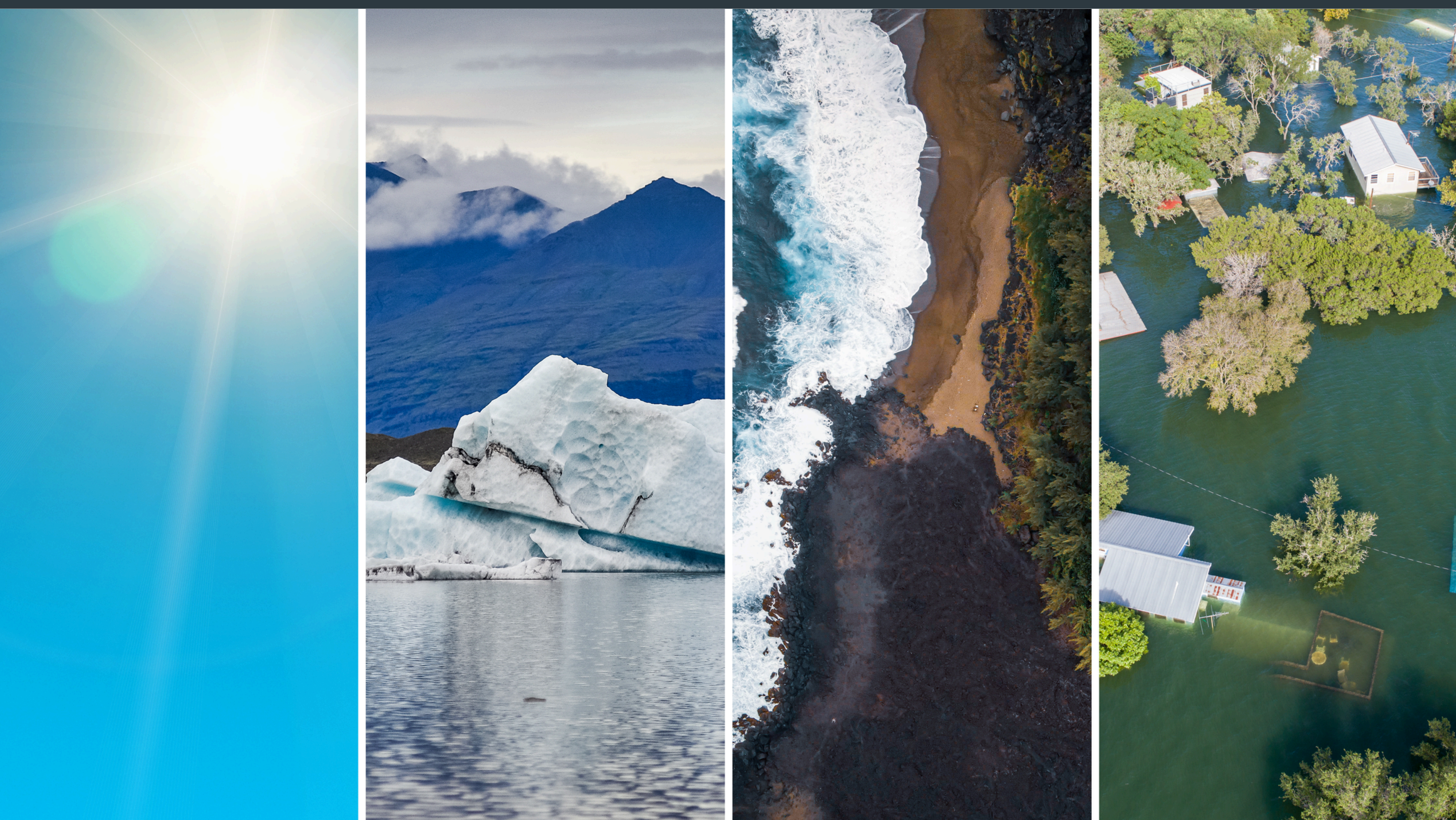
CLIMATE JUDICIARY PROJECT™

CLIMATE SCIENCE AND LAW FOR JUDGES

Sea Level Rise



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Sea-Level Rise

Anna Ruth Halberstadt, Ph.D., and Mark Nevitt, J.D., LL.M.*

The warming climate is already affecting people and nature around the globe, including through changes in sea level. This module draws from scientific consensus reports to discuss sea-level rise, including the causes and dynamics of sea-level rise, as well as the differences in how sea-level rise is felt by the human inhabitants of various coastal regions and the issues that may arise as humans react to sea-level changes.

Part 1 of the module first introduces the concepts of sea level and sea-level rise, examining why and how quickly sea levels are rising, how they are measured, and how we can use clues from the distant past to predict future sea levels. It also considers how sea-level rise impacts daily life, including through regular flooding or bigger reaches for storm surges.

Part II explores how sea-level rise manifests in the courtroom, exploring how adaptation efforts are interacting with constitutional, statutory, and common-law legal doctrines.

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I. Science of Sea Level

Sea-level rise challenges coastal communities in a myriad of complex and intersecting ways, including through environmental concerns, property rights, infrastructure, and public well-being. The cascading legal implications of sea-level rise are correspondingly complex. This section aims to provide judges with the necessary scientific foundation to make informed decisions within a legal landscape that is rapidly evolving in accordance with sea-level rise.

We first explore the factors and mechanisms that influence global and local sea levels (sections A, B). A scientific understanding of sea-level rise has practical implications in the judicial context; understanding why local sea-level rise can vary from global trends helps to clarify potential disputes over property damage, land use, and public safety. Similarly, knowing the mechanisms that impact local sea levels, such as ocean dynamics and vertical land movement, along with the methods of measuring sea level, provides context for evaluating the validity of scientific evidence presented in court.

Next, we discuss the current rate and acceleration of sea-level rise, as well as future projections (sections C-G). This information gives background to the ongoing and anticipated impacts of sea-level rise, highlighting areas of the law that may be underdeveloped or ill-prepared for the significant changes ahead. Finally, we delve into the consequences for coastal communities and the human dimensions of local sea-level rise (sections H-J).

We then focus on litigation-relevant scientific questions, such as how sea-level rise affects coastlines, the implications for coastal communities, and the extent to which these impacts can be attributed to human activities. Understanding these connections will enable judges to better navigate the legal complexities arising from sea-level rise.

A. What Is "Sea Level" and How and Why Does It Change?

The volume of water in the world's oceans is increasing. This change does not distribute uniformly across the globe. Although turning on the faucet in a bathtub raises the water level by the same amount on all sides of the tub, when applied to the oceans, this "bathtub" concept is complicated by a host of global and regional mechanisms that produce different local sea levels along the world's coastlines.[1] It is thus crucial to distinguish change in the global average sea level from change in sea level at a specific location. Scientists call this latter topic relative sea level, or local sea level, defined as the difference in elevation with respect to a fixed local land level. It is the change in the local, not the global, sea level, that impacts people and infrastructure at the coastlines. Local sea level in specific places, such as the U.S. East Coast, can differ by 30% or more from the global mean.[2]

[1] Robert E. Kopp et al., *Geographic Variability of Sea-Level Change*, 1 CURRENT CLIMATE CHANGE REP., 192 (2015).
[2] William V. Sweet et al., *Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines*, 111 NOAA TECHNICAL REP. NOS 01, February 2022 at 1.

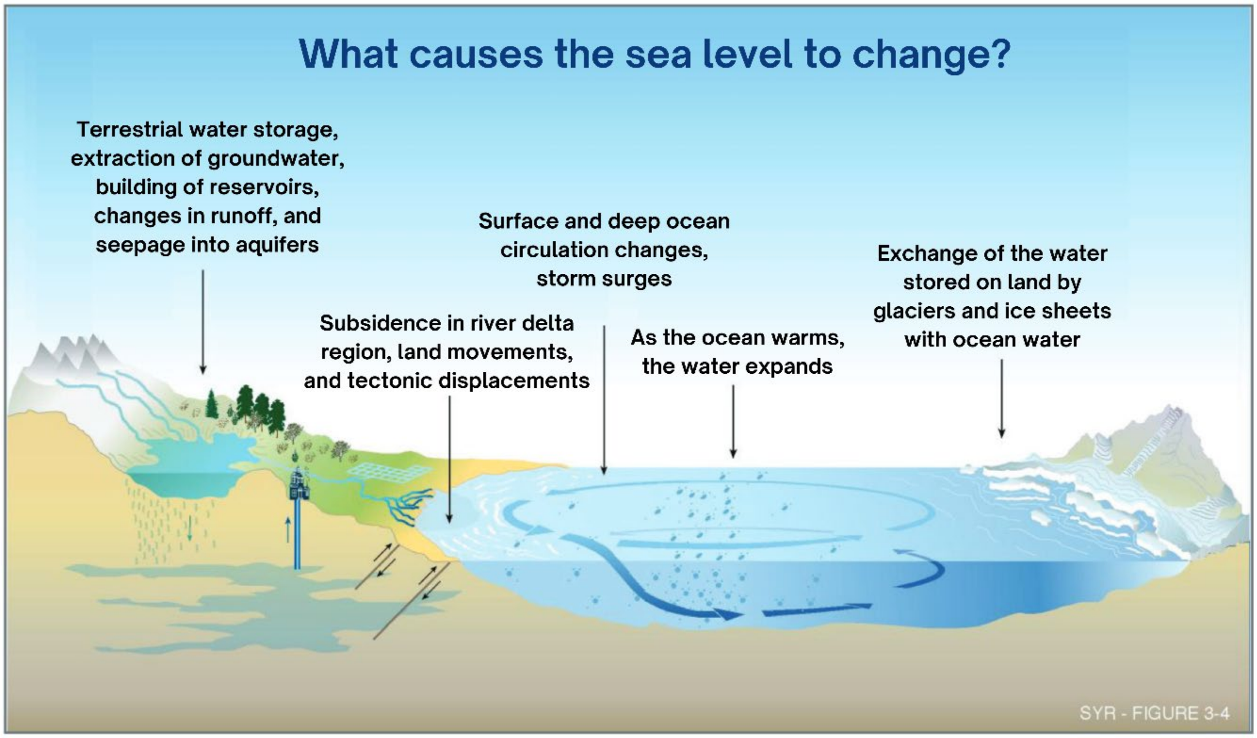

Figure 1. Global and local processes that affect sea-level change.[3]

Global sea-level rise (i.e., an increase in the volume of water in ocean basins) occurs on decadal to century timescales in two ways: first, by adding water to the oceans, and second through the expansion of ocean water due to warming temperatures (see Figure 1). Water stored on land can be added to the oceans through the melting of glaciers and ice sheets, or if groundwater and surface water storage decreases. In addition, water density decreases as the ocean warms or freshens, which results in an expansion of the volume of water in the oceans. Thus, global sea-level rise occurs as ocean temperatures warm, even without any additional inputs of water from melting land ice or other sources (see Figure 1).

B. What Mechanisms Impact Local Sea-Level Rise?

A variety of regional to local mechanisms affect how much of global sea-level rise is "felt" along any specific coastline as local sea-level rise. These mechanisms can be categorized as (1) ocean dynamic effects (involving changes in ocean circulation and atmospheric circulation), (2) static equilibrium effects (the gravitational redistribution of seawater), and (3) vertical land movement (changing the height of the land itself, relative to the ocean).

First, changes in the circulation of the ocean and atmosphere can alter sea surface height by redistributing heat and salinity (leading to density differences) or by ocean or wind currents pushing water around. For example, a northward shift of the Gulf Stream—the current that transports waters

[3] Figure adapted from Adam Parris et al., *Global Sea Level Rise Scenarios for the US National Climate Assessment*, NOAA TECHNICAL MEMO OAR CPO-1 (2012).

along the eastern U.S. to the northern North Atlantic—contributed to faster local sea-level rise along the northeastern U.S. coast during the 20th century.[4]

Second, when land ice melts, or groundwater or lake level changes, the Earth's gravity also changes. This impacts how ocean water is distributed around coastlines. The sea-level change in response to mass loss at a specific location is called a "static-equilibrium fingerprint." A melting ice sheet leads to a relative fall in local sea level near the ice sheet and an increase in local sea level farther away from the ice sheet because less ice means less mass, and thus less gravitational attraction of the ocean toward the ice sheet. Perhaps counterintuitively, this means that U.S. coastlines experience greater sea-level rise than the global average from losses to the Antarctic Ice Sheet. If the West Antarctic Ice Sheet contributed enough melted ice to raise global sea level by 1 foot, the local sea level along both eastern and western U.S. coasts would experience about 1.3 ft. increase due to this effect. In contrast, with 1 foot of global sea-level rise from the Greenland Ice Sheet, sea levels along the U.S. coastline would still rise, but by less than the global average (only about 0.5 to 0.9 ft.). Figure 2 shows the spatial patterns arising from gravitational changes associated with mass loss from both Greenland and Antarctic Ice Sheets.

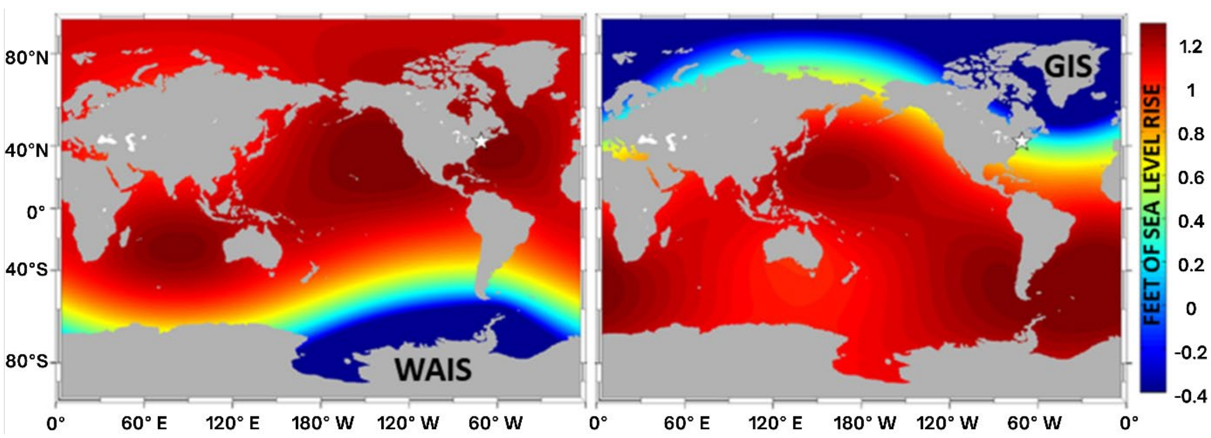

Figure 2. Colors show sea-level rise that would occur if each ice sheet (Greenland Ice Sheet "GIS," left-hand panel; West Antarctic Ice Sheet "WAIS," right-hand panel) were to lose enough ice to cause a 1-foot rise in global sea-level rise. The respective ice sheet locations are labeled in each panel. Locations with values greater than 1 (orange-red) experience more sea-level rise than the global average, while locations with values less than 1 (blue-yellow) experience less. Dark blue colors (proximal to the ice sheet losing mass) indicate a sea-level fall despite a globally averaged rise. The pattern can be scaled up or down for more or less ice loss. Boston (indicated by a star) is clearly more vulnerable to sea-level rise caused by an equivalent loss of ice on West Antarctica than on Greenland.[5]

Finally, in addition to changes in the volume and distribution of ocean water, the ongoing vertical motion of the land itself also influences the local sea level that is experienced at a coastline. The Earth's subsurface is still slowly moving in response to the removal of an ice sheet that covered Canada and

[4] *See* Jianjun Yin & Paul B. Goddard, *Oceanic Control of Sea Level Rise Patterns Along the East Coast of the United States*, 40 GEOPHYSICAL RSCH. LETTERS 5514 (2013), *and* Asbury H. Sallenger Jr. et al., *Hotspot of Accelerated Sea-Level Rise on the Atlantic Coast of North America*, 2 NATURE CLIMATE CHANGE 884 (2012).

[5] Carling Hay et al., *The Sea-Level Fingerprints of Ice-Sheet Collapse During Interglacial Periods*, 87 QUATERNARY SCI. REV. 60 (2014).

the northern part of the contiguous United States during the last ice age thousands of years ago. Like a memory-foam mattress, when an ice sheet is removed from the Earth's crust, the surface of the Earth slowly rebounds. In response to the unloading of this ancient ice sheet, parts of the land rose and are still rising. This rise in land is called "post-glacial rebound" or "glacial isostatic adjustment." In places that were directly covered by ice during the last ice age, this rebounding land surface leads to local sea-level fall (specifically, along Alaskan coastlines).[6] During the last ice age, a bulge formed in the Earth's crust at the edge of the ice sheet, as pressure pushed the land outward and upward like cookie dough under a rolling pin, including along what is today the eastern U.S. coastline; this bulge is now falling back, causing local sea levels there to rise.

In addition to post-glacial rebound, a variety of other local factors can lead to land height change (see Figure 1). These include, for example, sediment compaction caused by natural processes or by local extraction of groundwater and fossil fuels[7] and tectonic processes such as earthquakes and more gradual changes known as seismic creep. The rate of post-glacial rebound and other natural processes change very gradually, over perhaps hundreds to thousands of years. By contrast, human activities can induce large-scale variation in land subsidence rates on decadal timescales. For example, extraction of fossil fuels along the Gulf Coast of the United States has been linked with sinking land surface,[8] which can significantly influence local sea level. Other local processes, such as changes in the winds and tides, can further influence local sea levels. In a special report associated with the Fourth National Climate Assessment, scientists have identified the spatial distribution of these processes along the U.S. coastline.[9]

C. How Do Scientists Measure Sea Level?

In recent decades, the use of satellite sensors and rapid improvement of remote sensing have enabled precise and nearly global measurements of sea surface height. This **"satellite altimetry"** has been used to reconstruct global sea-level time series (see section D below). These satellite-based reconstructions are crucial for monitoring global and local sea-level changes during the last few decades.

Many climatic processes vary on time scales of tens to hundreds of years, called "natural variability" by climate scientists. These include, for example, the El Niño Southern Oscillation (see the module, What Is Causing Climate Change?). To untangle natural variability from human-caused change, local sea-level reconstructions must span beyond these timescales and shed light on slowly unfolding processes, such as ice-mass loss. Therefore, longer records of earlier global sea levels are required to provide context for recent sea-level changes. Such reconstructions must rely on earlier data, such as

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[6] *See* Yan Hu & Jeffrey T. Freymueller, *Geodetic Observations of Time-Variable Glacial Isostatic Adjustment in Southeast Alaska and Its Implications for Earth Rheology*, 124 J. GEOPHYSICAL RSCH. 9870 (2019).

[7] *See, e.g.*, Julia Pfeffer et al., *Decoding the Origins of Vertical Land Motions Observed Today at Coasts*, 210 GEOPHYSICAL J. INT'L 148 (2017).

[8] *See* Muhammad Younas et al., *Geospatial Analytics of Driving Mechanism of Land Subsidence in Gulf Coast of Texas, United States*, 902 SCI. TOTAL ENV'T 166102 (2023); Robert A. Morton et al., *Evidence of Regional Subsidence and Associated Interior Wetland Loss Induced by Hydrocarbon Production, Gulf Coast Region, USA*, 50 INT'L J. GEOSCIENCES 261 (2006), *and* Xin Zhou et al., *Rates of Natural Subsidence Along the Texas Coast Derived From GPS and Tide Gauge Measurements (1904-2020)*, 147 J. SURVEYING ENGINEERING 4 (2021).

[9] Donald J. Wuebbles et al., *Climate Science Special Report: Fourth National Climate Assessment*, 1 U.S. GLOBAL CHANGE RSCH. PROGRAM 470 (2017).

tide gauge measurements. Yet, these measurements present their own challenges in that they are less widely distributed and record a mixed signal of land height change along with relative sea-level change.

To understand sea levels before the beginning of the instrumental period, **geologic research methods** are needed. Sea-level data can be derived from a variety of geological archives of environmental change, including salt marsh sediment cores, coastal wave zones where past wave depth can be determined from the size of sand particles, and ancient coral reefs which reconstruct minimum sea levels because corals cannot grow below a certain water depth. To convert to global sea level, however, these indicators of local sea level still need to be corrected for vertical land movement, which becomes increasingly difficult to determine further back in time.

For much older geologic time periods, global sea level can be inferred from the ratio of different varieties of oxygen atoms, called isotopes, in the shells of organisms buried in the seafloor. The ratio of oxygen isotopes is different between ice (which contains a higher proportion of light oxygen atoms) and ocean water (which contains a higher proportion of heavy oxygen atoms). So, when land ice melts into the ocean, the relative abundance of light oxygen atoms in the water increases. This "isotopic signature" is then passed on to shell-forming organisms that live in ocean waters. When these organisms die, their shells become buried in the sediment. Measuring the ratio of oxygen isotopes in these ancient shells can therefore be related to the quantity of Earth's water stored in the oceans versus on land as ice, and this ratio can thus be interpreted as a proxy for global sea level in the distant past. Ancient sea levels provide crucial glimpses of warmer worlds during the last time(s) that carbon dioxide (CO_2) concentrations rose to modern levels (see section F).

D. How Fast Has Sea Level Risen?

Tide gauge measurements indicate that about 7 inches of total global sea-level rise has occurred since 1900.[10] Between 1993 and 2017, satellite measurements show that sea-level rise was occurring at a rate of approximately 0.13 inches per year[11]; this is nearly double the average rate of sea-level rise since 1900, and is the highest rate of sea-level rise measured in the last few millennia from both tide gauge reconstructions and geologic evidence.[12] The rate of sea-level rise is not only unprecedented within the last few millennia, it is also increasing. Sea-level rise has been accelerating consistently since about 1970.[13]

Although global sea-level rise provides an important metric for assessing global climate processes and trends, it is the local and not the global sea level that directly impacts coastlines, and local sea-level rise can differ dramatically. Local sea-level rise rates can exceed two times the global rate of sea-level change, especially along the southeastern coast of the United States.[14]

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[10] Sönke Dangendorf et al., *Persistent Acceleration in Global Sea-Level Rise Since the 1960s*, 9 NATURE CLIMATE CHANGE 705 (2019).
[11] Michaël Ablain et al., *Uncertainty in Satellite Estimates of Global Mean Sea-Level Changes, Trend and Acceleration*, 11 EARTH SYS. SCI. DATA 1189 (2019).
[12] Robert E. Kopp et al., *Temperature-Driven Global Sea-Level Variability in the Common Era*, 113 PROC. NAT'L ACAD. SCI. U.S.A. E1434 (2016).
[13] *See* Dangendorf et al., *supra* note 10, *and* Sweet et al., *supra* note 2.
[14] *See* Sweet et al., *supra* note 2. *See also* Figure 3 and the above section.

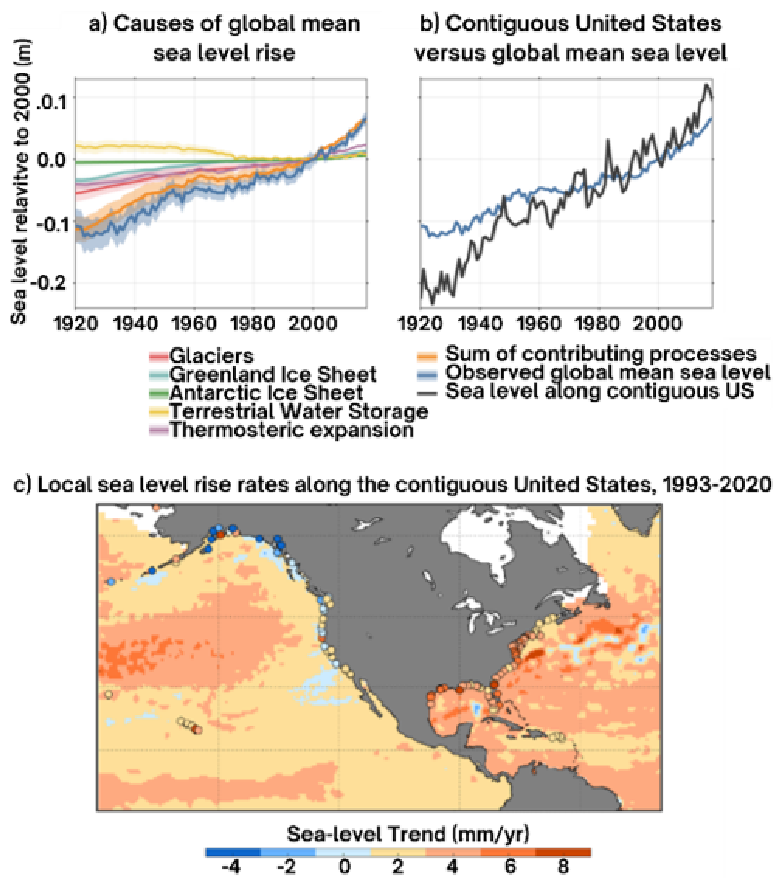

Figure 3. (a) Observed global sea-level change from tide gauges (blue line), along with the main sources of increased global sea-level rise ("thermosteric expansion" refers to the expansion of ocean water due to warming temperature). (b) Global sea-level change (blue line) as compared to the average local sea-level change measured by tide gauges around the contiguous United States (black line). (c) Local sea-level rates of rise (mm/year) from satellite altimetry, averaged over the 1993-2020 time period. Tide gauges over the same time period are also shown as circles.[15]

E. What Is Driving the Current High Rate and Acceleration of Global Sea-Level Rise?

The modern rate of sea-level rise is the highest in the last few millennia,[16] and continuing to accelerate.[17] Attribution of the multiple components that contribute to global sea-level rise is complicated by the fact that these contributions occur over different time scales, and measurements of some contributions are more complete than others.

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[15] Figures are from Sweet et al., *supra* note 2, and Thomas Frederikse et al., *The Causes of Sea-Level Rise Since 1900*, 584 NATURE 393 (2020).

[16] Kopp et al., *supra* note 12.

[17] *See* Dangendorf et al., *supra* note 10, *and* Sweet et al., *supra* note 2.

Thermal expansion of the ocean was the primary contributor to global rise over the 20th century, as the ocean has absorbed over 90% of excess heat.[18] Thermal expansion of the ocean can be estimated using widespread measurements of ocean temperature and salinity at different depths.

Although the oceans continue to warm,[19] the loss of land-based ice is now a greater contributor to global sea-level rise than thermal expansion.[20] This reflects a significant change in the Earth system, because land ice, which holds massive amounts of frozen water, has far greater potential to raise the global sea level than thermal expansion, especially on a scale of a century or longer.

Estimates of mass loss from glaciers and ice sheets are based on aerial imagery, satellite measurements of height changes, and satellite "gravimetry" or measurement of mass changes, combined with physical and statistical modeling techniques.[21] Melting mountain glaciers have contributed to global sea-level rise since 1900 and have currently added almost as much volume as the Greenland Ice Sheet has.[22] But their total potential contribution to global sea level is less than about 1.3 ft.,[23] while that of the Greenland Ice Sheet is, at 24.3 ft., nearly 20 times more.[24] Although the Antarctic Ice Sheet is currently contributing less to global sea level compared to either mountain glaciers or Greenland, it carries even greater threat to global sea-level rise. This is because its vulnerable "marine-based" ice, if melted, would translate to about 190 ft. of sea level.[25] The rate of ice loss from Antarctica tripled between 2012 and 2017 relative to previous decades.[26] Once triggered, collapse of the marine-based portions of the ice sheet could proceed rapidly and irreversibly.

Changes in land water (for example, snow, lakes, groundwater, etc.) also contribute to global sea-level rise. Over the last decade or so, the rate of groundwater depletion increased, adding to global ocean volume. But this effect was outweighed by dam construction that increased lake storage. Thus, the total contribution to global sea level from land water changes was actually negative or a net fall rather than rise.[27] The amount of global sea-level fall due to land water changes is small, however, compared to the positive contributions of thermal expansion and ice loss from glaciers and ice sheets.

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[18] *See* Intergovernmental Panel on Climate Change, *Special Report on the Ocean and Cryosphere in a Changing Climate* (2019), https://doi.org/10.1017/9781009157964.001 [hereinafter IPCC SROCC 2019]; Wuebbles et al., *supra* note 9; Frederikse et al., *supra* note 15; *and* WRCP Global Sea-Level Budget Group, *Global Sea-Level Budget 1993-Present*, 10 EARTH SYS. SCI. DATA 1551 (2018).

[19] Lijing Cheng et al., *Upper Ocean Temperatures Hit Record High in 2020*, 38 ADVANCES IN ATMOSPHERIC SCI. 523 (2021).

[20] IPCC SROCC 2019, *supra* note 18, *and* Wuebbles et al., *supra* note 9.

[21] *For example:* Jonathan L. Bamber et al., *The Land Ice Contribution to Sea Level During the Satellite Era*, 13 ENV'T RSCH. LETTERS 063008 (2018); The IMBIE Team, *Mass Balance of the Antarctic Ice Sheet From 1992 to 2017*, 558 NATURE 219 (2018); *and* IPCC SROCC 2019, *supra* note 18.

[22] IPCC SROCC 2019, *supra* note 18.

[23] Ben Marzeion et al., *Past and Future Sea-Level Change From the Surface Mass Balance of Glaciers*, 6 THE CYROSPHERE 1295 (2012).

[24] Mathieu Morlighem et al., *Deeply Incised Submarine Glacial Valleys Beneath the Greenland Ice Sheet*, 7 NATURE GEOSCIENCE 418 (2014).

[25] Peter Fretwell et al., *Bedmap2: Improved Ice Bed, Surface and Thickness Datasets for Antarctica*, 7 THE CYROSPHERE 375 (2013).

[26] IMBIE Team, *supra* note 21.

[27] Yoshihide Wada et al., *Recent Changes in Land Water Storage and Its Contribution to Sea Level Variations*, 38 SURV. GEOPHYSICS 131 (2017), *and* WRCP Global Sea-Level Budget Group, *supra* note 18.

Finally, climate variability through changing rainfall patterns on annual or shorter timescales can cause temporary global sea-level fluctuations,[28] but these are generally disregarded because they are small compared to the longer-term trends and they are difficult to predict.

F. What Can We Learn From the Distant Geologic Past?

Ice sheets respond slowly to global warming. As such, today's ice sheets have not yet fully responded to the magnitude of modern warming caused by human activity. Scientists can estimate the amount of "committed sea-level rise" that is already locked in based on the warming from historical greenhouse gas (GHG) emissions, but that has not yet been experienced.[29] Analyzing sea-level change during warm periods on longer timescales from the distant past may help build scientists' understanding of how the ice sheet will lose mass in the future and contribute to global sea-level rise. Thus, the deep past offers an analogue for modern and future climate.

Warm Periods in the Distant Past

Temperatures during the last interglacial period (the period between ice ages, about 125,000 years ago) were similar to modern temperatures. Global mean temperatures then were about 1 to 2 degrees Fahrenheit (°F) warmer than those in pre-industrial times,[30] while the global temperature in 2022 was comparable at roughly 1.6 °F warmer than pre-industrial times.[31] Sea surface temperatures were indistinguishable from temperatures today.[32] Despite the similarities in temperature, global sea level was somewhere between 8 to 30 ft. higher than it is today,[33] suggesting that the long-term response of the Greenland and Antarctic Ice Sheets to modern air and ocean temperatures has not yet been fully realized.

Further back in time, during the warm period about 3 million years ago, global mean temperatures were even higher,[34] and so was global sea level. An isotope-based reconstruction of global sea level reported a central estimate for this period of about 65 ft. above present,[35] and other more direct sea-level records support this (a paleo shoreline places an upper limit of 82 ft. above present[36]; whereas fossil coral reefs indicate 77 ft. above present.[37]

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[28] Anny Cazenave et al., *Estimating ENSO Influence on the Global Mean Sea Level, 1993-2010*, 35 MARINE GEODESY 82 (2012); Benjamin D. Hamlington et al., *Understanding of Contemporary Regional Sea-Level Change and the Implications for the Future*, 58 REV. GEOPHYSICS 3/1 (2020); *and* R. Steven Nerem et al., *Climate-Change-Driven Accelerated Sea-Level Rise Detected in the Altimeter Era*, 115 PROC. NAT'L ACAD. SCI. U.S.A. 2022 (2018).
[29] Anders Levermann et al., *The Multimillennial Sea-Level Commitment of Global Warming*, 110 PROC. NAT'L ACAD. SCI. U.S.A. 13745 (2013).
[30] Emilie Capron et al., *Temporal and Spatial Structure of Multi-Millenial Temperature Changes at High Latitudes During the Last Interglacial*, 103 QUATERNARY SCI. REV. 116 (2014).
[31] NASA, *Global Land-Ocean Temperature Index*, https://climate.nasa.gov/vital-signs/global-temperature/?intent=121 (last visited Jan. 13, 2025).
[32] Jeremy S. Hoffman et al., *Regional and Global Sea-Surface Temperatures During the Last Interglaciation*, 355 SCIENCE 276 (2017).
[33] Andrea Dutton et al., *Sea-Level Rise Due to Polar Ice-Sheet Mas Loss During Past Warm Periods*, 349 SCIENCE 6244 (2015), *and* Oana A. Dumitru et al., *Last Interglacial Global Mean Sea Level From High-Precision U-Series Ages of Bahamian Fossil Coral Reefs*, 318 QUATERNARY SCI. REV. 108287 (2023).
[34] Alan M. Haywood et al., *Large-Scale Features of Pliocene Climate: Results From the Pliocene Model Intercomparison Project*, 9 CLIMATE PAST 191 (2013).
[35] Kenneth G. Miller et al., *Cenozoic Sea-Level and Cryospheric Evolution From Deep-Sea Geochemical and Continental Margin Records*, 6 SCIENCE 20 (2020).
[36] Georgia R. Grant et al., *The Amplitude and Origin of Sea-Level Variability During the Pliocene Epoch*, 574 NATURE 237 (2019).
[37] Oana A. Dumitru et al., *Constraints on Global Mean Sea Level During Pliocene Warmth*, 574 NATURE 233 (2019).

Reconstructions of warm periods in the distant geologic past indicate that global sea levels were much higher in those periods (see Box 1 and Figure 4). Based on these reconstructions, scientists have inferred that Greenland, the West Antarctic Ice Sheet, and parts of the East Antarctic Ice Sheet contributed to higher sea levels. Some geologic data collected from the margins of the ice sheets reveal significant Antarctic ice loss during these periods.[38] Reconstructing global sea levels as well as ice sheet evolution during past warm periods is an ongoing and important area of scientific research. This research helps scientists to better identify the timing and contribution to global sea level from each ice sheet and pinpoint the climatic thresholds that trigger ice sheet collapse.

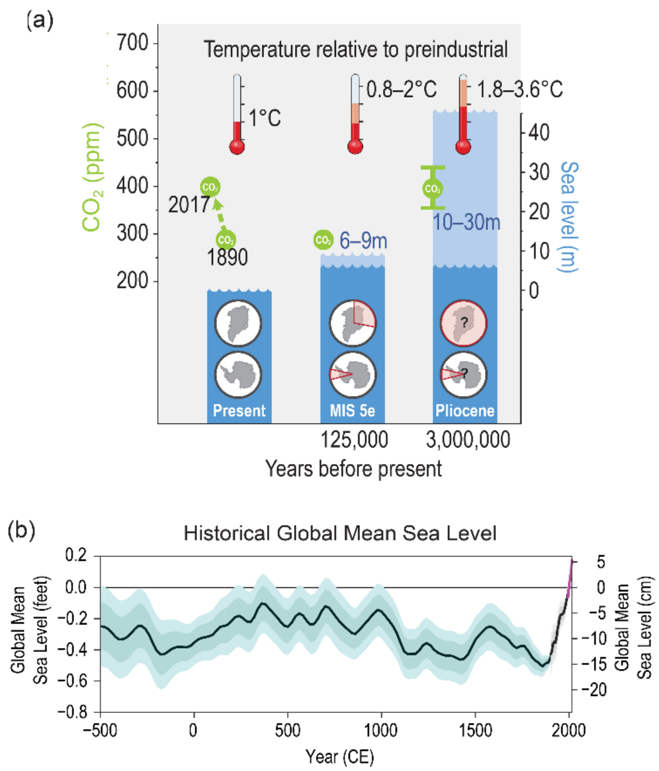

Figure 4. (a) The relationship between global temperatures, global sea level, and source(s) of meltwater for two periods in the past with global mean temperature comparable to or warmer than present. Note that the concentration of CO_2, depicted by the green dots, has increased from below 300 parts per million (ppm) in 1890 to over 400 ppm in 2017 (comparable to the concentration of CO_2 3 million years ago). Light blue shading indicates uncertainty of global sea-level maximum. Red pie charts over Greenland and Antarctica denote fraction, not location, of ice retreat.[39] (b) Global sea-level reconstruction, placing the modern sea-level rise (magenta)[40] into context with historical and geological sea level).[41]

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[38] *See, e.g.*, Rachel A. Betram et al., *Pliocene Deglacial Event Timelines and the Biogeochemical Response Offshore Wilkes Subglacial Basin, East Antarctica*, 494 EARTH & PLANETARY SCI. LETTERS 109 (2018), *and* Reed P. Scherer et al., *Windblown Pliocene Diatoms and East Antarctic Ice Sheet Retreat*, 7 NATURE COMM. 12957 (2016).

[39] Figure reproduced from Dutton et al., *supra* note 33.

[40] R. Steven Nerem et al., *Estimating Mean Sea Level Change From the TOPEX and Jason Altimeter Missions*, 33 MARINE GEODESY 435 (2010).

[41] Figure adapted from Sweet et al., *supra* note 2. *See also* Kopp et al., *supra* note 12, *and* Carling C. Hay et al., *Probabilistic Reanalysis of Twentieth Century Sea-Level Rise*, 517 NATURE 481 (2015).

G. How Will Global and U.S. Sea-Level Change in the Future?

Projections of global sea-level change are relevant in a variety of decisionmaking scenarios, including ecological habitat management, coastal flood insurance, water contamination risk, and many others. Given the key societal importance of this issue, many scientists have developed methods for projecting future global sea-level rise under a set of possible future climate pathways. These projections are generated using complex computer models that simulate the behavior of the Earth's climate system, including interactions between the atmosphere, oceans, land ice, and thermal expansion of seawater. Key inputs to these models include GHG emissions, ocean circulation patterns, ice sheet dynamics, and historical sea-level rise data. Scientists incorporate both physical processes and statistical methods to predict future sea-level rise under different climate conditions. The most well-known projections come from comprehensive scientific assessments like those of the Intergovernmental Panel on Climate Change (IPCC) and the U.S. National Climate Assessment (NCA).

These international and national bodies regularly publish sea-level rise projections under different climate pathways to inform decisionmaking, and update these projections periodically to reflect the emerging scientific consensus. The IPCC's sea-level rise projections are based on different GHG concentration pathways, previously known as Representative Concentration Pathways (RCPs) and now called Shared Socioeconomic Pathways (SSPs). These pathways represent a range of possible future emissions scenarios, from high-emissions futures where carbon levels continue to rise significantly (e.g., SSP5-8.5) to low-emissions pathways where strong mitigation efforts are made (e.g., SSP1-2.6). In its Sixth Assessment Report (AR6), the IPCC projects a global mean sea-level rise of 16.9 inches (between 11.4 and 23.2 inches) by 2100 under a low-emissions scenario, and 33.1 inches (between 24.0 and 43.3 inches) under a high-emissions scenario. However, uncertainties in ice sheet contributions, particularly from Antarctica, mean that there is a significant spread of possibilities, with some "worst-case" scenarios projecting over ~80 inches of sea-level rise by the end of the century. The NCA provides projections specific to the United States. As such, the report highlights regional variations in sea-level rise, driven by factors such as land subsidence, ocean currents, and changes in water temperature and salinity. The Fourth NCA, published in 2018, anticipates between about 11 inches and 4 feet of sea-level rise by 2100, depending on future emissions and ice sheet behavior.

Long term projections (beyond 2100) indicate a large dependence of the sea-level response to future carbon emissions trajectories (mainly from the Antarctic Ice Sheet).[42] A high-emissions scenario (RCP-8.5) results in about 30 feet of sea-level rise by the year 2300, compared to about 3 feet under a low-emissions scenario.[43]

Sea-level projections are used by a wide array of stakeholders, including coastal planners, government agencies, infrastructure developers, and conservationists. These projections inform policies for building codes, coastal defenses, zoning laws, and disaster preparedness plans. For example, municipalities may use these projections to determine where to invest in seawalls or managed retreat strategies, while environmental agencies might plan for the impacts on coastal wetlands and biodiversity. Insurance companies and financial institutions also rely on these projections to assess long-term risk, particularly in relation to real estate markets and asset exposure in coastal areas.

[42] Robert M. DeConto et al., *The Paris Climate Agreement and Future Sea-Level Rise From Antarctica*, 593 NATURE 83 (2021).
[43] *Ibid.* and IPCC SROCC 2019, *supra* note 18.

H. How Does Sea-Level Rise Impact the Coastline?

As the local water level at a coastline increases, so does the frequency of flooding. Local sea levels rise slowly over decades, but as they rise, storms or extreme tides more frequently exceed flooding thresholds. The frequency of these floods is measured by recurrence interval. The "100-year flood" recurrence interval means on average that a flood occurs once every 100 years, or a 1% probability of occurring annually. At many coastlines, scientists project that the 100-year flood, measured with respect to a 1991-2009 baseline, will occur multiple times per year by the end of the century.[44] For example, by 2100, today's 50-year flood—a once-in-a-lifetime event—will be exceeded almost every day during peak tide for 90% of the U.S. coast.[45]

Major flooding occurs more frequently because a rise in baseline local sea levels causes storm surges to reach further inland. Hurricanes are already the most expensive and lethal of the billion-dollar weather and climate disaster events.[46] Rising sea levels will exacerbate the impacts of hurricanes by continuing to increase the height of storm surges and expand the affected areas. Future hurricanes will also include heavier rainfall and a higher proportion of storms at the most damaging Category 4 and 5 level.[47] For at least one city (New York), scientists have found that the increase in flooding caused by sea-level rise is expected to become greater than the flooding caused by changing storm characteristics like heavier rainfall.[48]

For flat and low-lying regions, water levels that are heightened by only inches can flood miles further inland. Thus, minor flooding that once occurred rarely now happens more frequently during high tides, a phenomenon often called "sunny day flooding," "high-tide flooding," or "nuisance flooding" (see Figure 5). Accompanying such flooding is an increase in the land area that is permanently inundated, which poses risks to infrastructure such as roads, parks, bridges, and cropland. For example, the annual national costs to road networks due to high-tide flooding (over $1.3 billion in 2020) is estimated to increase to $28 billion by 2050 and $260 billion in 2100 under medium to high GHG emissions scenarios.[49]

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[44] Michalis I. Vousdoukas et al., *Global Probabilistic Projections of Extreme Sea Levels Show Intensification of Coastal Flood Hazard*, 9 NATURE COMM. 2360 (2018).

[45] Mohsen Taherkhani et al., *Sea-Level Rise Exponentially Increases Coastal Flood Frequency*, 10 SCI. REP. 6466 (2020).

[46] National Centers for Environmental Information & NOAA, *Billion-Dollar Weather and Climate Disasters*, https://www.ncei.noaa.gov/access/billions/summary-stats (last visited Jan. 14, 2025).

[47] NOAA & U.S. Department of Commerce, *State of the Science Fact Sheet: Atlantic Hurricanes and Climate Change*, GEOPHYSICAL FLUID DYNAMICS LABORATORY (2023).

[48] Ali Sarhadi et al., *Climate Change Contributions to Increasing Compound Flooding Risk in New York City*, 105 BULL. AM. METEOROLOGICAL SOC'Y E338 (2024).

[49] Charles Fant et al., *Mere Nuisance or Growing Threat? The Physical and Economic Impact of High Tide Flooding on US Road Networks*, 27 J. INFRASTRUCTURE SYS. 04021044-1 (2021).

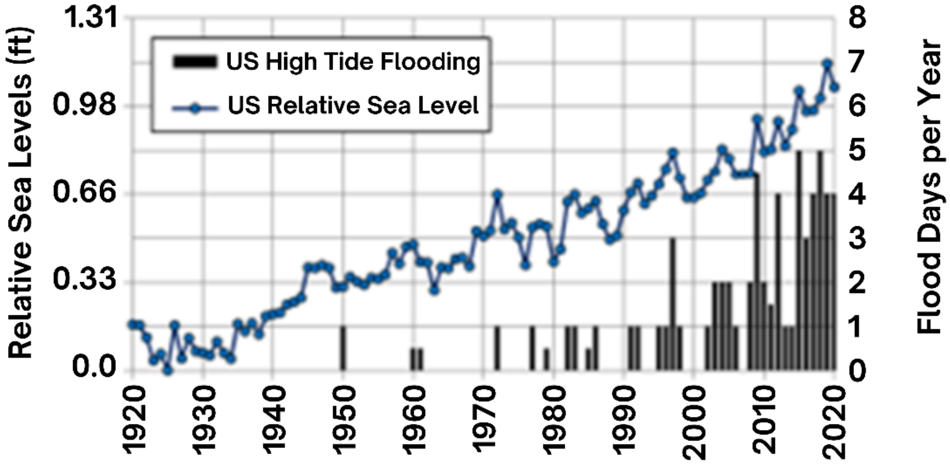

Figure 5. Increasing relative (local) sea levels are associated with high tide flooding at 98 National Oceanic and Atmospheric Administration (NOAA) tide gauges along the contiguous U.S. coastline.[50]

The rate of sea-level rise will increase by the end of the century even under low emissions scenario,[51] and will continue to rise for centuries after 2100, regardless of emissions trajectories.[52] Therefore, in some places, islands will be rendered uninhabitable due to submersion, saltwater intrusion into groundwater, storm surge, and other factors.[53] U.S. island territories such as Guam, U.S. Virgin Islands, and Puerto Rico are particularly vulnerable to sea-level rise. In addition to being low-lying islands, they are located in the equatorial Pacific where they experience greater-than-global-average sea-level rise from both Greenland and Antarctic Ice Sheet contributions (see Figure 2).

These areas rely heavily on their coastal ecosystems for livelihoods, tourism, and subsistence. One of the major issues these territories face is the displacement of populations, particularly in low-lying coastal areas. As sea levels rise, some communities may experience chronic flooding, making it difficult for residents to remain in their homes. This could result in forced relocations, creating economic and social disruptions.[54]

Critical infrastructure like ports, airports, and power plants are situated near the coast, placing them at higher risk of damage from flooding. Military installations and Indigenous communities are located in coastal zones, where rising waters threaten both national security interests and local ways of life. Ecological impacts to coral reefs, mangroves, and other coastal habitats are also under threat from rising seas and increased water temperatures. These systems provide natural storm protection and support fishing and ecotourism, which are key economic drivers in these territories.

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[50] Figure adapted from Sweet et al., *supra* note 2.

[51] International Panel on Climate Change, *IPCC Sixth Assessment Report Working Group I: The Physical Science Basis, Summary for Policymakers* (2021).

[52] *See* Peter U. Clark et al., *Consequences of Twenty-First-Century Policy for Multi-Millennial Climate and Sea-Level Change*, 6 NATURE CLIMATE CHANGE 360 (2016); Baylor Fox-Kemper et al., *Ocean, Cyrosphere and Sea Level Change*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, CONTRIBUTION OF WORKING GROUP I TO THE SIXTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (2021); *and* Michael Oppenheimer et al., *Sea Level Rise and Implications for Low Lying Coasts and Communities*, *in* IPCC SROCC 2019, *supra* note 18.

[53] IPCC SROCC 2019, *supra* note 18.

[54] *Id.*

I. Can Sea-Level Rise (and Associated Storm Damages) Be Attributed to Human Activity?

Attribution scientists study the links between human-caused emissions and physical impacts, including the damage and loss associated with sea-level rise (see Drawing the Causal Chain: The Detection and Attribution of Climate Change and Applying Attribution: Impacts of Climate Attribution Science on Tort Litigation). A variety of approaches can be used to attribute global trends to human activity versus natural climate variability, and all of them find that a substantial fraction of global sea-level rise since 1900 can be directly linked to human activities. This finding has been reported by national and international agencies with *high confidence*, a metric that is determined by the total body of scientific evidence and the agreement among that body of evidence (see the How Climate Science Works module).[55]

One approach establishes the relationship between the long-term historical temperature and rate of global sea-level rise, concluding that global sea levels would have risen 51% less over the 20th century without human-caused climate warming.[56] Models simulating climate evolution with and without human GHG emissions attribute about 70% of global sea-level rise to human emissions.[57] These estimates are also supported by time-series analysis. Because natural climate variability on these timescales is well understood, scientists can separate out its contributions from the global sea-level rise due to human activity.[58]

As outlined above, local sea-level rise increases storm surge and flooding extent during extreme events. Because sea-level rise can be attributed to human activity, scientists can therefore also attribute increased storm damages to human activity. For example, one group found that approximately 13% of the economic damages caused by Superstorm Sandy in 2012 are attributable to human-caused sea-level rise (accounting for $8.1 billion dollars of added damage).[59]

To determine these figures, the researchers first established how much global sea-level rise resulted from human activity by comparing scenarios with and without human-caused emissions. They reported about 4.1 inches of human-induced global sea-level rise, or 50% of the total global sea-level rise (a low estimate compared to other attribution literature summarized above). This added 4.1 inches of global average rise translated to 3.8 inches of local sea-level rise along the New York coastline where Sandy made landfall. They then used "hydrodynamic" or water-flow modeling to compare the actual flood extent to flooding that might have unfolded at the non-human-influenced sea level (see Figure 6). A relatively small increase in baseline water level has large spatial impact when it is added to a storm surge: this additional local rise caused Sandy's flood to impact about 8% to 10% more people, land,

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[55] *See* IPCC SROCC 2019, *supra* note 18; Weubbles et al., *supra* note 9.
[56] Kopp et al., *supra* note12.
[57] Aimée B.A. Slangen et al., *Anthropogenic Forcing Dominates Global Mean Sea-Level Rise Since 1970*, 6 NATURE CLIMATE CHANGE 701 (2016); Svetlana Jevrejeva et al., *Anthropogenic Forcing Dominates Sea Level Rise Since 1850*, 36 GEOPHYSICAL RSCH. LETTERS L20706 (2009).
[58] Sönke Dangendorf et al., *Detecting Anthropogenic Footprints in Sea Level Rise*, 6 NATURE COMM. 7849 (2015); Melanie Becker et al., *Long-Term Sea Level Trends: Natural or Anthropogenic?*, 41 GEOPHYSICAL RSCH. LETTERS 5571 (2014).
[59] Benjamin H. Struass et al., *Economic Damages From Hurricane Sandy Attributable to Sea Level Rise Caused by Anthropogenic Climate Change*, 12 NATURE COMM. 2720 (2021).

and housing units than without the human-caused sea-level rise. It was that increased spatial impact that resulted in those billions of dollars of added damage.

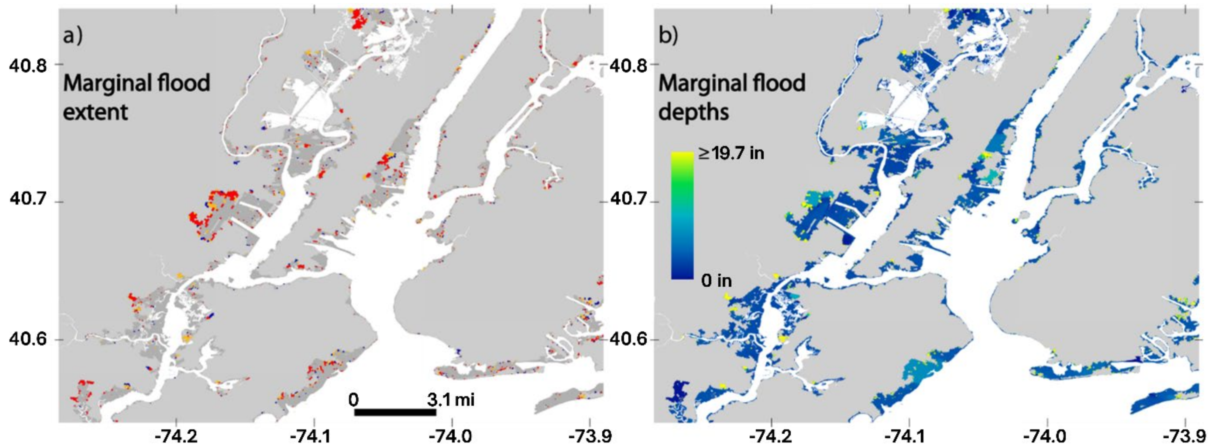

Figure 6. The added contributions to Superstorm Sandy flood extent that are attributable to human-caused sea-level rise (figure source: Strauss et al., 2021). (a) Sandy would not have flooded blue areas if the baseline local sea level had been 4 cm (1.6 inches) lower; neither blue nor orange areas if 10 cm (3.9 inches) lower; and neither blue, orange nor red areas if 20 cm (7.9 inches) lower. The slightly darkened gray areas would have flooded in any of these cases. (b) The estimated additional contribution to flood depths due to human-caused sea-level rise.[60]

While the authors of the Superstorm Sandy study did not discuss any potential legal consequences, this type of attribution protocol might be used to support a legal claim linking the resulting loss and damage to emissions.[61] Further, the developing field of "source attribution" (see Drawing the Causal Chain module) is attempting to link physical impacts to specific sources of emissions, which is informing plaintiffs' arguments across a number of cases. One frequently cited study attributes fractions of observed temperature and sea-level changes to emissions from 90 of the largest carbon producers.[62]

In order to conduct these studies, scientists require access to both detailed historical data and state-of-the-art climate models that are capable of simulating events of interest. However, in lower-income regions, insufficient meteorological observations, model deficiencies, and a sparsity of local expertise can hinder formal event attribution analyses[63] In places where baseline data are lacking and detailed attribution studies aren't yet possible, regional trends might be useful for understanding the impacts of sea-level rise.

[60] Figure adapted from Strauss et al., *supra* note 59.
[61] Jessica Wentz et al., *Research Priorities for Climate Litigation*, 11 EARTH'S FUTURE e2022EF002928 (2022).
[62] Brenda Ekwurzel et al., *The Rise in Global Atmospheric CO_2, Surface Temperature, and Sea Level Emissions Traced to Major Carbon Producers*, 144 CLIMATIC CHANGE 579 (2017).
[63] Andrew D. King et al., *Event Attribution Is Not Ready for a Major Role in Loss and Damage*, 13 NATURE CLIMATE CHANGE 415 (2023); Friederike E.L. Otto et al., *Challenges to Understanding Extreme Weather Changes in Lower Income Countries*, 101 BULL. AM. METEOROLOGICAL SOC'Y E1851 (2020).

J. How Do Communities Live With Sea-Level Rise? (Adaptation and Mitigation)

The impacts of sea-level rise on human societies are widespread and multidimensional. They include flood loss and damage, ecosystem changes, and exacerbated social vulnerabilities (see the Climate Justice module). Online tools, such as the NOAA SLR Viewer or Climate Central's Surging Seas, offer ways to investigate local impacts and explore projections of local sea-level rise and extreme events along U.S. coastlines. In September 2024, the U.S. federal government launched an interagency task force on sea-level rise, which serves as a central repository for federally supported sea-level data.[64] In addition, the Fifth National Climate Assessment includes region-specific chapters that provide greater granularity into climate impacts.[65]

The human response to local sea-level rise—adaptation—bridges physical, social, and governmental actions to build resilience in coastal areas experiencing sea-level rise. Adaptation responses can be categorized as resistance, accommodation, or retreat; these strategies are often used in tandem.

Resistance against flooding, erosion, and saltwater intrusion can take the form of hard armoring measures such as dikes, seawalls, and breakwaters, or sediment-based protection such as beach, shore, and dune nourishment.[66] Beach nourishment is a common strategy for erosion mitigation and maintaining recreation and tourism, but is generally costly and temporary, and can be detrimental to marine ecosystems. Another form of resistance entails conserving or restoring coastal ecosystems such as wetlands and reefs, which lessens wave energy and thus reduces storm surge flooding. Healthy wetlands and reefs can also stabilize and regrow coastal land in the longer term. Resistance approaches provide only limited protection, however, and as discussed below, some resistance strategies may implicate constitutional takings law.[67]

"Accommodation" is the second category of adaptation, encompassing legislative or regulatory actions that are designed to increase resilience and habitability of coastal zones in the face of sea-level rise and storm surge. Some examples of accommodation include elevating homes, or adjusting agriculture or aquaculture to more salt-tolerant crops. As discussed below, some of these measures may trigger similar constitutional challenges.

Finally, adaptation can take the form of "retreat." Here, coastal risk is mitigated by moving people, activities, and infrastructure away from the coastal hazard zone, sometimes referred to as managed retreat or community relocation, among other terms. Retreat can be voluntary ("migration") or forced ("displacement"). Relocation programs are typically managed by local or federal governments; some rely on incentives such as voluntary buyouts.

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[64] Interagency Sea Level Task Force, *Rising Seas, Changing Coasts*, https://sealevel.globalchange.gov (last visited Jan. 14, 2025).

[65] The NCA regions include Northeast, Southeast, U.S. Caribbean, Midwest, Northern Great Plains, Southern Great Plains, Northwest, Southwest, Alaska, and Hawaii and U.S.-affiliated Pacific islands. The NCA states that "Accelerating sea level rise and climate change will transform the coastal landscape, requiring a new paradigm for how we live with, or adapt to, these changes (*high confidence*)." FIFTH NATIONAL CLIMATE ASSESSMENT, U.S. GLOBAL CHANGE RESEARCH PROGRAM: REPORT IN BRIEF 82 (2023) [hereinafter NCA5].

[66] *See* Mark Nevitt, *The Legal Crisis Within the Climate Crisis*, 76 STAN. L. REV. 1051 (2024), *and* Anne R. Siders, *Managed Retreat in the United States*, 1 ONE EARTH PERSP. 216, 218 (2019) (using the "resist," "accommodate," and "retreat" adaptation categories).

[67] U.S. CONST. amend. V.

Adaptation measures vary in terms of their technical limits, costs, benefits, co-benefits, economic efficiency and barriers, and governance challenges.[68] The unique legal challenges associated with each type of adaptation response are only beginning to be recognized. As cities and states continue to enact laws that encourage or require adaptation actions, more projects will advance, each with their own set of legal obstacles and opportunities for litigation.

A key element of the human response to sea-level rise is mitigation. Adaptation strategies can only buffer the effects of sea-level rise up until a certain level; all adaptation measures have an upper limit of protection. Depending on the trajectory of carbon emissions, the rates (and acceleration) of future sea-level rise will overwhelm many of these measures. Beyond 2100, long-term sea-level rise is far higher under high emissions pathways compared to low-emissions pathways (Section G). Therefore, near-term mitigation (reducing carbon emissions) is critical for reducing sea-level impacts in both short- and long-term timescales.[69] Given that attribution studies are attempting to link anthropogenic carbon emissions to loss and damage, mitigation efforts will likely play a key role in future climate-related litigation.

II. Sea-Level Science in the Law

As discussed above, climate scientists are increasingly highlighting the linkage between human activities and climate impacts. These climate impacts include sea-level rise, which exacerbates flooding, makes storms more damaging, and contributes to erosion (a loss of land, which takes place gradually over time) and avulsion (a sudden loss of or addition of land by the action of water, often after a major storm).[70] Indeed, the Congressional Budget Office (CBO) estimates that due to sea-level rise and other factors, "the costs associated with hurricane damage will increase more rapidly than the economy will grow."[71] According to the CBO, expected annual hurricane damage stands at $28 billion, and this estimate is poised to grow in the coming century.[72] In response, governments and private citizens alike are turning to climate adaptation measures.[73] Perhaps not surprisingly, these changes mean that state and federal judges are now wrestling with novel constitutional, property, environmental, and tort cases centered around sea-level rise impacts and response.

Indeed, federal and state courts are seeing an uptick in climate change litigation (see Overview of Climate Litigation module), and courts in coastal jurisdictions will be at the leading edge of sea-level rise litigation. And judges must have a facility and understanding of the issues so that they can make better-informed decisions based on the evidence presented to them. What's more, judges may be

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68 IPCC SROCC 2019, *supra* note 18.
69 IPCC SROCC 2019, *supra* note 18.
70 ANNE SIDERS, COLUMBIA CTR. FOR CLIMATE CHANGE LAW, MANAGED COASTAL RETREAT: A LEGAL HANDBOOK ON SHIFTING AWAY FROM VULNERABLE AREAS 56 (2013).
71 Congressional Budget Office, *Potential Increases in Hurricane Damage in the United States: Implications for the Federal Budget* (June 2, 2016).
72 *Id.*
73 The value of properties exposed to flood risk (closely related to sea-level rise) is extraordinary. Zillow, a real estate website, estimates that climate change will place 3.4 million homes—worth $1.75 trillion—at increased flood risk by the end of this century. CLIMATE CENT., OCEAN AT THE DOOR: NEW HOMES AND THE RISING SEA 2 (2019), https://ccentralassets.s3.amazonaws.com/pdfs/2019Zillow_report.pdf; *see also Housing Market Impairment From Future Sea-Level Rise Inundation—Federal Reserve Bank of Kansas City (kansascityfed.org).*

called upon to apply legal doctrines designed for a far more stable time to a physical environment that is changing rapidly now due to climate change.[74] Concerns over sea-level rise impacts, extreme weather, and nuisance flooding have already disrupted insurance markets; several private insurance companies have stopped issuing new policies in Florida, California, and Louisiana.[75] And sea-level rise also increases saltwater intrusion and drinking water salinity.

This section examines how federal and state courts have incorporated climate science into judicial decisionmaking, addressing both major U.S. Supreme Court decisions and a number of state cases that have addressed sea-level rise, with a particular focus on the following five areas:

A. Justiciability: The Role of Standing in Sea-Level Rise Cases
B. Administrative Decisionmaking: Land Use Controls and Zoning
C. Physical and Regulatory Takings Challenges
D. Shifting Property Boundaries
E. Emerging Issues

A. Justiciability: The Role of Standing in Sea-Level Rise Cases

1. Supreme Court Cases

Before a case reaches the merits in federal court, the plaintiff must establish Article III standing.[76] In a key environmental law case from 1992, *Lujan v. Defenders of Wildlife*, the Supreme Court, laid out a three-part test to establish standing: a "litigant must demonstrate that it has suffered a concrete and particularized injury that is either actual or imminent, that the injury is fairly traceable to the defendant, and that it is likely that a favorable decision will redress that injury."[77]

Fifteen years after *Lujan,* the Supreme Court decided *Massachusetts v. EPA,* arguably its most important climate change case in which several states, municipalities, and nonprofit organizations together petitioned the U.S. Environmental Protection Agency (EPA) to regulate GHG emissions under the Clean Air Act (CAA) (see Overview of Climate Litigation). While not a sea-level rise adaptation case per se, *Massachusetts v. EPA* discussed the role of sea-level rise and coastline loss in its standing analysis.

Before the Supreme Court granted review, a three-judge panel of the U.S. Court of Appeals for the District of Columbia (D.C.) Circuit sided with EPA in denying petitioners' rulemaking request under the CAA. That court, in a 2-1 decision, held that it was "reasonable for EPA to base its decision on scientific uncertainty . . . ."[78] Writing for the majority, Judge David Sentelle found that the petitioners failed to demonstrate an injury. In dissent, Judge David Tatel disagreed, highlighting that Massachusetts had, indeed, satisfied each element of Article III standing (injury, causation, redressability).[79] Specifically, Judge Tatel noted that there was a "substantial probability" that projected sea-level rise would lead to a serious loss of coastal property in Massachusetts, thus

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[74] Nevitt, *supra* note 66.
[75] *See* Mark Nevitt & Michael Pappas, *Climate Risk, Insurance Retreat, and State Response*, 58 GA. L. REV. 1603 (2024) (discussing insurance retreat in Florida, Louisiana, and California).
[76] U.S. CONST. art II, §2.
[77] Lujan v. Defenders of the Wildlife, 504 U.S. 555 (1992).
[78] Mass. v. EPA, 415 F.3d 50, 58 (D.C. Cir. 2005).
[79] *Id.* at 60-61.

satisfying the injury-in-fact requirement. In Judge Tatel's reasoning, this cognizable injury was a "far cry" from the kind of generalized harm that is insufficient to establish standing. And Judge Tatel noted that EPA's failure to curb GHG emissions contributed to these sea-level rise changes that threatened Massachusetts' coastal property.[80]

At the Supreme Court, as a leadup to the standing analysis, the majority opinion authored by Justice John Paul Stevens addressed the consensus science from leading international and domestic scientific reports. This included Assessment Reports published by the U.N. IPCC, the U.S. NCA, and data on CO_2 concentrations in the atmosphere collected from the Mauna Loa observatory in Hawaii.[81] Looking at historic CO_2 levels, the Court noted that in 1959 the observatory recorded a mean level of CO_2 in the atmosphere of 316 parts per million. A decade later, at the time of the CAA's passage in 1970, the observed concentration had increased to 325 parts per million. (In 2024, observed CO_2 levels at the observatory exceed 420 parts per million.)

The Court also referenced several scientific reports from the National Research Council (NRC), the working arm of the National Academies of Sciences, Engineering, and Medicine. These NRC reports were issued in response to a White House query to "identify areas in the science of climate change where there are the greatest certainties and uncertainties."[82] While the Court discussed two domestic laws—the 1978 National Climate Program Act and 1987 Global Climate Protection Act—the Court largely focused on the IPCC report to establish consensus climate science findings.[83] In addition to these reports, declarations from two prominent U.S. climate scientists were featured, Michael MacCracken and Michael Oppenheimer.[84]

Following this scientific discussion, the Court tied the consensus science to whether the Commonwealth of Massachusetts had standing to sue. The Court adopted much of Judge Tatel's reasoning, finding that climate change-driven sea-level rise directly impacted the Massachusetts coastline. This harm, in turn, constituted a concrete and particularized injury that was actual or imminent, that was caused by defendant's actions, and was a harm that the Court could redress.

Further, as part of its standing analysis, the Court found that Massachusetts possesses "quasi-sovereign" interests to protect its citizens within its sovereign territory that may suffice when the state is a litigant.[85] With respect to injury, the Court drew upon affidavits from climate scientists who estimated that global sea-level rise had risen by 20 centimeters in the 20th century, finding that "[t]hese rising seas have already begun to swallow Massachusetts' coastal land."[86] Justice Stevens continued:

> Because the Commonwealth "owns a substantial portion of the state's coastal property," it has alleged a particularized injury in its capacity as a landowner. The severity of that injury will only increase over the course of the next century: If sea levels continue to rise as predicted, one Massachusetts official believes that a

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[80] *Id.* at 65.
[81] Mass. v. EPA, 549 U.S. 497, 504-10 (2007).
[82] *Id.* at 511.
[83] *Id.* at 508-11.
[84] *Id.*
[85] *Id.* at 518 (citing to Georgia v. Tennessee Copper Co., 206 U.S. 230, 237 (1907)).
[86] Mass. v. EPA, 549 U.S. 521, 522 (2007).

> significant fraction of coastal property will be "either permanently lost through inundation or temporarily lost through periodic storm surge and flooding events."[87]

Under the causation prong, the Court addressed the linkage between GHG emissions and whether this can be traced to actual harm (see the Drawing the Causal Chain and Applying Attribution modules), *not* on whether there is a causal connection between human-caused GHG emissions and global warming. Significantly, the George W. Bush-era EPA did not dispute the existence of consensus science and this causal connection.[88] The Court found that EPA's refusal to regulate such emissions "contributes" to Massachusetts' injuries.[89] The Court explained that "petitioners' affidavits more than adequately supported the conclusion that EPA's failure to curb GHG emissions contributed to the sea-level changes that threatened Massachusetts' coastal property."[90]

Finally, under the redressability prong, the Court emphasized that a plaintiff "need not show that a favorable decision will relieve his *every* injury."[91] The Court found that although requiring EPA to regulate tailpipe emissions may not "solve" Massachusetts' territorial loss, it may slow or reduce its impact—and that is enough to meet the standing requirement in federal court. Notably, the Court also emphasized that other countries' emissions should not preclude EPA's action, observing that "[a] reduction in domestic emissions would slow the pace of global emissions increases, no matter what happens elsewhere."[92]

In sum, Massachusetts satisfied all three standing prongs (and ultimately won on the merits). Each one of these standing "wickets" creates a hurdle for prospective sea-level rise litigants. In particular, the scientific linkage between GHG emissions and sea-level rise is critical to satisfy the injury-in-fact requirement of standing analysis. The Court's decision in *Massachusetts*, however, provides an example of how to think about standing and sea-level rise, at least in a case brought by a state about motor vehicle emissions.

Another 15 years later, in 2022, the Supreme Court decided *West Virginia v. EPA*, another case about EPA's authority under the CAA to regulate GHG emissions, finding that with the regulation challenged there, EPA had exceeded its authority. While not a sea-level rise case, sea-level rise impacts were discussed by Justice Elena Kagan in her dissenting opinion.[93] Quoting from the NCA, she wrote, "[t]he Earth is now warmer than at any time 'in the history of modern civilization,' with the six warmest years on record all occurring in the last decade." She went on to note that this rise in temperatures brings with it "coastal inundation and erosion."[94] Quoting from an amicus brief submitted by several climate scientists, including Oppenheimer, Justice Kagan noted that severe injuries inflicted by climate change with "children born this year could live to see parts of the Eastern seaboard swallowed by the ocean."[95]

[87] *Id.* at 522-23 (internal citations omitted).
[88] *Id.* at 523.
[89] *Id.*
[90] *Id.* at 515.
[91] *Id.* at 525 (citing Larson v. Valente, 456 U.S. 228, 244, n.15 (1982)).
[92] *Id.* at 526.
[93] West Virginia v. EPA, 142 S. Ct. 2587, 2626-44 (2022) (Kagan, J., dissenting).
[94] Quoting American Elec. Power v. Connecticut, 564 U.S. 410, 417 (2011).
[95] West Virginia v. EPA, 142 S. Ct. 2587, 2627 (2022) (Kagan, J., dissenting).

In sum, while the Supreme Court has not squarely addressed a sea-level rise case on its merits—both *Massachusetts v. EPA* and *West Virginia v. EPA*, cases brought under CAA, demonstrate that climate change-driven sea-level rise and territorial loss can prove central to the standing analysis even in ostensibly non-water-related disputes.

2. Federal Appellate and District Courts

Federal appellate courts have cited scientific reports, such as those produced by the IPCC and NCA, to provide similar baseline science and highlight climate impacts, including sea-level rise and increased temperatures.[96] There are two federal appellate court cases worth mention; both tie climate-related impacts to Article III standing analysis.

- In *Juliana v. United States*, a constitutional and public trust-based challenge brought by youth against several federal agencies for activities related to climate change, a divided U.S. Court of Appeals for the Ninth Circuit panel held that although the plaintiffs established that their injury was caused by the U.S. government defendants, the court would not be able to redress their injury.[97] For more on that case, see the Climate Litigation Overview module. As applied to sea-level rise, the court noted that, "[e]ven government scientists project that, given current warming trends, sea levels will rise two feet by 2050, nearly four feet by 2070, over eight feet by 2100, 18 feet by 2150, and over 31 feet by 2200." Further, the "IPCC Report predicts an increase in global average temperatures between 1.8 and four degrees Celsius by the end of the 21st century.[98]

- In *Native Village of Kivalina v. ExxonMobil Corp.*, a Native Alaskan tribe brought a public nuisance claim seeking damages against several energy companies for injuries from land loss due to climate change.[99] The plaintiffs argued that the energy companies' GHG emissions resulted in a reduction of Arctic sea ice, which historically buffered the community against winter storms. According to plaintiffs, reduced sea ice cover provided less protection from storms, resulting in an erosion of their ancestral land.[100] The Ninth Circuit affirmed the trial court's dismissal of the case, explaining that the CAA displaced any federal common law addressing GHG emissions.[101]

3. State Constitutional Claims

In 2023, a Montana trial court relied on evidence from the IPCC, NCA, Montana Climate Assessment, as well as expert witnesses from the University of Montana and Montana State University to support the plaintiffs' claims about climate change over the defendants' objections. In

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[96] *See, e.g.*, Juliana v. United States, 947 F.3d 1159, 1176 (9th Cir. 2020) ("Temperatures have already risen 0.9 degrees Celsius above pre-industrial levels . . . and each year since 1997 has been hotter than the previous average. This extreme heat is melting polar ice caps and may cause sea levels to rise 15 to 30 feet by 2100."), citing NOAA, TECHNICAL REP. NOS CO-OPS 083, *Global and Regional Sea Level Rise Scenarios for the United States* 23 (Jan. 2017).
[97] *Juliana*, 947 F.3d 1159.
[98] *See also* Green Mt. Chrysler Plymouth Dodge Jeep v. Crombie, 508 F. Supp. 2d 295, 341 (D. Vt. 2007).
[99] Native Village of Kivalina v. ExxonMobil Corp., 696 F.3d 849 (9th Cir. 2012).
[100] *Id.* at 854.
[101] *Id.* at 858.

Held v. Montana,[102] the defendants objected on hearsay grounds when plaintiffs introduced parts of the IPCC assessment report; Judge Kathy Seeley overruled the objection, and the evidence was allowed in.[103] While *Held* did not address sea-level rise, the trial court noted that climate change is already harming the plaintiffs by, among other things, increasing variability in water levels in Powder River, Montana.[104]

B. Administrative Decisionmaking: Land Use Controls and Zoning

Sea-level rise litigation can come in many forms, but often centers around the interaction between coastal communities' efforts to implement various land use controls.[105] Climate change-driven sea-level rise is altering the boundaries between public and private property along the coastline, resulting in Fifth Amendment takings claims.[106] Beyond permanent physical takings, Fifth Amendment claims can arise from regulations that go too far. And the Supreme Court recently reaffirmed that temporary physical occupation can also result in a taking. Indeed, in *Arkansas Game & Fish Commission v. United States*, the Court addressed a legal challenge to the government's sea-level rise adaptation measures when diversion of sea water causes flooding elsewhere.[107] But if the government does nothing, takings challenges are unlikely to succeed, as successful takings challenges typically require an underlying affirmative governmental action. Prof. Dan Farber has labelled this incentive to not invest in ex ante adaptation measures as "the adaptation dilemma."[108]

The following examples showcase the issues associated with private landowners and government sea-level rise regulations designed to consider a changing climate. These cases all stem from the California Coastal Commission's decision to place additional conditions that consider sea-level rise and erosion on construction permits for coastal development. Predictably, this has led to property owners challenging various permit restrictions.[109]

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[102] Jarryd Page, *Unpacking the Headline: Climate Science and* Held v. State of Montana, ELI Vibrant Environment Blog (Sept. 13, 2023), https://www.eli.org/vibrant-environment-blog/unpacking-headline-climate-science-and-held-v-state-montana.

[103] According to reporting by the *New York Times*:

> The first day of the [*Held v. Montana*] trial also featured an extensive review of charts and scientific reports, exploring the history of rising levels of carbon dioxide in the atmosphere, how the trend is linked to fossil fuels, the ways in which it contributes to a warming planet and the effects on Montana. But some of the scientific details became a point of conflict. When the plaintiffs introduced the most recent climate assessment from the Intergovernmental Panel on Climate Change, convened by the United Nations, which warned that there was "a rapidly closing window" to secure a "livable" future, the state objected, calling it "hearsay." When the plaintiffs contended that the report was a government document based on government data, the Montana lawyers retorted: "I don't think it's our government."

The judge allowed the report to be admitted. Mike Baker, *A Landmark Youth Climate Trial Begins in Montana*, N.Y. TIMES (June 12, 2023), https://www.nytimes.com/2023/06/12/us/montana-youth-climate-trial.html.

[104] Held v. State of Montana, CDV-2020-307, 48 (Aug. 14, 2023).

[105] *See, e.g.*, Legal Risk Analysis for Sea Level Rise Adaptation Strategies in San Diego, ENV'T L. INST. (2017), https://www.eli.org/sites/default/files/eli-pubs/legal-risk-analysis-sea-level-rise-adaptation-strategies-san-diego.pdf.

[106] Stop the Beach Renourishment v. Florida Dep't of Env't Prot., 560 U.S. 702 (2010).

[107] Arkansas Game & Fish Commission v. United States, 568 U.S. 23, 38-39 (2012) (holding that "government-induced flooding temporary in duration gains no automatic exemption from the Takings Clause").

[108] Dan Farber, *Temporary Takings and the Adaptation Dilemma*, LEGAL PLANET (May 6, 2024), https://legal-planet.org/2024/05/06/temporary-takings-and-the-adaptation-dilemma/.

[109] 11 Lagunita, LLC v. California Coastal Commission, No. G058436 (Ct. App. 4th Dist., Dec. 18, 2020).

1. Cases Challenging the California Coastal Commission

First, in 2019, the California Court of Appeals for the Fourth Appellate District decided *Lindstrom v. California Coastal Commission*, a case where plaintiffs challenged the Commission's conditions imposed on private coastline construction that included a setback condition as well as other regulatory requirements. The Commission's regulations required construction of this new home to be set back 62 feet from the edge of a bluff to safely account for projected sea-level rise. In establishing this new setback line, the Commission relied upon a peer-reviewed, Federal Emergency Management Agency (FEMA) study from 1999.[110] This FEMA study addressed various historic erosion rates, and the Commission used the highest *historic* erosion rate as a tool to take into account future sea-level rise. The California Court of Appeals upheld the setback provision, finding that the Commission's reliance upon the 1999 study was a reasonable way to consider predicted erosion rates.[111]

Second, one year later, in *11 Lagunita, LLC v. California Coastal Commission,* the same California Court of Appeals court addressed the legality of a Commission cease-and-desist order issued against a homeowner who built a seawall on private property without previous consultation with the Commission.[112] The homeowner constructed the seawall to alleviate climate change-driven sea-level rise and storm surge. Any new development in the coastal zone required a Coastal Development Permit. They argued that the seawall was not a "new development," but instead was merely the repair and maintenance of an older wall. The Commission rejected this characterization and upheld the cease-and-desist order. Further, the court upheld the $1 million administrative penalty imposed by the Commission.

Third, in 2021, that court considered yet another Commission-related case, *Martin v. California Coastal Commission*. Here, the homeowner challenged a setback provision analogous to the one at issue in *Lindstrom*, as well as a condition forcing the homeowner to eliminate a basement from the proposed home.[113] The California appellate court considered evidence related to a local (Encinitas) Coastal Program requirement providing for an additional setback safety factor that took into account future sea-level rise. The court referenced its earlier decision in *Lindstrom,* finding that the Commission's approach to calculating sea-level rise was supported by "substantial evidence." Specifically, the court agreed with Commission staff, who relied on a state-specific report identified as the "best available science on which to base future planning on issues of sea-level rise science."[114] This report included modeling tools developed by the U.S. Geological Survey and California sea-level rise recommendations as set forth in a report by the Ocean Protection Council Science Advisory Team.[115]

What can we make of these three cases addressing the California Coastal Commission's regulatory authority? In all three instances, California state courts upheld the Coastal Commission's decisions, deferring to its expertise. It did not second-guess the scientific basis for the Commission's decisions;

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[110] Lindstrom v. California Coastal Commission, No. D074132 (Cal Ct. App. 2019).

[111] *Id.* The Court did, however, invalidate one condition as overbroad and unreasonable as drafted—that required the structured be removed in the event a government agency ordered the structure "not be occupied."

[112] *11 Lagunita, LLC*, *supra* note 109.

[113] Martin v. California Coastal Commission, No. D076956 23 (Cal. Ct. App. 2021).

[114] *Id.*

[115] *Id.*

rather, it relied upon the scientific reports upon which the Commission had relied. Nor did the courts defer to private property owner's interpretation of existing regulations.

State courts outside of California have also been asked to consider sea-level rise and climate impacts as they review local zoning board variance decisions. In the past decade, Connecticut and Virginia have wrestled with such cases, with many cases arising when the property owner sought to rebuild a home destroyed by Hurricane Sandy.

2. Connecticut: *Coastal Site Plans and Sea-Level Rise: A Piece of Paradise, LLC v. Borough of Fenwick Zoning Board of Appeals* (2015)

In *A Piece of Paradise, LLC v. Borough of Fenwick Zoning Board of Appeals*, a property owner challenged the zoning board's denial of a variance for a single-family home that did not comply with the coastal site plan.[116] The Connecticut superior court (the state's trial court) upheld the zoning board's decision, highlighting that the owner of the property—which bordered Long Island Sound and a tidal marsh—failed to consider environmental impacts, which included climate change-driven sea-level rise. Specifically, the court emphasized the role that the state's coastal management statutes, which are integrated into zoning regulation, played and that the zoning board is empowered to broadly consider factors affecting the public health, safety, convenience, and welfare.[117] Relevant to this case, one section of the state coastal management plan directs:

> [M]unicipalities [t]o consider in the planning process the potential impact of a *rise in sea level, coastal flooding, and erosion* patterns so as to minimize damage to destruction of life and property and minimize the necessity of public expenditure and shoreline armoring to protect future new development from such hazards as part of the coastal site plan review by the commission.[118]

The court found that the board's denial of the zoning variance was *not* illegal, arbitrary, capricious, or an abuse of discretion.[119] In upholding the local zoning board's decision, the court cited to a 2010 Report by the Adaptation Subcommittee to the Governor's Steering Committee on Climate Change that addressed climate change impacts throughout the state.[120] The court noted that its decision was "underscored by the likely impact on Long Island Sound from rising sea levels—with estimates ranging from twelve to fifty-five inches by the end of the century."[121] Further, the court rejected the plaintiff's contention that the zoning boards' variance denial constituted a taking.[122] *A Piece of Paradise* indicates that state courts may look to the underlying purpose of state coastal management plans when examining localized climate impacts. Part of this examination includes state governmental climate reports. Building variances sought within the coastal plain may well be subject to extra scrutiny if the variance sought runs contrary to projected sea-level rise impacts.

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116 A Piece of Paradise, LLC v. Borough of Fenwick Zoning Board of Appeals, No. LNDCV136047679S (Conn. Super. Ct. 2015).
117 *Id.* at 10.
118 *Id.* at 11 (emphasis added).
119 *Id.* at 12.
120 Adaption Subcommittee to the Governor's Steering Committee on Climate Change, "The Impacts of Climate Change Connecticut on Agriculture, Infrastructure, Natural Resources and Public Health" at 8 (2010), *available at* https://portal.ct.gov/-/media/deep/climatechange/impactsofclimatechangepdf.pdf.
121 *Id.*
122 *Id.* at 8.

3. Connecticut: *Turek v. Zoning Board of Appeals for the City of Milford* (2015)

In another Connecticut case, *Turek v. Zoning Board of Appeals for the City of Milford*, property owners sought a variance related to the proposed height of the waterfront home they were rebuilding after their original home was destroyed by Hurricane Sandy.[123] At issue was the proposed structure's height, which was designed to comply with laws and FEMA regulations as it was located in the FEMA-designated special flood hazard area (SFHA). Specifically, the local zoning regulations limited the height of homes in this area to 35 feet, but the property owners sought to build a home slightly above 38 feet to comply with FEMA regulations that mandated homes be built 13 feet above sea level.

The City of Milford unanimously denied the homeowners' application, and the owners challenged the decision, arguing that the zoning board's decision was "illegal, arbitrary and an abuse of discretion."[124] In particular, they argued that "the topography, the slope, the location in two zones in the special flood hazard area (SFHA) and the FEMA and state regulations present a *unique hardship* not impacting other properties within the same district."[125]

While the Connecticut court noted that the zoning board of appeals is entitled "with a liberal discretion," the court sided with the property owners. Why? First, the court explained that the board's denial based on a local "aesthetic" height requirement had failed to consider "the nuances and immediacy of flood hazard or sea-level rise and the elevation requirements . . . and is thus contrary to law and logic."[126] The height requirement failed to account for FEMA and state elevation mandates that were designed to protect the home. Indeed, failure to comply with FEMA regulations would jeopardize the property owner's ability to obtain flood insurance under the National Flood Insurance Program (NFIP).

Second, the court stated that Connecticut municipalities must consider sea-level rise changes published by NOAA—a requirement that the Town of Milford already acknowledged. The court cited to a study by the Connecticut Institute for Resilience and Climate Adaptation at the University of Connecticut that projected increased sea-level rise and increased flood risk in coastal areas. This risk amounted to a public safety concern, with the court highlighting that the aesthetic height requirement "should not outweigh consideration of the elevation requirement based upon public safety."[127] Finally, the court found that the plaintiffs experienced a hardship based upon the destruction of the home by Hurricane Sandy.

4. Connecticut: *Lauridsen Family Limited Partnership v. Zoning Board of Appeals of Town of Greenwich* (2018)

In another Connecticut case following Hurricane Sandy, property owners received approval from the Town of Greenwich to raze and rebuild an existing, nonconforming cottage that was destroyed by the hurricane.[128] The property was located in the coastal overlay and flood hazard zone, where it was exposed to coastal flooding during storm events. The new home, which was smaller than the

[123] Turek v. Zoning Board of Appeals for the City of Milford, No. LNDCV156063404S (Conn. Super. Ct. 2015).
[124] *Id.* at 2.
[125] *Id.*
[126] *Id.*
[127] *Id.*
[128] Lauridsen Family Limited Partnership v. Planning and Zoning Commission of the Town of Greenwich et al. CV-17-6080201-S (July 12, 2018).

original cottage, was described as a "modern, cube shaped design made of stone, concrete, and glass."[129] The owners sought a variance of the "flood area ratio" because raising the existing structure over eight feet to comply with flood hazard regulations was not feasible, as the existing foundation was built into the rocky shore. The owners also sought a "setback variation" for front, rear, and side yards so that the cottage "would be built to meet or exceed [FEMA requirements]."[130] These facts were somewhat unique in that the owners could not build on the existing site and still comply with existing flood regulations.

After the Greenwich zoning board conditionally granted approval of the variance, neighbors appealed.[131] A Connecticut Superior Court upheld the board's decision, citing the need to accommodate sea-level rise and flood hazards and noting that existing regulations concerning nonconforming uses failed to adequately take into account sea-level rise. The court found that the proposed dwelling would not substantially affect the comprehensive zoning plan, and the new dwelling did meet the flood hazard elevation requirements.[132] Notably, the comprehensive zoning plan addressed sea-level rise with a flood hazard overlay zone, but the existing plan failed to address future sea-level rise calculations or other climate impacts.

To support its decision, the court pointed to Greenwich's Plan of Conservation and Development that recognized sea-level rise as a basis to elevate homes.[133] The plan stated that "coastal flooding is also an increasingly important issue, as concerns about global warming and sea-level rise draw additional attention to this topic."[134]

The court also highlighted that the owners had already suffered hardship that was "not self-imposed" due to Hurricane Sandy.[135] In the court's reasoning, "the combination of the near total destruction by the storm and the need to meet federal and state flood hazard regulations constitute an extreme hardship."[136] The *Lauridsen* court favored a pragmatic approach, particularly because the variance was meant to comply with flood zone regulations and safeguard their home.[137] The court highlighted that "other storm damaged waterfront homes cannot realistically be rebuilt or elevated and comply with the new flood regulations *without some elasticity in the application of regulations*."[138] Further, that court appeared frustrated that zoning regulations failed to keep pace with climate change and sea-level rise, noting that "towns have been slow and inconsistent in addressing these issues in their regulations."[139] The court concluded by urging the Connecticut Legislature to update zoning regulations to better account for sea-level rise and climate-driven catastrophe.[140]

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[129] *Id.* at 3.
[130] *Id.* at 10.
[131] The board stated that there was "hardship due to the lot's shape, size and location of the property within a flood zone combined with a reduction of nonconformities." *Id.* at 9.
[132] *Id.* at 13.
[133] *Id.* at 15 (stating that "[c]oastal flooding is also an increasingly important issue as concerns about global warming and sea level rise draw attention to this topic. Areas within the Old Greenwich coastal zone are particularly affected.").
[134] *Id.* at 15. The court also referenced the work done by the Connecticut Institute for Resilience and Climate Adaptation finding that Connecticut will get more sea-level rise than other areas. *Id.* at 15 n.22.
[135] *Id.* at 18.
[136] *Id.* at 21.
[137] The court referenced transcript comments from commission members that highlighted changing conditions, and the need to get houses out of the flood zone. *Id.* at 14.
[138] *Id.* at 19 (emphasis added).
[139] *Id.* at 19 n.27.
[140] *Id.* at 19.

5. Virginia: *Argos Properties II, LLC v. City Council for Virginia Beach* (2018)

In Virginia, in *Argos Properties II, LLC v. City Council for Virginia Beach*, a real estate developer challenged a zoning decision that would have prevented a residential development in an area threatened by sea-level rise.[141] The Virginia Beach city council required applicants to comply with stricter stormwater and flooding standards than the state's minimum requirements. The court affirmed the city council's decision to require the builder to account for future sea-level rise and flooding projections, finding it was a reasonable exercise of its authority even though this new sea-level rise criteria was not specifically contained in local ordinances or state regulations.

C. Physical and Regulatory Takings Challenges

As outlined above, the IPCC reports and U.S. National Climate Assessment have consistently highlighted sea-level rise impacts to the American coastline. In response to these scientific developments, some state and local governments are restricting building along the coast and considering other protective measures, including armoring.

Coastal armoring is one adaptation response to sea-level rise. Armoring may occur in the form of temporary sandbags put in place before an extreme weather event or could include more permanent installations, such as seawalls or offshore breakers in harbors. Although armoring is intended to prevent erosion, it may result in increased erosion of surrounding areas, as armoring modifies the natural pattern of sand movement and replenishment along the coast. These actions may raise issues under the U.S. Constitution's Fifth Amendment's Takings Clause, which prohibits the taking of private property for public use without just compensation.[142] Any physical invasion of property, however small, implicates the Takings Clause.[143]

Courts have determined that armoring, whether hard (e.g., sea walls) or soft (e.g., living shorelines to buffer storm surges),[144] qualifies as a "public use" within Fifth Amendment jurisprudence.[145] Therefore, when a government action mandates armoring on private property, it implicates the Fifth Amendment's prohibition on physical takings and requires just compensation to be paid to the property owner.[146] Alternatively, a local governmental entity may well deny an armoring permit sought by a private party out of concerns that the diverted water will harm adjacent property owners.

What's more, armoring often causes a new physical diversion of water. Armoring the shoreline can cause seawater and saltwater to flow elsewhere, causing damage to adjacent properties and coastal aquifers that were previously untouched by this water intrusion. This diverted water can create

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141 Petition for Review and Complaint, Argos Properties II v. City Council for Virginia Beach, CL1800289-00 (Va. Cir. Ct. May 17, 2018).

142 U.S. CONST. amend. V. The Fifth Amendment's prohibition on taking private property has been incorporated to apply to state and local action. Chicago, Burlington & Quincy Railroad Co. v. City of Chicago, 166 U.S. 226, 241 (1897). BLACK'S LAW DICTIONARY 365 (11th ed. 2019).

143 Loretto v. Teleprompter Manhattan CATV Corp., 458 U.S. 435-40 (1982).

144 For a discussion of soft armoring techniques, see Ryan Rowberry, *Avoiding Atlantis: Protecting Urban Cultural Heritage From Disaster*, *in* HOW CITIES WILL SAVE THE WORLD: URBAN INNOVATION IN THE FACE OF POPULATION FLOWS, CLIMATE CHANGE AND ECONOMIC INEQUALITY (ed. Ray Brescia & John Travis Marshall) 49, 52-54 (2016).

145 Kelo v. City of New London, 545 U.S. 469, 480 (2005).

146 *Loretto*, 458 U.S. at 435-40.

liability under existing property or tort law through the negative impacts on nearby property owners who can credibly argue that the government's installation of a sea wall, including beyond the directly affected property, amounts to a taking, albeit indirectly.[147]

The concept of an *indirect* taking was first articulated in 1872 by the Supreme Court in *Pumpelly v. Green Bay Co.* In *Pumpelly,* the United States constructed a dam that resulted in "superinduced additions of water" that flooded a citizen's property.[148] The Court held that "where [private property] is actually invaded by superinduced additions of water, earth, sand and other material, or by having any artificial structure placed on it, so as to effectively destroy or impair its usefulness, it is a taking, within the meaning of the Constitution."[149] Thus, any sea wall armoring that diverts water onto another property, causing damage, may constitute a physical taking.[150]

Property owners who invest in coastal armoring at their own expense may also incur legal risk. Historically, the "Common Enemy" doctrine has characterized water runoff as a common enemy, thus indemnifying the private property owner from water runoff onto an adjacent property.[151] But, while the Supreme Court has not yet wrestled with the outer scope of the Common Enemy doctrine, the doctrine is no longer an absolute defense.[152] The following examples highlight physical and regulatory takings challenges.

1. Coastal Zone Regulations: *Lucas v. South Carolina Coastal* (1992)

Beyond coastal armoring, states and localities may choose to pursue an accommodation strategy in addition to or in lieu of armoring. Accommodation may come in the form of new land use laws that take into account climate science, such as prohibiting building in certain coastal areas exposed to sea-level rise. These coastal regulations are intended as a response to an environmental challenge, but also risk implicating the takings doctrine.[153]

Historically, states and localities have enjoyed broad deference and discretion in promulgating zoning regulations provided that they "substantially advance[ ] a legitimate state interest."[154] But this discretion is not absolute, and a broader assertion of coastal regulations—such as the prohibition on construction in areas uniquely vulnerable to sea-level rise—may give rise to regulatory takings claims. Regulatory takings is a 100-year-old common-law doctrine that emerged well before climate

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147 If this is due to the actions of a private-property owner, the Takings Clause is not implicated, but there may be a cause of action in tort. See discussion *infra* Part IV.A.
148 Pumpelly v. Green Bay Co., 80 U.S. (13 Wall.) 166, 181-82 (1872).
149 *Id.* at 181.
150 Arkansas Game Comm. v. United States*,* 568 U.S. 23 (2012) (holding that temporary flooding can trigger a compensable taking).
151 The common enemy doctrine is a long-standing legal principle by which landowners have "the right to repel or capture water without becoming liable for the adverse effects this might have on neighbors." SIDERS, *supra* note 70.
152 *See, e.g.*, Grundy v. Thurston County, 117 P.3d 1089, 1090 (Wash. 2005) (holding that the common enemy doctrine does not apply to seawater intrusions).
153 U.S. CONST. amend. V; U.S. CONST. amend. XIV, §2. Robin Kundis Craig, *Of Sea-Level Rise and Superstorms: The Public Health Police Power as a Means of Defending Against "Takings" Challenges to Coastal Regulation*, 22 N.Y.U. ENV'T L.J. 84 (2014). The Fifth Amendment prohibition on taking private property has been incorporated to encompass governmental action at the state and local level.
154 *See id. See generally* Steven J. Eagle, *A Prospective Look at Property Rights and Environmental Regulation*, 20 GEO. MASON L. REV. 725 (2013) (addressing the future interaction of environmental regulation and private-property rights).

change was fully understood, and well before land use regulations accounted for climate change-driven sea-level rise.[155] However, in the face of sea-level rise and associated litigation, the doctrine has increased importance.

In *Lucas v. South Carolina Coastal Council*, the Supreme Court addressed the outer scope of South Carolina's authority to regulate its coastal zone under the Coastal Zone Management Act (CZMA) and South Carolina's Coastal Management Plan (CMP).[156] This timeline highlights the key dates and events that led to litigation.

- 1977: South Carolina Legislature passes a CMP, restricting development activities in the coastal zone. Building in the relatively narrow "critical area" requires a permit from the S.C. Coastal Council.
- 1986: petitioner David Lucas purchases property outside of the critical area on the Isle of Palms for $975,000.
- Oct. 1986: South Carolina appoints a "Blue Ribbon Committee on Beachfront Management" to develop possible solutions to combat beach erosion.
- Mar. 1987: Committee finds that South Carolina's beaches were "critically eroding" and proposes land use restrictions.
- July 1988: South Carolina Legislature enacts the Beachfront Management Act which barred Lucas from erecting any permanent habitable structure on his land.[157]

Relevant to Mr. Lucas, the Committee's proposed regulations enlarged the designated critical areas to include his land. Referencing an earlier EPA report, the Committee stated that:

> Sea-level rise in this century is a scientifically documented fact. Our shoreline is suffering from its effects today . . . [EPA] predicts a possible one-foot rise in sea-level rise over the next thirty to forty years and approximately three feet over the next hundred years. It must be accepted that regardless of attempts to forestall the process, the Atlantic Ocean . . . is ultimately going to force those who have built too near the beach front to retreat.[158]

The Blue Ribbon Committee's Report is remarkably prescient, written in 1987 before the First Assessment Report for the IPCC and the First NCA. It demonstrates that future sea-level rise was well understood as an environmental and "scientifically documented fact." While climate change is not emphasized in this report, it demonstrates that the issue of sea-level rise is not new. And since the Report was written, our collective knowledge of sea-level rise has only increased.

In *Lucas*, the Court held that South Carolina's prohibition on construction amounted to a taking, requiring just compensation. In ruling for the property owner, the Court announced a new takings category: when governmental action deprives the owner of "all economically viable use" of

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155 Pennsylvania Coal Co. v. Mahon, 260 U.S. 393, 415 (1922).
156 Lucas v. South Carolina Coastal Council, 505 U.S. 1003 (1992).
157 *Lucas*, 505 U.S. at 1037. Coastal Management Plans are developed pursuant to the federal CZMA.
158 S.C. BLUE RIBBON COMM. ON BEACHFRONT MGMT., REPORT at ii (1987).

property.[159] The Supreme Court highlighted that background principles of state nuisance and property law are limitations placed on land ownership.[160]

Decided in 1992, the opinion does not explicitly discuss climate change, but over 30 years later, this creation of a new categorical taking may be having a chilling effect on state and local governmental entities that desire to pass forward-looking adaptation measures but fear a *Lucas*-stylized lawsuit.[161] To be sure, courts have been reluctant to find *Lucas*-stylized per se takings, but as Law Prof. Robin Craig has argued, even unsuccessful takings litigation can "chill" the willingness of state and local governments to engage in innovative coastal management.[162]

In addition, writing for the majority, Justice Antonin Scalia noted "that the fact that a particular use has long been engaged in by similarly situated owners ordinarily imports a lack of any common-law prohibition (though *changed circumstances or new knowledge* may make what was previously permissible no longer so . . .).[163] The Court in *Lucas* did not elaborate on what, precisely, includes a changed circumstance or new knowledge. But climate science and our collective understanding of sea-level rise has certainly evolved since *Lucas* was decided in 1992—whether this aspect of the total taking inquiry will be more broadly applied by judges to future *Lucas*-stylized construction prohibitions remains to be seen.

State and federal courts' treatment of inverse condemnation are also of growing importance for prospective sea-level rise litigation. Inverse condemnation is an "action brought by a property owner for compensation from a governmental entity that has taken the owner's property without bringing formal condemnation proceedings."[164] Consider the following state court cases from California, Maryland, and Florida.

2. California: *Arreola v. County of Monterey* (2002)

In 2002, the California Court of Appeals grappled with how to address governmental inaction in the face of a known flooding risk in *Arreola v. County of Monterey*.[165] That case involved a property owner who sued Monterey County under an inverse condemnation theory for damage caused by flooding

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[159] *Lucas*, 505 U.S. at 1031, 1035. *Lucas* is predicated on depriving an owner of all beneficial use—a regulation that reduces the value of the property by 95% (for example) is not a per se taking under *Lucas*. *See also* Palazzolo v. Rhode Island, 535 U.S. 606, 630-32 (2001).
[160] *Lucas*, 505 U.S. at 1028.
[161] *See, e.g.*, Danaya C. Wright, *Weaponizing Private Property and the Chilling Effect of Regulatory Takings*, *in* THE CAMBRIDGE HANDBOOK OF DISASTER LAW AND POLICY 347 (2022). *But see* Richard Lazarus, *Putting the Correct "Spin" on* Lucas, 45 STAN. L. REV. 1411, 1427 (1993) (noting that "because environmental laws almost never result in total economic deprivations . . . categorical exemptions will rarely apply").
[162] Craig, *supra* note 153, at 87.
[163] *Lucas*, 505 U.S. at 1031 (emphasis provided).
[164] BLACK'S LAW DICTIONARY 365 (11th ed. 2019). In inverse condemnation proceedings, a claimant sues the government following the passage of a regulation or similar action that imposes a large economic burden on its property that "in all fairness and justice" the government should provide just compensation. Armstrong v. United States, 364 U.S. 40, 49 (1960).
[165] Arreola v. Cnty. of Monterey, 99 Cal. App. 4th, 722, 122 Cal. Rptr. 2d 38, 55 (2002).

from a river levee breach.[166] The owner claimed that governmental officials were aware that the levee was in danger of failing but did not take action to safeguard its residents.[167]

The California court ruled in favor of the property owner, even though the County did not take an affirmative action. Instead, the court found that governmental inaction in the face of a *known risk* was sufficient to support an inverse condemnation claim. The court focused on California's constitutional duties, which stated that private property may be taken or damaged only when just compensation has been paid.[168] The court elaborated that to "support liability in inverse condemnation it is enough to show that the entity was aware of the risk posed by its public improvement and deliberately chose a course of action—or inaction—in the face of that known risk."[169] Thus, in *Arreola,* the government was found liable for damages that resulted from the failure to maintain a structure that it had created.

Since *Arreola* was decided in 2002, several NCA and IPCC reports have increased societies' collective climate knowledge of the dangers of sea-level rise and storm surge described in detail in the first half of this module. Nonetheless, courts have been reluctant to find that there is an affirmative duty on governmental actors to safeguard a community in the face of sea-level rise. Accordingly, this "adaptation dilemma" seems to favor governmental inaction.[170] Indeed, taking ex ante, proactive measures to reduce coastal flooding hazards may well be "legally disfavored."[171]

In addition, the sheer scope and scale of the climate problem may act as a shield to regulatory takings (discussed below)—particularly if the government is upfront about the risks of living in a particular location. This may shape any reasonable investment-backed expectations analysis, a key factor in shielding the government from regulatory takings challenges.[172]

3. Maryland: *Litz v. Maryland Department of the Environment* (2016)

In *Litz v. Maryland Department of the Environment,* the owner of a recreational campground alleged that the Town of Goldsboro, Maryland, failed to adequately maintain the town's septic system, causing millions of dollars in damage to their property. The Court of Appeals of Maryland applied *Arreola*'s reasoning, holding that the Maryland Department of the Environment failed to adequately maintain important infrastructure in the face of a known danger. This failure to repair infrastructure in the face of a known danger amounted to an inverse condemnation, requiring just compensation.[173]

While neither *Arreola* nor *Litz* are about sea-level rise per se, taken together they nevertheless demonstrate a willingness for courts to uphold inverse condemnation claims in the face of a known

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166 *Id.*
167 The County had been alerted to this danger by affected property owners. *See id.*
168 CAL. CONST., art. I, §19.
169 122 Cal. Rptr. 2d at 69-72.
170 Dan Farber, *Temporary Takings and the Adaptation Dilemma*, LEGAL PLANET (May 6, 2024).
171 *Id.*
172 Penn Central Transportation Company v. New York City, 438 U.S. 10 (1978).
173 Litz v. Maryland Dept. of Environment, 131 A.3d 923 (Md. 2016). "An inverse condemnation claim is characterized as a shorthand description of the manner in which a landowner recovers just compensation for a taking of his property of his property when condemnation procedures have not been instituted." *Id.* at 930 (quoting Coll. Bowl, Inc. v. Mayor & City of Council of Baltimore, 394 M.D. 482, 489 (2006)).

risk. Indeed, if this "known risk" standard is more widely embraced in states and localities vulnerable to sea-level rise, a flood of litigation may follow. For example, if a state fails to adequately maintain shoreline armoring in a climate-exposed barrier island, plaintiffs might assert that the government failed to take action in the face of a known risk as sea-level rise and storm surge were reasonably foreseeable. But again, no such claim would follow if the government did not invest in adaptation measures in the first instance.

4. Florida: *Jordan v. St. Johns County* (2011)

A deliberate disinvestment strategy can also trigger an inverse condemnation challenge, on the theory that a failure to maintain roads and services effectively condemns the properties made inaccessible by a lack of access. Some communities may decide to stop maintaining or repairing infrastructure that is uniquely vulnerable to sea-level rise and other climate impacts. Specifically, localities faced with climate impacts to their public roads and other infrastructure are ceasing maintenance of certain coastal roads and considering the cessation of city services.[174] Some communities are even considering shutting off emergency services[175] to areas exposed to hazards made worse by climate change.[176]

A 2011 Florida case illustrates this interplay. In that case, St. John's County failed to follow its own procedures when it stopped investing in a coastal road exposed to climate impacts. Along Florida's Atlantic coast, extreme weather events—exacerbated by sea-level rise—routinely battered a coastal road, Old A1A.[177] This imposed substantial costs on St. John's County, as it struggled to maintain and repair the road.[178] In light of these climate change-induced impacts and the financial burden of maintaining the road, the County allowed Old A1A to atrophy and Old A1A fell into disrepair, preventing homeowners from accessing their home.

Wealthy landowners living on a coastal barrier island community in Summer Haven, Florida, who accessed their homes via Old A1A, asserted an inverse condemnation claim against the local county government, alleging that the county had de facto abandoned Old A1A without following the formal road abandonment procedures required by local law.[179] Under the plaintiffs' theory, the county had an affirmative duty to maintain the road, keep Old A1A in good order, and ensure continuous vehicular access.[180] In response, St. John's County claimed that it has wide discretion in determining the level of road maintenance.[181]

After the trial court ruled against the plaintiffs, the Florida Fifth District Court of Appeals reversed, holding that "the County ha[d] a duty to reasonably maintain Old A1A as long as it is a public road

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[174] Jordan v. St. Johns County, 63 So. 3d 835, 836 (Fla. App. 5th Dist. 2011).
[175] "Emergency services" is defined capaciously here to include fire, police, emergency first responders, and the National Guard.
[176] As a general matter under tort law, the government does not have an affirmative legal duty to provide emergency services. Deshaney v. Winnebago County Department of Social Services, 489 U.S. 189, 197-98 (1989).
[177] Old A1A is surrounded by the Atlantic Ocean and the Intracoastal Waterway. Despite the clear climate risks, property value along Old A1A has exploded in recent years.
[178] By one estimate, the cost to repair and maintain Old A1A was $250,000, a figure that exceeded the municipality's entire road budget.
[179] Jordan v. St. Johns County, 63 So. 3d 835, 839 (Fla. App. 5th Dist. 2011).
[180] *Id.* at 837.
[181] *Id.* at 837.

dedicated to the public use."[182] The court, however, rejected the notion the County had any "duty to maintain the road in a particular manner or at a particular level of accessibility."[183] Rather, the county was obligated to "provide a *reasonable level of maintenance that affords meaningful access*, unless or until the County formally abandons the road."[184]

In holding that the County's failure to maintain and repair Old A1A could support a cognizable inverse condemnation claim,[185] the appellate court referenced an earlier Florida Supreme Court decision that had found that inverse condemnation claims do not necessarily require a complete loss of property.[186] It noted that natural forces played a role in the road's degradation. Still, it held that the County's failure to maintain the road may have effectuated a de facto abandonment—a key factual question for the lower courts to resolve.[187] The Florida Court of Appeals remanded after which the parties agreed to a settlement. But *Jordan*'s core reasoning—that governmental inaction could support a takings claim—now binds lower Florida trial courts.[188]

D. Shifting Property Boundaries

Sea-level rise causes land loss via erosion, accretion, or avulsion. Accretion can be a slow addition or removal of sand while avulsion "is a sudden loss or addition of land, usually in a large amount."[189] Accretion occurs via slow onset beach erosion, soaking up the land gradually over time. Avulsion is quick and often violent, and occurs when a storm causes catastrophic damage and moves the beach. These changes can result in shifting property lines between state property lines and private property lines, thus raising legal issues about how those lines should be treated.

In *Severance v. Patterson*, the Texas Supreme Court addressed the difference between avulsion and accretion in the contexts of rolling easements.[190] In that case, the Texas Supreme Court was answering a question of Texas law certified to it by the U.S. Court of Appeals for the Fifth Circuit about whether existing public easements moved onto private beachfront properties on Galveston Island's West Beach when there was an avulsive event. The Texas court said they did not, that the property lines were unaffected by the event; however, the state could establish new public easements pursuant to Texas statute or the common law.

In *Stop the Beach Renourishment v. Florida Department of Environmental Protection*, the Supreme Court considered a case brought by property owners in two counties in the Florida panhandle (Destin and Walton) who claimed that beach restoration project amounted to a taking. Florida's Beach and Shore Preservation Act governs beach renourishment and restoration and authorized the creation of a new "erosion control line" that delineates the border between Florida state property and private

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[182] *Id.* at 838.
[183] *Id.*
[184] *Id.* (emphasis added).
[185] *Id.* at 839. "We conclude that governmental inaction—in the face of an affirmative duty to act—can support a claim for inverse condemnation." *Id.*
[186] *Id.* at 839 (quoting Palm Beach County v. Tessler, 538 So. 2d 846, 849 (Fla. 1989)).
[187] *Id.* Further, the County had issued several building permits in recent years resulting in several additional beachfront homes being built. *Id.* at 838.
[188] Shana Jones et al., *Roads to Nowhere in Four States: State and Local Governments in the Atlantic Southeast Facing Sea-Level Rise*, 44 COLUM. J. ENV'T L. 67, 112 (2019).
[189] SIDERS, *supra* note 70, at 56.
[190] Severance v. Patterson, 345 S.W.3d 49 (Tex. 2011).

property. Those counties were granted permits by the Florida Department of Environmental Protection to restore almost seven miles of a beach by adding 75 feet of dry sand seaward from the former mean high tide line.

The property owners (who received considerable benefit from the beach renourishment project) sued the Department, arguing that their property would no longer be directly on the coast and they would be deprived of the right to future "accretions" to their property. The Florida Supreme Court rejected this argument, finding that submerged lands that become dry following a storm become property of the state and this remains true regardless of what causes the change (i.e., renourishment or nature). The Supreme Court agreed, finding that no taking had occurred.[191]

These Florida communities are not unique. Many localities are investing in expensive beach renourishment projects to fight erosion, and while many homeowners have welcomed this adaptation effort, others have pursued takings litigation claiming a dune reconstruction effort has resulted in part of their property being condemned. While this constitutes a physical taking, it is less clear how to calculate "just compensation" particularly when the homeowner benefits from the reconstruction, but also loses their oceanfront vista.

This issue was presented in a 2013 case from New Jersey, *Borough of Harvey Cedars v. Karan*. The Borough had taken part of the Karans' beachfront property to construct a dune to "serve as a barrier-wall, protecting the homes and businesses of Long Beach Island from the destructive fury of the ocean." The Karans sued and were awarded $375,000 in damages, premised mostly on the loss of their oceanfront view. The New Jersey Supreme Court reversed and remanded, holding that because the homeowners obtained a real storm protection benefit from the dune, this benefit must be included as part of the just compensation analysis.[192] On remand, the jury awarded damages to the Karans of only $300.[193]

Other issues around "just compensation" are likely to arise because as sea levels rise, millions of homes face certain inundation. Many local governments will consider actions to address public safety issues, but what is just compensation when a property faces increased flooding and is certain to eventually be under water? A court might conclude that the market price is the only just compensation. Alternatively, it might conclude that the market price is inflated by lack of understanding of sea-level rise risk and that the public interest demands that compensation amounts reflect declining value due to impending sea-level rise and the cost to government of removing an abandoned structure posing a public health threat.

E. Emerging Issues

Just compensation is not the only emerging issue. Two more of interest are:

- **Relocation From Rising Seas:** Rising seas will inundate millions of homes and other property along the U.S. coast forcing relocation to higher ground. Government may choose

[191] Stop the Beach Renourishment v. Fla. Dept. of Env't Protection, 560 U.S. 702, 729-32 (2010).
[192] Borough of Harvey Cedars v. Karan, 214 N.J. 384 (2013).
[193] *See* Acting Attorney General Hoffman Announces Legal Victory for Beachfront Easement Acquisition Efforts in Harvey Cedars (June 2014), *available at* https://nj.gov/oag/newsreleases14/pr20140630b.html.

to let individuals make relocation decisions or may decide to manage the relocation process to varying degrees. Managed retreat is defined as the purposeful movement of people and property out of harm's way.[194] Indeed, large-scale migration from low-lying coastal areas is inevitable; the only uncertainty is the time scale. This movement of people and communities can take many forms, with some more managed and planned than others. In certain instances, mandatory, government-led and enforced retreat from climate areas via eminent domain authority may make sense, but will require just compensation.[195] But eminent domain is politically unpopular,[196] and would likely leave governments paying an enormous fiscal and political price tag. A key legal issue will be whether government actions, short of outright eminent domain, such as condemnation of unsafe structures due to rising seas and flooding, will be considered a taking under the Fifth Amendment. Some government actions, such as disclosure of sea-level rise risks, could discourage takings litigation.

- **Disclosure Laws:** Increasingly, states are requiring that sellers disclose past and future flood risk as part of a real estate transaction and some states are also requiring disclosure of sea-level rise-related flood risk. For example, New Jersey now requires that sellers and landlords disclose known and potential flood risks associated with real property, and discusses these in the context of climate change.[197] Hawaii's disclosure requirement is even more specific to sea-level rise. There, sellers must disclose sea-level rise risks for properties within a Sea-Level Rise Exposure Area, or those properties that are at risk given a 3.2-foot rise in sea levels by 2050. These and similar policies will certainly impact the *Penn Central Transportation Company v. New York City* reasonable investment-backed expectations analysis, but it remains unclear how judges will weigh such disclosure laws.

F. Conclusion

Climate change is leading to higher sea levels, more intense storms, and increased flooding in vast swaths of the United States. These impacts are often compounding. For example, repeated flood damage is associated with decreasing coastal property values and increasing insurance rates, which is exacerbated by the loss of salt marsh ecosystems that previously moderated storm flooding.[198] In response, private property owners are taking proactive adaptation steps to safeguard their homes. And governmental officials are wrestling with resisting, accommodating, or retreating from climate impacts.[199] Each strategy faces unique and evolving challenges for the law as well as society at large. The noncomprehensive table below summarizes some of the physical, environmental, and social impacts of sea-level rise accompanied by examples of related legal issues.

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[194] Siders, *supra* note 66, at 216.
[195] U.S. CONST. amend. V.
[196] For a discussion of the political upheaval associated with the City of New London's use of eminent domain to foster economic redevelopment, see Kelo v. City of New London, 545 U.S. 469, 480 (2005) (emphasis added).
[197] New Jersey Dept. of Env't Protection, *Flood Risk Notification*, *available at* https://dep.nj.gov/flooddisclosure/.
[198] *See* Mark Nevitt & Michael Pappas, *Climate Risk, Insurance Retreat, and State Response*, 58 GA. L. REV. 1603 (2024) (discussing insurance retreat in Florida, Louisiana, and California).
[199] Nevitt, *supra* note 66.

Impacted category	Examples of impacts	Repercussions	Legal Issues
Infrastructure - Public roads, parks, bridges, government buildings, ports, municipal health and safety infrastructure, etc.	- Reduced or inconsistent coastal access to goods and services via ports, impacts to overseas trade - Contamination of drinking water[200] - Flooding and storm damage to U.S. military bases[201]	- Increased cost of damage repair; disputes around how these costs are allocated[202] - Increased pressure on already weak infrastructure systems (e.g., freshwater drinking supplies)	- Regulatory takings challenges if the government fails to upkeep roads[203] - Statutory challenges if a governmental entity does not follow the prescribed road abandonment procedures[204] - Legal challenges if the U.S. Army Corps of Engineers fails to adequately maintain levees/dams[205] -Damage to military installations and national security infrastructure undermine military department mission to "man, train, equip"[206]
Property & Livelihood - Homes and property - Businesses and livelihoods (agriculture, fisheries, coastal energy production, etc.)	- Property damage due to enhanced storm flooding - Loss of land due to erosion and/or inundation - Loss of crops or due to inundation/storm flooding, or flooding-related soil	- Economic loss; disputes around responsible parties for flood-related damages - Disputes around responsible parties for adaptation measures - Property values often drop in flood zones - Insurance rates go up in flood zones, or insurance	- National Flood Insurance Program facing bankruptcy for Repetitive Loss Properties - Privacy Act & state flood laws obfuscate flood risk[209] - Seawall armoring implicates Takings Clause[210]

[200] For example, saltwater intrusion up the Mississippi River can damage water infrastructure and corrode lead pipes in New Orleans and other nearby regions. *See* Chelsea Branstead & Carlie Kollath Wells, *What We Know About the Saltwater Intrusion in New Orleans*, AXIOS (Sept. 25, 2023), https://www.axios.com/2023/09/25/mississippi-saltwater-intrusion-drinking-supply.

[201] John A. Hall et al., *Regional Sea Level Scenarios for Coastal Risk Management: Managing the Uncertainty of Future Sea Level Change and Extreme Water Levels for Department of Defense Coastal Sites Worldwide*, U.S. DEPARTMENT OF DEFENSE, STRATEGIC ENVIRONMENTAL RESEARCH PROGRAM (2016).

[202] For example, arguments over government spending on infrastructure that benefits only a few residents; *see* Christopher Flavelle & Patricia Mazzei, *Florida Keys Deliver a Hard Message: As Seas Rise, Some Places Can't Be Saved*, N.Y. TIMES (Dec. 4, 2019).

[203] This implicates the scope of the duty to maintain and duty to repair infrastructure.

[204] Jordan v. St. Johns County, 63 So. 3d 835, 836-37 (Fla. App. 5th Dist. 2011).

[205] These may not be successful. *See* St. Bernard Par. Gov't v. United States, 887 F.3d 1354 (2018) (overruling St. Bernard Par. Gov't v. United States, 121 Fed. Cl. 687 (2015), and finding plaintiff's indirect takings claim based on government inaction failed).

[206] 10 U.S.C. §5013.

[209] 5 U.S.C. §552a (2020); 44 C.F.R. §206.110 (2020); *see also Frequently Asked Questions About NFIP Policies and Data Claims*, FEMA, https://nfipservices.floodsmart.gov/frequently-asked-questions-about-nfip-policies-and-claims-data (last visited Feb. 7, 2024). For a discussion of the role of the Privacy Act's role in obfuscating climate risk, see Mark Nevitt, *Destroy, Rebuild, Repeat: How to Break the Climate Disaster Cycle*, 76 VAND. L. REV. __ (2025) (forthcoming).

[210] U.S. CONST. amend. V.

	contamination or salinization[207]	companies pull out altogether[208] - Economic instability arises when local/municipal funds are needed for damage repair	- Stafford Act focused on ex post disaster rebuilding[211]
Ecosystem & Environment - Estuaries, deltas, marshes, mangroves, seagrasses, beaches, and reefs - Species living in coastal environments	- Salinization causes ecosystem restructure, degradation - Increased wave erosion causes loss of wetlands, less carbon storage potential - "Coastal squeeze": loss of natural habitats causes landward transgression of animals and plants, but anthropogenic structures or actions compress these habitable zones	- Loss of (non-human) life; threats to endangered species (or extinction)[212] - Economic loss as coastal tourism opportunities diminish - Loss/degradation of natural flood mitigation barriers puts human communities at risk - Ecosystem degradation causes compounding harm to fisheries	- Endangered Species Act ability to address climate risk[213] - Property law challenges to beach renourishment efforts[214] - Shifting property boundaries due to avulsion and accretion
Human Dimensions - Health (mental, physical), loss of life, displacement, loss of assets/livelihood	- Displacement causes short- or long-term migration - Health impacts from water contamination[215] - Livelihood risks, e.g., subsistence fishing or local food reliance	- Exacerbated social inequities; impacts are disproportionate among marginalized social groups and thus compound with other vulnerabilities - Displacement requires resettlement agreements - "Coastal squeeze" in human populations, not just animals, can cause a housing crisis and climate gentrification (e.g.	- Wealthier communities use existing laws to "game the system" for relocation funds - Other equity and environmental justice issues may implicate Due Process and Equal Protection concerns

[207] Michael Graff, *Millions of Dead Chickens and Pigs Found in Hurricane Floods*, THE GUARDIAN (Sept. 22, 2018).
[208] RRBH Law, *Why Are Home Insurance Companies Leaving Florida?* (last modified July 25, 2023) https://rrbhlaw.com/why-are-home-insurance-companies-leaving-florida/.
[211] The Stafford Act governs disaster declarations. *See* CONG. RSCH. SERV., IN11696, *Climate Change, Slow-Onset Disasters, and the Federal Emergency Management Agency* (May 28, 2024), *available at* https://crsreports.congress.gov/product/pdf/IN/IN11696.
[212] *Barrier Reef Rodent Is First Mammal Declared Extinct Due to Climate Change*, The University of Queensland, Australia (June 14, 2016), https://www.uq.edu.au/news/article/2016/06/barrier-reef-rodent-first-mammal-declared-extinct-due-climate-change.
[213] J.B. Ruhl, *Climate Change and the Endangered Species Act: Building Bridges to the No-Analog Future*, 88 B.U. L. REV. 1, (2008).
[214] Stop the Beach Renourishment v. Fla. Dept. of Env't Protection, 560 U.S. 702, 729-32 (2010).
[215] For example, floodwater can contain harmful substances, or groundwater can be contaminated. *See* Fatemeh Izaditame et al., *Sea-Level-Rise-Induced Flooding Drives Arsenic Release From Coastal Sediments*, 423 J. HAZARDOUS MATERIALS 127161 (2022).

		displacement of existing lower-income communities by wealthier ones moving inland) - Lack of food access (e.g., subsistence fishing) can have negative effects on nutrition, encroach on tribal rights - Obtaining sufficient aid for adaptation or recovery efforts can be challenging -People exposed to weather- or climate-related disasters experience mental health impacts (depression, post-traumatic stress disorder, and anxiety, often simultaneously[216]	

[216] Kristie L. Ebi et al., *Chapter 14: Human Health*, *in* IMPACTS, RISKS AND ADAPTATION IN THE UNITED STATES: FOURTH NATIONAL CLIMATE ASSESSMENT, VOLUME II, U.S. GLOBAL CHANGE RESEARCH PROGRAM (2018).