Sea-level rise and coastal flood risk

Ryan L. Sriver
Department of Atmospheric Sciences
University of Illinois

Sea-level rise poses considerable risks to Earth's coasts. Many areas in the southeastern United States have already experienced increases in the number and severity of floods events in recent years, and the impacts are expected to worsen with future sea-level rise. Reliable projections of sea-level rise and variability, and careful characterization of the uncertainties, are critical for regional coastal flood risk assessments and adaptation planning. A major challenge now facing the scientific community is to characterize and communicate the uncertainties effectively, and to work with stakeholders and city planners to develop robust strategies to protect coastal investments.

Future projections of global sea-level are deeply uncertain. Best estimates of global sea-level rise in the year 2100 are around 2/3 of a meter. The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment (AR5) reported a "likely" sea-level range between roughly 0.5 and 1 meter by 2100 for a business as usual projection scenario (e.g. continuation of current trends in fossil fuel consumption). Here the term "likely" is meant to represent one-third of the probability of 2100 sea-level rise, thus two-thirds of the probability falls outside this range. The likely range does not capture the tails or potentially extreme sea-level rise scenarios greater than 1 meter, but these more extreme scenarios also pose the greatest risk and the potential for more severe floods.

Global sea-level rise depends on multiple factors, including thermal expansion due to ocean warming, melting of land ice (glaciers and ice sheets), and changes in land water storage. During the last 100 years, ocean warming has been the largest contributor to global sea-level rise. Contributions from melting land ice have been increasing over the last 1-2 decades due to increases in Greenland and Antarctic ice sheets contributions. Observational evidence suggests contributions from melting land ice have been increasing in recent years, and these effects may accelerate rapidly in the near-future.

There may be potential for extreme sea-level rise much greater than the "likely" range reported by the IPCC, and upper bounds of projections exceed 2 meters within the next one hundred to two hundred years. The wide gap between the most-likely and worst-case scenarios is largely due to the deep uncertainties surrounding future contributions of melting land ice.

Threshold responses in sea-level changes, such as abrupt sea-level rise due to ice sheet disintegration, have occurred in the past during glacial-interglacial cycles where sea-level rise can vary by more than hundreds of meters over thousands of years. On these time scales, ice sheets tend to melt abruptly, but it takes thousands of years to build up again. For the present-day conditions, additional warming may cause catastrophic ice loss, but the timing and magnitude of the rates of increase are difficult to estimate reliably. In addition, sea-level rise depends on physical interactions between the ocean, ice, and atmosphere that are poorly understood and difficult to represent in a physically-based numerical model. To date most climate projections are largely silent on the effect of polar land ice sea-on global sea-level rise.

Global sea-level rise represents an average over the entire planet. There is large spatial variability in sea-level patterns, and actual sea-level rise at any given location can vary significantly from the global average. In addition, local flood risk assessments depend on additional factors beyond mean sea-level, such as frequency and severity of storms (e.g. hurricanes), ocean circulation, coastal geography, land use and flood protection, surface hydrology, and river dynamics. Many of these regional effects co-vary with sea-level rise. For example, global warming will likely contribute to an increase in the severity of coastal storms, storms and ocean heat content. Estimating the combined effects of the environmental hazards requires fine-scale and highly-localized coupled analysis specific to each region.

The local impacts can also be exacerbated by failures in built infrastructure and/or flood protection measures, leading to catastrophic compound events. Recent examples include Hurricane Katrina in 2005 which devastated New Orleans Louisiana, and Hurricane Harvey in 2018 that caused widespread flooding across Houston Texas. In both instances, major flooding occurred as a result of failures in local flood prevention measures.

Several different approaches are commonly used to characterize sea-level rise uncertainties in regional flood hazard assessments. One common method is to define deterministic sea-level rise scenarios based on community assessments of best-estimates, worst case scenarios, and physically plausible upper-bounds. While simple in concept, this approach is limited by the subjectivity of the decision makers. For instance, how does one define a worst case scenario, and what are the tradeoffs for different stakeholder groups?

Probabilistic assessments are another useful set of tools to characterizing sea-level rise uncertainties for decision-making. These assessments combine projections from multiple sea-level rise data and model products to produce probability density functions of sea-level rise for different forcing scenarios, which in turn can be used with a risk-based decision framework such as cost-benefit analysis. The approach is useful in that it assigns probabilities to sea-level rise outcomes, and it provides a first-order representation of the uncertainties across different models and data products. However, these models typically do not yet sample the full range of uncertainties due to missing physics and polar land ice sheet dynamics, thus leading to overconfidence in the projections (e.g. undersampling of potential extreme sea-level rise scenarios).

Decision making strategies, such as Robust Decision Making, can yield additional insight about pros and cons of potential investment decisions under deep uncertainty. This technique analyzes different proposed decisions across a wide range of potential scenarios, helping to expose vulnerabilities in the system and minimize overall risk across a set of possible choices. Recent work has shown these methods to be cost-effective in cases where investments can be easily described in economic terms, such as imports/exports at an international port, but they are more difficult to implement for broader scale and more complex systems such as a coastal city, which features a wide variety of stakeholders from different sectors representing different interests and objectives.

New methods are also emerging to analyze flood risk within multi-sectoral complex adaptive systems, which consider not only the environmental hazards but also aspects of human systems and decision making. One example uses hierarchical modeling to combine multiple different sources of sea-level rise data with statistical estimation and calibration for highly-localized flood risk assessments. Sea-level information can come from different sources featuring different spatial and temporal scales, such Earth system models, tide gauge records, high-resolution regional flood models, and semi-empirical time series models. The result is fine-scale flood risk assessment for urban planning, insurance pricing, and coastal preservation.

Hybrid data-model methods are also useful for examining compound flood events. Compound events are extreme floods resulting from multiple contributing factors occurring at or around the same time. One example is a landfalling hurricane, in which case local flooding depends on the amount of storm surge on top of uncertain sea-level rise, amount of precipitation, surface hydrology and river flows, and potential failures in built infrastructure (e.g. flood prevention measures). Combining different sources of model and observational data can help estimate the probability of these tail events and identify potential vulnerabilities. Hybrid stat-model-data approaches also enable new types of information beyond standard projections, such as estimation of timing of sea-level exceedances (for example 1 meter?). This type of information can be more useful to decision-makers but it is also more difficult to estimate using standard numerical climate models.

In closing, sea-level rise is deeply uncertain and there is a significant possibility of catastrophic outcomes above 2 meters in the next 100 to 200 years. New methods are being developed to characterize sea-level rise uncertainties and assess changing flood risks with global warming. Ultimately sea-level rise affects multiple sectors of society, and adaptation planning will require multi-disciplinary efforts between scientists, engineers, economists, city planners, and the community in order to create robust adaptation strategies.