Volume II on Impacts, Risks, and Adaptation (USGCRP, 2018) in the United States highlights the disproportionate impacts of climate change on Indigenous and other frontline and fenceline communities. This threat is highlighted in the IPCC special report on Oceans and Cryosphere (IPCC, 2019), and is especially relevant to our discussion today, as social and environmental justice must be central to our climate strategies and solutions.

For the last seven years, Earth's global average surface temperature has been the warmest on record (NASA, 2021). In addition to its severe terrestrial impacts, this warming is dramatically changing the physical characteristics of the ocean and altering its ecosystems in unprecedented ways (IPCC, 2019, medium to high confidence). The impacts are felt today and will continue for decades, and their duration will extend even longer if action is not taken to rapidly reduce greenhouse gas emissions. Among the most obvious direct impacts of climate change are melting ice sheets and increased ocean heat content (IPCC, 2019, medium to high confidence), which together have caused global sea level to rise by nearly 10 centimeters since 1993 (very high confidence), a rate nearly double that of last century. Ice sheets contain the greatest amount of freshwater on Earth and their loss contributes to both the freshening of the surface ocean in polar regions and to rising sea level. The 2019 IPCC report on oceans and cryosphere (IPCC, 2019) predicts global sea level to rise by one third to one meter by the end of this century, subjecting U.S. coastal zones to inundation, flooding, and erosion and threatens our homes, our infrastructure, and our well-being. There are large regional variations in relative sea level rise, with some areas of the U.S. experiencing much faster local sea level rise due to compounding drivers such as subsidence and tectonics (USGCRP, 2018). The impacts to coastal communities are likely to be dire - 13 million people in the U.S. could be forced to relocate by 2100, moving to cities and increasing pressure on infrastructure (Robinson et al, 2020). The very existence of low lying island nations and cultures is being challenged. Polar sea ice has also melted at an accelerating rate as well with estimates of 28 trillion tons of ice lost since the mid-1990s (Slater et al., 2021). The decline in extent and thickness of sea ice over the last several decades has resulted in younger Arctic sea ice that is easier to melt with less surface area to reflect sunlight (very high confidence), leading to a rise in ocean temperatures. It is essential to note is that most of these global findings would be unconfirmed without the contribution of sustained observations and analyses of Earth observing satellite data.

The ocean significantly influences Earth's weather and climate. The ocean exchanges large quantities of heat, water, and carbon dioxide with the atmosphere, absorbing approximately one-third of annual carbon dioxide emissions. The ocean moves excess heat, like a conveyor belt, from the tropics to the poles over hundreds to thousands of years. Near the poles, cold, salty, and dense water sinks from the surface and carries carbon dioxide and heat into the interior ocean where it may be stored for hundreds to thousands of years. Understanding ocean dynamics is therefore central to understanding Earth's climate crisis. The ocean conveyor belt is directly impacted by climate change and if any or all of its major currents diminish in the future, both heat and carbon dioxide could accumulate in the atmosphere at an accelerated rate. Changes in the distribution of heat within the belt occur over tens to hundreds of years. Excess heat is absorbed by the ocean thermocline, the transition zone between warmer surface and colder deep waters. Energy or heat in the thermocline fuels ocean storms. The conveyor belt is complemented by vigorous surface currents driven by atmospheric winds. Surface ocean variations may be linked to short-term climate changes, while long-term changes in the deep ocean may take longer to detect.

The portion of this global conveyor belt in the Atlantic Ocean is known as the Atlantic Meridional Overturning Circulation, or AMOC. In recent weeks, newly published research suggests that the warming atmosphere is impacting the AMOC, specifically the powerful Gulf Stream in the North Atlantic (Caesar et al., 2021). The Gulf Stream moderates temperatures in economically important human and marine habitats along the east coast of North America, Western Europe, and northwestern Africa, among others. The consequences of such a change in the Gulf Stream remain a subject of very important research, and these findings are potentially weighty. We know the system will slowdown, and we have yet to definitively measure this slowdown due to our relatively short observational records and large amplitude short-term climate signals. At the opposite end of the Earth, the Southern Ocean functions as a sink for excess heat and carbon dioxide, but observations over the last several decades indicate that the water is warming, freshening, and decreasing in oxygen (Sallée, 2018). Continued warming and declines in sea ice will lead to a decrease in carbon drawdown (Brown et al., 2019) in the Southern Hemisphere.

The 2019 IPCC report presented the extreme damage being done to the world's glaciers, permafrost, and oceans by climate change. For example, there has been a temperature rise and increase in frequency of marine heatwaves (Oliver et al., 2018; IPCC, 2019) that can devastate marine life, including mammals and seabirds. The report also contains recommendations on needed steps to mitigate and adapt to these impacts. Dramatic changes are projected to continue under every emissions scenario, but outcomes under a business as usual approach are especially grim. However, if global emissions are capped in the near term and reduced sharply by mid-century, and if aggressive approaches are taken to support resilience in marine ecosystems and coastal communities, we may yet avoid the worst impacts.

Ocean chemistry is impacted by carbon dioxide uptake from the atmosphere and, since the beginning of the Industrial Revolution, this uptake has increased the acidity of surface ocean waters by about 30%. In tropical oceans, warming and acidification have increased coral bleaching, mortality events, and reef decline worldwide over the last two decades. Even if global warming remains below two degrees Celsius, existing coral reefs will decline and the remaining shallow coral reef communities will differ in species composition and diversity from present reefs, decreasing ecosystem services. The 2019 IPCC report identifies additional changes in ecosystem distributions and migration patterns. On average, marine species have moved poleward at rates of up to 50 kilometers per decade since the 1950s, sometimes more. A recent study showed that the annual migration of several important fish stocks in Narragansett Bay in my home state of Rhode Island have been altered by warming temperatures in ways that will impact both fishers and managers (Langan, 2021). This same pattern is being repeated in stocks along both coasts of the continental U.S. and Alaska. Importantly, these changes are not simply a response to fish following a given temperature gradient but are also reflective of deeper ecosystem shifts in spawning behavior and predator-prey interactions. Geographic shifts in species distributions may soon raise jurisdictional challenges – even potential conflict – as stocks move across borders and become accessible to new fishers while others lose access. Long-term research on these ecosystems is a key to understanding how marine species distributions are changing, and how to manage commercially and recreationally important species under such quickly changing conditions.

Climate change impacts on ocean physical and chemical properties cause additional wide-ranging ecosystem responses, including frequent harmful algal blooms, altered ocean plant growth, and reduction of fish stocks, many of which are either fully exploited or overexploited already. These problems will be exacerbated by an overall decline in ocean productivity with some regions such as the tropics potentially seeing a 50% decline in available fish stocks under worst case scenarios. We have already seen a nearly 10% decline in some fish stocks in response to Earth's warming (IPCC, 2019). Coupled to the fact that over 90 percent of the world's fish stocks are either fully exploited or overexploited already, the additional stress from warming is inhibiting the ability of overexploited stocks to recover and increases the likelihood of overfishing. While aquaculture is proposed as a part of the solution to declining fish stocks, these facilities are not immune to climate change effects, and will have to be incorporated in to climate adaptation plans. These diverse climate change effects threaten foundations of marine food webs, putting whole ecosystems – and those who rely on them for food and jobs – at risk.

Physical and ecological impacts of climate change go well beyond the ocean surface. The deep sea plays a critical role in global climate regulation through the aforementioned uptake and storage of heat and carbon dioxide. However, global warming exacerbates acidification and open ocean deoxygenation, or the decline in oxygen due climate-driven changes in ocean circulation, solubility, and biological productivity. This leads to decreased biodiversity and distributions of deep-sea fauna, impacting ecosystem services. As the home environment for deep-sea species, including deep-sea fish, corals and sponges within the North Atlantic shifts, recent research projects a decrease of 28%–100% in suitable habitat for cold-water corals and a shift in suitable habitat for deep-sea fishes of 2.0°–9.9° towards higher latitudes (Morato et al, 2020).

In polar ecosystems, rapid changes in Arctic food webs pose a challenge for adaptation. The rapid loss of sea ice exposes previously ice covered regions to solar radiation, even through melt ponds, changing the timing and nature of regional ecosystem cycles. The warming also causes challenges for large marine mammals and fish stocks that have adapted to a polar environment. The general trend of poleward migration of species is especially pronounced in the Arctic with whole ocean ecosystems shifting poleward at a rate six times greater than terrestrial species (Lenoir, 2020).

Two major anthropogenic forces, climate change and whaling, have altered trophic dynamics of marine krill predators in the Southern Ocean (McMahon, 2019). Pioneering molecular isotope techniques have been used to reconstruct carbon flow and trophic dynamics of Antarctic penguins. One species is able to capitalize on dramatic environmental shifts in prey, while another species' dietary specialization has made the population vulnerable to recent declines in krill availability associated with sea ice decline. This work provides historical context to recent shifts in ecosystem dynamics in one of the fastest changing regions of the world, and provides valuable scientific support in the context of the growing Southern Ocean krill fishery.

Impacts of climate change on Earth's ocean have a cost, but provide an opportunity to invest in our future. The Fifth National Climate Assessment, under the U.S. Global Change Research Program, will analyze impacts of global change in the United States in a balanced and policy-neutral way, identify climate knowns and unknowns, and ideas for investment in to our future. Some may balk at the cost of the sustained investment needed to understand and protect our home planet and its limited resources from the pressures of anthropogenic climate change. I offer this example to reflect on those long term potential returns on our research investments. Hurricane-prone landfall areas of the U.S., including the Atlantic and Gulf Coasts, face above-average climate risks. Hurricane Katrina impacted 93,000 square miles of the Gulf Coast with a storm surge that crested at 27ft, or over eight meters, at a staggering cost of $125 Billion U.S. (NOAA, 2020). A 2014 (Cooke et al.) paper estimated that a tripling of the then current global climate research budget from $5 billion to $15 billion U.S. per year is needed for at least 30 years to monitor Earth's climate, a cost that includes the infrastructure plus advances in climate monitoring, process studies, and advanced climate modeling. An updated analysis in 2018 (Weatherhead et al, 2018) pointed to the additional $10B per year global cost of such a system in net present value is ~$200–$250 billion U.S. When compared to a $10–$20 trillion U.S. value of information of such a system, the return on investment varies from 40 - 100 to 1, or roughly $50 return for every $1 invested. Even if total uncertainties in the economic analysis were off by a factor of five above or below such estimates, the return on investment would still be worthy of proceeding. Not acting would be costly; an advanced climate observing system takes years to develop and implement. On a global scale, the IPCC report estimates that climate-induced declines in ocean health will cost the global economy $428 billion per year by 2050 and $1.98 trillion per year by 2100. The U.S. needs to invest in research infrastructure, from ground networks to field and laboratory studies, to provide data that enable us to manage future scenarios. When coupled with proactive planning and steps to adapt to more frequent, widespread, and severe climate change driven events, we can conserve economically important coastal ecosystems and decrease direct losses and cascading impacts. While one could view such a scenario with a pessimistic lens, these situations have historically generated opportunity for innovation and U.S. leadership in engineering, science, and technology, while also protecting our homeland.

Substantial and sustained reductions in global greenhouse gas emissions will significantly reduce projected risks to ocean ecosystems and communities that rely on them. We need investments in research *and* management. Here, I would like to recognize and applaud Congressman Grijalva for his introduction earlier this year of the Ocean Based Climate Solutions Act, which includes many needed steps for adapting to and mitigating the climate change impacts. A separate report released by the High Level Ocean Panel For A Sustainable Ocean Economy (Hoegh-Guldberg et al., 2019), identifies opportunities for ocean management as both a source of adaptation and mitigation. The Panel calls for increased investments in: 1) ocean-based sources of renewable energy; 2) that we work toward "net zero" emissions in ocean transportation; 3) restoration and protection of coastal and marine habitats to both increase their resilience and carbon storage; 4) expand sustainable approaches to aquaculture and fisheries as part of a dietary shift away from greenhouse gas emissions-heavy protein sources; and 5) increase research into carbon storage in the sea bed. This would result in a sustainable blue economy, 12 million new jobs by 2030, and billions of dollars in energy and sustainable seafood benefits by 2050.

Strategic investments at federal agencies must bridge ocean exploration to economics, facilitate diverse institutional collaborations, and engage the U.S. population and allow them to play a role in climate solutions. We must better connect science with states, local, and tribal governments, and a range of community stakeholders. We need to better define the boundaries to commercial partnerships for long-term scientific analyses, modeling, and technology - balancing fiduciary responsibilities with government support of industries to provide a short term deliverable for profit. This must be inherently federal responsibilities and investments – and each domestic or international partner must contribute resources toward a common goal. The U.S. government must allow federal agencies to pursue their missions and new ideas through investments in America's future without unfunded mandates or mandatory pathways to solutions grounded in the best science available, and provide funds for new and innovative investments for these agencies to connect basic research with applied research that supports management, decision and policy makers.

Recent federal investments connecting research to management are groundbreaking, including the U.S. and National Science Foundation's contribution to an international global profiling robotic network measuring key ocean properties essential for understanding ocean carbon cycles and ecosystem health. Coupling these observations with new Earth viewing satellite data, such as NASA's Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission and, potentially, an ocean-profiling satellite lidar system, will provide researchers and managers unprecedented local and global scale observations of our living ocean and marine resources. I applaud these investments, but they are an appetizer.

Supporting a more sophisticated understanding of the ocean's role in the climate system, and the impact of climate change on ecosystems and coastal communities, will require the U.S. to develop a comprehensive observing strategy and a plan for continuity of Earth science observations and data records. Without this coordinated information, scientists and managers may not know the impacts of climate variability and change until it is too late to undo the damage or effectively adapt. The Graduate School of Oceanography at the University of Rhode Island hosts the longest running time series of on Earth for ocean plankton, tiny animals that provide food for fisheries (Time Series, 2021). The National Science Foundation recently extended this ocean sampling from the Narragansett Bay estuary all the way to the continental shelf edge, crossing one of the most productive and economically significant fisheries in the US. This commitment and investment in sustained observations puts the state of Rhode Island, and all scientific and management partners, in a position to better understand how climate influences local and commercially important marine resources.

Modeling is particularly important for climate change research and impact, adaptation, and mitigation studies. Modeling elements of interdisciplinary research programs must be considered from early planning stages forward. Success stories, such as NASA's Carbon Monitoring System, connect scientists and managers to test real solutions to climate change. Modeling barriers include scientific knowledge and the provision of open source, affordable, robust, and meaningful high-resolution products for user and stakeholder communities. Here, an avenue for advancement may be increased partnering with private entities and enterprise-level cloud-based computing, while simultaneously recognizing issues of repeatability, sustainability, public access, and security that are associated with all climate data records.

We must facilitate and capitalize on investments in science, technology, engineering, computing, architecture, and education. These investments are strategic, tactical, and sustain our blue economy.

All of my comments point to a pivotal need: to understand climate change and its impacts on the Earth, we need sustained investments in global observing networks and high performance computing, integrated with science communication, public engagement, and education programs. We need a well-trained, interdisciplinary, climate-literate workforce, including natural and social science as well as policy experts, engineers, and educators. We must engage our next generation of scientists, particularly marginalized and low-wealth groups disproportionately affected by climate change, and facilitate opportunities, education, and innovations to diversify science and engineering if we are to effectively tackle all of the consequences of the climate crisis. All of these investments directly impact our standing in the world, our ability to lead 21st century global economy, and our role in advancing Earth system climate science that yields innovative solutions connecting exploration, discovery, and research with social science, management, and policy.

As we look ahead, we must allow our science questions to evolve as our needs change, we must begin to meaningfully invest in adaptive science to support adaptive and sustainable management of marine resources, and we must never forget that the climate change crisis is no longer a threat of the future but a reality already impacting us today.

Thank you for the opportunity to discuss these Earth and ocean system issues and to present ideas for future research and adaptive science. I would be pleased to respond to questions.

References:

Brown, M.S., Munro, D.R., Feehan, C.J. et al. Enhanced oceanic CO2 uptake along the rapidly changing West Antarctic Peninsula. Nat. Clim. Chang. 9, 678–683 (2019). https://doi.org/10.1038/s41558-019-0552-3

Caesar, L., McCarthy, G.D., Thornalley, D.J.R. et al. Current Atlantic Meridional Overturning Circulation weakest in last millennium. Nat. Geosci. 14, 118–120 (2021). https://doi.org/10.1038/s41561-021-00699-z

Cooke, R., Wielicki, B. A., Young, D. F., & Mlynczak, M. G. (2014). Value of information for climate observing systems. Journal of Environment, Systems, and Decisions, 34, 98–109. https://doi.org/10.1007/s10669-013-9451-8

Hoegh-Guldberg. O., et al. 2019. ''The Ocean as a Solution to Climate Change: Five Opportunities for Action.'' Report. Washington, DC: World Resources Institute. Available online at http://www.oceanpanel.org/climate

IPCC, 2019: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

Langan, J.A., Puggioni, G., Oviatt, C.A., Henderson, M.E., and J. S. Collie, Marine Ecology Progress Series, Climate alters the migration phenology of coastal marine species, Vol. 660: 1–18, 2021. https://doi.org/10.3354/meps13612

Lenoir, J., Bertrand, R., Comte, L. et al. Species better track climate warming in the oceans than on land. Nat Ecol Evol 4, 1044–1059 (2020). https://doi.org/10.1038/s41559-020-1198-2

McMahon, K.W., Michelson, C.I., Hart, T., McCarthy, M.D., Patterson, W.P. , and M. J. Polito. Divergent trophic responses of sympatric penguin species to historic anthropogenic exploitation and recent climate change, PNAS 2019 116 (51) 25721-25727; https://doi.org/10.1073/pnas.1913093116

Morato T, González-Irusta J-M, Dominguez-Carrió C, et al. Climate-induced changes in the suitable habitat of cold-water corals and commercially important deep-sea fishes in the North Atlantic. Glob Change Biol. 2020;26:2181–2202. https ://doi.org/10.1111/ gcb.14996

The Narragansett Bay Long-Term Plankton Time Series, 2021. https://web.uri.edu/gso/research/plankton/

NASA, 2020 Tied for Warmest Year on Record, NASA Analysis Shows, 2021: (https://www.nasa.gov/press-release/2020-tied-for-warmest-year-on-record-nasa-analysis-shows)

NASA Sea Level Portal, 2020: (https://sealevel.nasa.gov)

National Oceanic and Atmospheric Administration. "Costliest U.S. Tropical Cyclones Tables Updated," Page 2. Accessed Jan. 28, 2020.

Oliver, E.C.J., Donat, M.G., Burrows, M.T. et al. Longer and more frequent marine heatwaves over the past century. Nat Commun 9, 1324 (2018). https://doi.org/10.1038/s41467-018-03732-9

Robinson C., B. Dilkina, and J. Moreno-Cruz. Modeling migration patterns in the USA under sea level rise. PLOS ONE, 2020; 15 (1): e0227436 DOI: 10.1371/journal.pone.0227436

Sallée, J.-B. 2018. Southern Ocean warming. Oceanography 31(2):52–62, https://doi.org/10.5670/oceanog.2018.215.

Slater, T., Lawrence, I. R., Otosaka, I. N., Shepherd, A., Gourmelen, N., Jakob, L., Tepes, P., Gilbert, L., and Nienow, P.: Review article: Earth's ice imbalance, The Cryosphere, 15, 233–246, https://doi.org/10.5194/tc-15-233-2021, 2021

USGCRP, 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018.
Weatherhead E. C., Wielicki B. A. Ramaswamy V., Abbott M., Ackerman T. P., Atlas R., Brasseur G., Bruhwiler L., Busalacchi A. J., Butler J. H., Clack C. T.M., Cooke R., Cucurull L., Davis S. M., English J. M., Fahey D. W., Fine S. S., Lazo J.K., Liang S., Loeb N.G., Rignot E., Soden B., Stanitski D., Stephens G., Tapley B. D., Thompson A. M., Trenberth K. E., & Wuebbles D. (2018), Designing the Climate Observing System of the Future, Earth's Future, 6, 80–102,https://doi.org/10.1002/2017EF000627.