Rising sea levels

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Introduction

The oceans on the globe are a significant source of water on the Earth. They cover about 70% of the surface area of the Earth (Costello et al., 2010) and hold about 97% of the Earth's water (Charette and Smith, 2010). The water in the oceans also determine the sea levels of coasts all around the world. Over time, measurements of global sea levels have become more accurate due to increased availability of tide gauges around the globe and also due to the use of satellites to measure global sea levels (Hay et al., 2015; Dangendorf et al., 2015). Sea levels all around the world have been rising since the start of the 20th century (Hay et al., 2015). Adaptation and mitigation strategies will become necessary in order to reduce the effects of sea level rise. The purpose of this literature review is to examine the causes of sea level rise, to examine the effects that rising sea levels will have on people all around the world, and to examine some mitigation/adaptation strategies to sea level rise.

Causes of Sea Level Rise

Research on global sea levels has found that since the start of the 20th century, the global mean sea level has been steadily rising, as shown in the following figure:

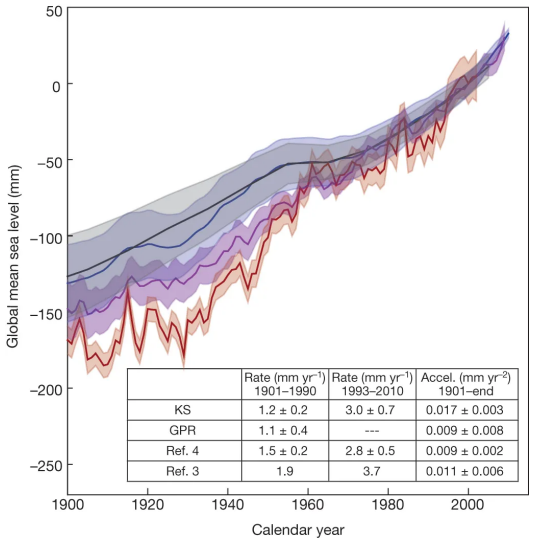

Figure 1. Global mean sea-level rise from 1900-2010. Global sea levels have been rising since the 20th century. (Hay et al., 2015).

Not only have global sea levels been rising since the 20th-century but also that, over the last few years, global sea levels have been rising at an accelerating rate (Dangendorf et al., 2017; Church & White, 2011). The rise in sea levels in recent years has been caused by climate change.

Climate change refers to the changes in the Earth's climate system that are occurring as a result of human activities. Human activities, particularly the burning of fossil fuels, has resulted in an increase of greenhouse gas concentrations in the atmosphere which causes changes to the Earth's climate (Pachauri et al., 2014). In recent time, climate change has resulted in increased global surface and ocean temperatures, increased melting of glaciers and ice sheets, and a significant rise in global sea levels (Pachauri et al., 2014). Thermal expansion and the melting of land-based ice, caused by climate change, are the main causes of rising sea levels and are jointly responsible for about 75% of the observed rise in global mean sea levels (Pachauri et al., 2014).

Researchers agree that one of the main causes of rising sea levels is thermal expansion caused by warming of the oceans. There has been a positive trend of warming in the upper depths of the oceans since 1995 (Levitus et al., 2009). This warming of the ocean leads to thermal expansion. Thermal expansion means that as water warms up, it expands. Thermal expansion mainly occurs in the surface layers of the oceans where warming of the oceans is the greatest (Wigley and Raper, 1987). Research has been conducted in order to determine how thermal expansion of the oceans has impacted the rate of global sea level rise (Levitus et al., 2009; Ishii and Kimoto, 2009). The results showed that from 1955 to 2001, thermal expansion caused a rate of sea level rise of 0.3 millimeters per year and 0.4 millimeters per year for the Ishii

and Kimoto study and Levitus et al. study, respectively (Cazenave and Llovel, 2010). Therefore, thermal expansion certainly is a main cause of sea level rise in recent years.

Another main cause of global sea level rise that researchers have determined is the melting of land-based ice. Land-based ice mainly refers to glaciers and ice sheets. Research on the sudden and dramatic melting of the Jakobshavn Isbræ glacier in Greenland determined that the Jakobshavn Isbræ glacier experienced a sudden increase in subsurface water temperatures in 1997 before thinning of the glacier began to occur (Holland et al., 2008). Therefore, it was concluded that warming ocean temperatures caused melting of the Jakobshavn Isbræ glacier and, subsequently, melting of land-based ice (Holland et al., 2008). In recent years, melting of the Antarctic ice sheet has experienced an increase in the rate of ice sheet loss. Research examining the loss of ice mass from the Antarctic ice sheet in recent years determined that the Antarctic ice sheet has experienced an increase in rate of ice sheet loss from 1992 to 2006 (Rignot et al., 2008). Research by Shepherd and Wingham (2007) also agrees with the findings of Holland et al. and Rignot et al. Shepherd and Wingham's analysis of the mass balance data of the Greenland and Antarctic ice sheets from a variety of studies shows that the rates of ice melt and mass loss had increased for both ice sheets. This is significant because if all of the ice from the Antarctic and Greenland ice sheets were to melt, sea levels could rise by up to 70 meters (Shepherd & Wingham, 2007). Thus, the melting of land-based ice from Greenland and Antarctica is a significant cause of rising sea levels.

Effects of Sea Level Rise

If sea levels continue to rise, human populations and coastal communities will be impacted all around the world in several ways. 190 million people currently live on land that is at

risk of being below sea level by the year 2100 (Kulp & Strauss, 2019). However, these people will be impacted differently by sea level rise based on where they live and how close to sea level they are (Kulp & Strauss, 2019). Most of the coastal populations who will be living below sea level by 2100 are in Asia, specifically in China and southeast Asia (Kulp & Strauss, 2019; Neumann et al., 2015). Additionally, an increase in global sea levels will also result in an increase in coastal flooding (Kulp & Strauss, 2016). Without adaptation to sea level rise, large numbers of people around the world will be inundated by sea level rise and coastal flooding (Hinkel et al., 2014; Neumann et al., 2015). Sea level rise could also result in large losses of annual global GDP if communities and governments fail to address or adapt to sea level rise (Hallegatte et al., 2013; Darwin et al., 2001). The researchers found that the United States will experience large economic losses, especially in the cities of Miami, New York City, and New Orleans, by 2100 without adaptation to sea level rise. If major coastal cities fail to adapt to rising sea levels, economic losses of more than 1 trillion US dollars a year could occur by the year 2050 (Hallegatte et al., 2013). Overall, research from several scientists and researchers shows that rising sea levels will impact large numbers of people and will have a large economic impact all around the world.

Adaptation/Mitigation to Rising Sea Levels

Due to the significant impacts that rising sea levels will have on coastal populations and global economies, mitigation and adaptation strategies will become necessary in order to address these impacts. The most significant mitigation strategy that can be taken is the reduction of greenhouse gas emissions into the atmosphere (Pachauri et al., 2014). This mitigation strategy reduces the impacts of climate change and sea level rise which makes it an effective and

important strategy to consider (Hinkel et al, 2014; Pachauri et al., 2014). Adaptation strategies such as the construction of dikes and other infrastructure-based adaptation will have to be implemented in order to reduce the impacts of sea level rise on coastlines and economies (Hallegatte et al., 2013; Hinkel et al., 2014). By 2100, the global costs of dikes will be $12-71 billion which is significantly less than the damage costs from rising sea levels (Hinkel et al., 2014).

Conclusion

Thermal expansion of the oceans and melting of land-based ice in Greenland and Antarctica are the main causes of sea level rise that have resulted in an increase in global sea levels since the 20th century. Based on sea level rise projections, global population data and several other factors, researchers have determined that rising sea levels will impact coastal communities and economies all over the globe. The warming of the ocean in recent years can be attributed to global warming caused by increased concentrations of greenhouse gases in the atmosphere from human activities (Levitus et al., 2001). In other words, global warming/climate change have caused warming of the oceans which has led to thermal expansion and the melting of land-based ice. Therefore, conducting research on rising sea levels and its potential effects will explain more about climate change and the costs of failure to address climate change. Mitigation and adaptation to sea level rise is necessary to address the potential impacts of sea level rise.

References

Cazenave, A., & Llovel, W. 2010. Contemporary sea level rise. Annual Review of Marine Science. 2: 145-173.

Charette, M. A., & Smith, W. H. 2010. The volume of Earth's ocean. Oceanography. 23(2): 112-114.

Church JA, White NJ. 2011. Sea-level rise from the late 19th to the early 21st century. Surveys in geophysics. 32(4): 585-602.

Costello, M. J., Cheung, A., & De Hauwere, N. 2010. Surface area and the seabed area, volume, depth, slope, and topographic variation for the world's seas, oceans, and countries. Environmental Science & Technology. 44(23): 8821-8828.

Dangendorf, S., Marcos, M., Wöppelmann, G., Conrad, C. P., Frederikse, T., & Riva, R. 2017. Reassessment of 20th century global mean sea level rise. Proceedings of the National Academy of Sciences. 114(23): 5946-5951.

Darwin, R. F., & Tol, R. S. 2001. Estimates of the economic effects of sea level rise. Environmental and Resource Economics. 19(2): 113-129.

Hallegatte, S., Green, C., Nicholls, R. J., & Corfee-Morlot, J. 2013. Future flood losses in major coastal cities. Nature Climate Change. 3(9): 802-806.

Hay, C. C., Morrow, E., Kopp, R. E., & Mitrovica, J. X. 2015. Probabilistic reanalysis of twentieth-century sea-level rise. Nature. 517(7535): 481-484.

Hinkel, J., Lincke, D., Vafeidis, A. T., Perrette, M., Nicholls, R. J., Tol, R. S., Marzeion, B., Xavier, F., Cezar, I., Levermann, A. 2014. Coastal flood damage and adaptation costs

under 21st century sea-level rise. Proceedings of the National Academy of Sciences. 111(9): 3292-3297.

Holland, D. M., Thomas, R. H., De Young, B., Ribergaard, M. H., & Lyberth, B. 2008. Acceleration of Jakobshavn Isbræ triggered by warm subsurface ocean waters. Nature Geoscience. 1(10): 659-664.

Ishii, M., & Kimoto, M. 2009. Reevaluation of historical ocean heat content variations with time-varying XBT and MBT depth bias corrections. Journal of Oceanography. 65(3): 287-299.

Kulp, S. A., & Strauss, B. H. 2016. Global DEM errors underpredict coastal vulnerability to sea level rise and flooding. Frontiers in Earth Science. 4(36).

Kulp, S. A., & Strauss, B. H. 2019. New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding. Nature Communications. 10(1): 1-12.

Levitus, S., Antonov, J. I., Boyer, T. P., Locarnini, R. A., Garcia, H. E., & Mishonov, A. V. 2009. Global ocean heat content 1955–2008 in light of recently revealed instrumentation problems. Geophysical Research Letters. 36(7).

Levitus, S., Antonov, J. I., Wang, J., Delworth, T. L., Dixon, K. W., & Broccoli, A. J. 2001. Anthropogenic warming of Earth's climate system. Science. 292(5515): 267-270.

Neumann, B., Vafeidis, A. T., Zimmermann, J., & Nicholls, R. J. 2015. Future coastal population growth and exposure to sea-level rise and coastal flooding-a global assessment. PloS one. 10(3): e0118571.

Pachauri RK, Allen MR, Barros VR, Broome J, Cramer W, Christ R, Church JA, Clarke Leon, Dahe Q, van Ypserle JP, et al. 2014. Climate change 2014: synthesis report. Contribution

of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change (p. 151). Ipcc.

Rignot, E., Bamber, J. L., Van Den Broeke, M. R., Davis, C., Li, Y., Van De Berg, W. J., & Van Meijgaard, E. 2008. Recent Antarctic ice mass loss from radar interferometry and regional climate modelling. Nature Geoscience. 1(2): 106-110.

Shepherd, A., & Wingham, D. 2007. Recent sea-level contributions of the Antarctic and Greenland ice sheets. Science. 315(5818): 1529-1532.

Wigley, T. M., & Raper, S. C. B. 1987. Thermal expansion of sea water associated with global warming. Nature. 330(6144) 127-131.