IMPROVING REPORTING OF UNCERTAINTIES IN SEA LEVEL RISE ASSESSMENTS

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Sea level rise (SLR) assessments are commonly used to identify the extent that coastal populations are at risk to flooding. However, the data and assumptions used to develop these assessments contain numerous sources and types of uncertainty, which limit confidence in the accuracy of modeled results. This study illustrates how the intersection of uncertainty in digital elevation models (DEMs) and SLR lead to a wide range of modeled outcomes. SLR assessments are then reviewed to identify the extent that uncertainty is documented in peer-reviewed articles. The paper concludes by discussing priorities needed to further understand SLR impacts.

Uncertainty in sea level rise assessments

There are many sources and types uncertainty that compromise the accuracy of SLR assessments. Errors may arise from measuring and monitoring sea level (*1*), determining trends (*2*), estimating trajectories of change (*3*), predicting social change (*4*), predicting shoreline change (*5*), and using inadequate data and methods to quantify impacts. These uncertainties limit confidence in SLR models (*6*, *7*).

DEMs are often used to evaluate SLR impacts in the absence of information on the location of future shorelines. Many sources of DEMs are available at local scales – each source having unique characteristics and data quality. USGS Level 1 (USGS L1) DEMs are frequently used to evaluate SLR impacts at local scales in the United States given that these data are computationally efficient, inexpensive to obtain, and higher resolution data may not be available. USGS L1 DEMs were developed as a standardized elevation data set for 7.5 minute quadrangles. Elevation units are provided in whole feet or meters, referenced to mean sea level, and have a 30 x 30 m spatial resolution. Errors in DEMs are a function of the collection process, processing, quality control of data, and geographic characteristics of the land (*8*). The root mean square error (RMSE) is frequently used to assess the vertical accuracy of DEMs as it enables a straightforward comparison of error with other DEMs and because it is difficult to obtain other information on the collection or processing of the data. All USGS L1 DEMs are required to have a RMSE value less than 15 meters, though less than seven meters is preferred (*9*).

There are also many uncertainties in predicting the rate and magnitude of sea level change. Major uncertainties include predicting future greenhouse gas emissions, understanding the sensitivity of the climate to a doubling of carbon dioxide, and understanding ice dynamics (*10*). These factors contribute to global SLR predictions that range from 18 to 200 cm by the year 2100 (*3, 11*). The following section illustrates the extent that uncertainty in DEMs and SLR scenarios lead to a wide range of populations at risk to SLR.

Compounding uncertainties: SLR scenarios and DEMs

Nine simple inundation simulations were used to illustrate how uncertainty in DEMs and future SLR lead to different estimates of the population at risk throughout Charleston County, South Carolina. Each of the nine simulations represented a different combination of SLR change and elevation estimate from USGS L1 DEMs.

Continuous elevation values throughout Charleston County were obtained from 32, USGS L1 DEMs. Three different elevation surfaces were used to account for the uncertainty in elevation. The first elevation surface was based on the reported elevation value, while the second and third elevation surfaces were based on two error budget models. Each error budget model was based on the reported RMSE for each quadrangle. RMSE values, which ranged from one to four meters, were added or subtracted from the reported elevation using a local function. Adding and subtracting the RMSE from the reported elevation value represents an underprediction and overprediction of the elevation surface, respectively. This procedure provides 68% confidence that the actual elevation value lies within the range of the two error budget models. Spatial stationary and normality are assumed for errors within each DEM.

Three scenarios were used to represent the projected range of SLR by 2100. The lowest scenario (37.4 cm) was based on extrapolated sea level trends from the NOAA CO-OPS tidal gauge measurements in Charleston (*12*). The middle scenario (80 cm) represents an accelerated rate of SLR that accounts for plausible increases in ice flow dynamics (*11*). The high scenario (2 m) represents the upper end of accelerated SLR that could arise from increased ice flow (*11*). Census tract level data was distributed homogenously among each census tract to determine the population at risk (*13*).

Results indicate that uncertainty within DEMs and SLR contributes to substantially different estimates of population at risk (Table 1). The uncertainty in USGS L1 DEMs alone contributes to estimates of population at risk that range from 2 to 104,000 people for the 37 cm SLR scenario. Results also illustrate the sensitivity of DEMs to different SLR scenarios. Specifically, these DEMs did not reveal a difference between the 37 and 80 cm SLR scenarios. This is because elevation units are reported in whole meters and thus lack the sensitivity to detect changes in sea level that that occur between integers.

	Modeled population at risk to SLR		
SLR Scenario	Overpredicted Elevation	Reported Elevation	Underpredicted Elevation
37 cm	104,200	50,351	2
80 cm	104,200	50,351	2
2 m	166,621	98,365	32,646

Table 1: Population at risk for different SLR scenarios and DEMs.

Documenting uncertainty in sea level rise assessments

Documenting uncertainty is important to increasing the transparency within and comparability among SLR assessments. This section reviews 97 SLR assessments to evaluate the extent that uncertainties are reported in peer-reviewed journals. The ISI Web of Knowledge search engine and keywords “sea level rise” and “vulnerability”, “adaptive capacity”, “resilience”, or “adaptation” were used to identify the sample. Among the 240 articles initially identified, these 97 specifically addressed SLR and were written in English.

Many sources of uncertainty were documented within the sample of SLR assessments. The rate and magnitude of future SLR, climate change, human dimensions, and DEMs were the most frequently cited uncertainties. The human dimensions category included future changes in population, policy, and human responses to SLR.

Documenting DEM characteristics used in SLR assessments is important to standardize findings and increase comparability among assessments. Seventy-three of the initial 240 assessments were selected to identify the reporting of DEM characteristics. Each of the 73 assessments used a DEM and SLR scenario to model SLR impacts. Three criteria were established to evaluate the appropriate reporting of DEM characteristics: documentation of the source, providing horizontal resolution, and providing vertical resolution. Accuracy of the DEM was not used as a criterion. Based on these criteria, only 10 assessments (13.7 percent of the total) met all 3 criteria for the appropriate use of DEMs (Figure 1). Although reporting each criterion steadily increased between 1992 and 2008, less than half of all studies reported the source of the DEMs and less than one-third of the studies mentioned the horizontal or vertical resolution.

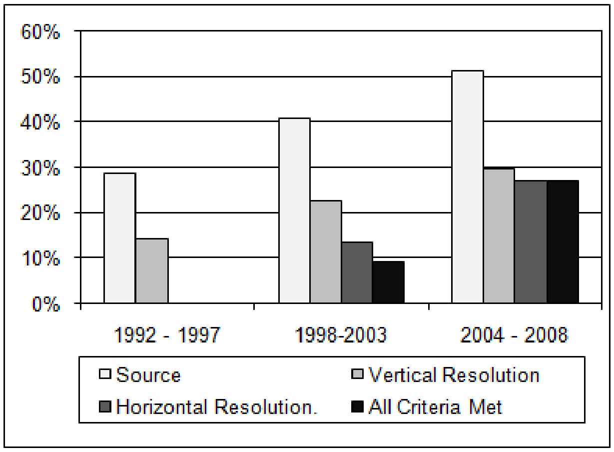

Figure 1: DEM characteristics reported in SLR assessments.

Discussion

This study illustrated how uncertainties within two elements of SLR assessments can lead to a large range of modeled results. Specifically, estimates of population at risk to SLR ranged from 2 to 166,000. These findings demonstrate that results of SLR assessments are sensitive to the assumptions, choices, and methods selected for analysis. It also demonstrates the importance of using scenarios to bound uncertainty.

Many SLR assessments do not document uncertainties, despite its notable role in affecting modeled outcomes. At a minimum, SLR assessments must include documentation on the assumptions regarding which SLR scenarios was used, the tidal datum selected (high or low tide), and the source, horizontal resolution, and vertical resolution of the DEM. Guidelines for the appropriate reporting of DEMs exist (*14*), yet many authors and editors do not adhere to these standards. These results suggest that it is not possible to evaluate the accuracy of the findings or compare results from one region or assessment to another. Education and outreach efforts are also important to increase the capacity of decision makers to interpret SLR assessments and maps accurately (see, *15*).

Research Priorities

The following two recommendations are provided to improve our understanding and communication of uncertainties in SLR assessments.

1) Develop methods to improve existing DEMs. It may be possible to use land cover or other source data to improve existing DEMs, given that DEMs tend to over-predict elevation when modeling the canopy surface (*8, 16*).

2) Improve representation of compounding uncertainties. This analysis may be extended by including other sources of uncertainty. For example, there are many ways to distribute population data among a defined area, including centroid-based, homogenous, and dasymetric approaches, and each of these techniques is likely to yield different estimates of population at risk (*17*). Further, many studies use static population data while projecting dynamic changes in sea level. This uncertainty analysis could be extended by using both static and dynamic population change estimates. There are also several other sources of uncertainty that are known, but cannot yet be quantified. These uncertainties include predicting shoreline change, understanding how humans will adapt to future conditions, and quantifying social, economic and biological impacts (*4, 5, 18, 19*). Methods and techniques to represent the extent that these uncertainties affect SLR assessments would be useful in judging risks and tradeoff

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