Arctic Answers
Science briefs from the Study of Environmental Arctic Change
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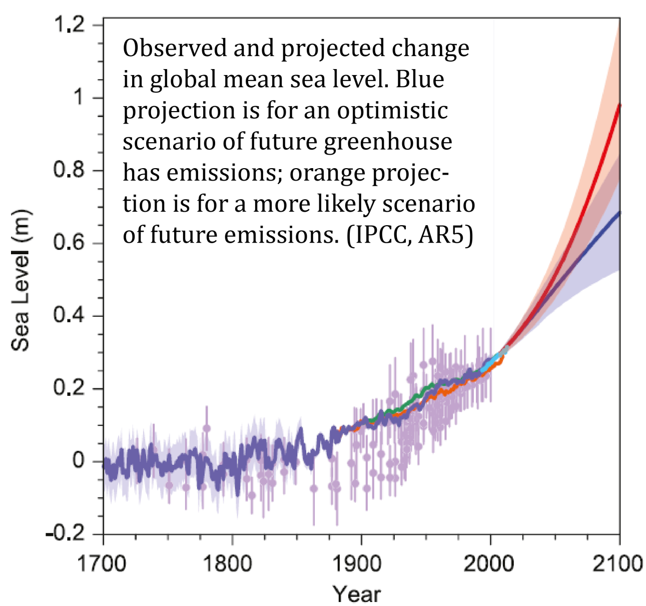
How fast is sea level rising?

THE ISSUE. A direct and ubiquitous consequence of our warming climate is rising sea level. Increasing rates of warming have accelerated the rate of sea level rise and the frequency of coastal flooding.

WHY IT MATTERS. Flooding is the most common and most expensive natural disaster. Sea level changes tend to be gradual, but serve as the "launching pad" for storm surges, tides, and waves, allowing them to drive water farther inland, increasing damage to ecosystems and coastal development and threatening human life. Between storms, a gradually rising sea level erodes coastal infrastructure, shortening the lifetimes of resort facilities and commercial industries. Multiple factors contribute to rising sea level but regardless of source, the interconnectedness of the world's oceans distribute these changes globally.

STATE OF KNOWLEDGE. Sea level has been rising since the end of the last ice age (~20,000 years ago). During periods of rapid ice sheet loss, sea level rose as high as 30 mm/yr [1]. During the 20th century, the rate averaged 1.5-1.9 mm/yr, due primarily to warming of the upper ocean (thermal expansion) but with a nearly equivalent contribution from glacier loss [2]. More recently, the rate of sea level rise has increased to a present value of 3.4 mm/yr due to increasing losses from glaciers and the Greenland ice sheet [3]. The globally averaged rate of sea level rise is projected to continue to increase as the oceans continue to warm and glaciers and both the Greenland and Antarctic ice sheets shrink faster. Estimates of globally averaged sea level by 2100 are likely in the range of 0.26 to 0.82 m higher than during the years 1986-2005, depending on the actual emissions of greenhouse gases by continued global development [4, 5].



Observed and projected change in global mean sea level. Blue projection is for an optimistic scenario of future greenhouse has emissions; orange projection is for a more likely scenario of future emissions. (IPCC, AR5)

Local changes of sea level can differ markedly from these globally averaged rates [6]. Three major factors affect local variations, each of which have unique geographic variability; each is discussed in separate briefs. **Warming ocean waters** raise sea level due to thermal expansion of the water. Heating is greatest in the tropics, but spreads to higher latitudes by the motion of major ocean currents. **Loss of land-ice** (e.g., glaciers and grounded ice sheets) increases the volume of the oceans as warmer temperatures both melt more ice and increase ice flow into the ocean. **Deformation of Earth's crust** causes vertical shifts in the land. These are driven by the redistribution of large masses across the planet, such as changes in ice sheet mass, movement of large volumes of water, and tectonic movement. While a partial response to these mass changes is immediate, the full effect can take thousands of years to fully emerge and spread across the globe. Each of these three major factors has its own unique geographical patterns and time scales.

These three major factors are interrelated, complicating the analysis of any one in isolation from the others. Secondary effects, such as changes in oceanic circulation and atmospheric pressure also can influence regional sea-level.

Coastal flooding and inundation are driven more directly by weather events such as severe storms and tsunamis. The frequency of extreme weather events is more difficult to project, nevertheless, higher sea level leads directly to more frequent flooding occurrence by providing a higher "launching pad". The impact of higher sea level can be used to adjust the likelihood of floods of a particular height, but these should be regarded as underestimates of the actual future impacts.

WHERE THE SCIENCE IS HEADED. Uncertainty in the precise quantity and timing of future sea level rise and flooding is recognized as the main hurdle to incorporating this scientific knowledge in practical applications. Each contributing factor discussed above adds some degree of uncertainty, which scientists are striving to minimize. Among the largest uncertainty is the difficulty in predicting the future behavior of ice sheets. Past data of rapid ice sheet collapse, driven by the action of warm water on the ice sheet margin, raise the specter of unseen surprises. Research studies at these margins are expensive, risky and require many years to collect sufficient data to validate a quantitative understanding of ice-ocean interaction that can be incorporated into predictive computer simulations. Vertical land motion and thermal expansion contribute far less uncertainty due to their gradual nature and protracted time scale.

The dependence of coastal flooding on future storm frequency and intensity provides additional challenges. Improvements in this area will parallel improved prediction of storm frequency.

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