Distributed Technological Tools for Global Sea Level Rise Response Planning

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Abstract

How much would it cost to protect the world's seaports against two meters of sea level rise? How long would it take to construct coastal defenses? Does the world even have the necessary resources? To address these questions quantitatively, we created a technological tool that combines remote sensing, computer models, and database management called "Sebastian."

Developed by Stanford University's Project on Engineering Responses to Sea Level Rise (SUPERSLR), Sebastian interfaces with Google Earth to estimate the material requirements, time, and labor costs necessary to armor ports and harbors worldwide. Sebastian constructs a solution to protect the 179 economically most important ports[1] across the globe with a "credible minimum-criteria design" dike structure that is optimized for each port based on bathymetry and elevation data.

Our preliminary results on global and regional scales provide insight into the construction industry's capacity to respond to future climate-change induced scenarios. Global-scale environmental hazard response planning for climate change, in particular with regard to coastal engineering, can be costly and time-consuming. By distributing the collection of information to local experts worldwide, Sebastian greatly reduces the cost and time required to reach a useful level-of-detail for studies seeking to answer global environmental response questions.

Note: *Updated 14-May-2011 to reflect newly updated data*

[1] Port cities with a population of 100 million or greater and the top 50 ports in terms of shipping volume by tonnage or containers (TEUs)

Contents

I. Introduction

Many studies have been conducted and are currently underway to characterize the causes of sea level rise and to measure and predict its rate of change (Vermeer 2009). However, comparatively little focus has been given to planning for the response that would be required to protect coastal communities in the event that sea level rise does occur on a significant scale (Brooks, et al 2006). Stanford University's Project on Engineering Responses to Sea Level Rise (SUPERSLR) has developed a comprehensive coastal protection response strategy by examining various engineering and policy solutions along the spectrum of "hard" (e.g., seawalls) to "soft" (e.g., managed retreat) that would be suitable for the different conditions found in coastal and port cities worldwide.

A key focus of our research has been to quantify the resources, time, and cost required to implement the "hard" solution of constructing coastal defenses. By aggregating on a global scale, we are estimating the maximum industry capacity for the simultaneous construction of structures around the globe. Based on foreseeable growth trends in the industry, our preliminary results show that capacity would be exceeded. Early indicators of the kind of industry strain ahead include the challenges faced by the U.S. construction industry in responding to the ravage of Hurricane Katrina (Kates, et al 2006).

SUPERSLR[2] consists of several projects, including the Sebastian GeoData System introduced in this paper, a global survey of port administrators (Becker in review), a study of the global construction industry's capacity, and a project seeking to understand the impacts of sea level rise and climate change on coastal industries, such as dredging .

Sebastian is named after the wise, know-it-all character from *The Little Mermaid* to reflect this system's service as the data hub for SUPERSLR. This name also serves a function as grateful acknowledgement of Walt Disney Imagineering Research & Development as a source of project funding.

I. A. Climate change motivation

Among the many predicted scenarios likely to result from climate change is an increase in the mean sea level (MSL) of between .6 and 2 meters on a planetary scale by 2100 (Rahmstorf 2010; IPCC 2007). Although the MSL changes differ depending on the location in question (National Research Council (NRC) 2010; IPCC 2007), it is clear that at some point additional protection in the form of dikes, levees, sea walls, et cetera will be required to protect ports, harbors, and other coastal developments where the cost and practicality of relocation is believed to outweigh the constructed alternative (Nicholls 2007).

II. Our Approach

No. Known. Future.

We consider three scenarios in our approach: *No Solution*, *Known Solutions*, and *Future Solutions*.

In a scenario where coastal and port cities do not respond to sea level rise, *No Solution*, many will face inundation of infrastructure. The increased flooding of port structures will hamper operations and could result in an eventual closure of the port. In addition, increased storm surges will damage or destroy sensitive structures. This scenario results in massive storm-recovery costs, but requires virtually no upfront costs and may be thought of as the "do nothing" scenario. This scenario provides a benchmark against which to compare other possibilities.

The bulk of our work to date has been to determine the maximum effort/resources required to use *Known Solutions* from engineering to protect or armor coastal and port cities against sea level rise. In other words, given what is known today, this strategy is the most likely to be employed were it is deemed necessary today to respond to a 2-meter SLR. Many factors are involved, including materials, equipment, labor, and engineers, but it is unclear what role each of these items plays in the scheme of a large project to armor coastline. We seek to determine the limiting factors in applying various known engineering designs for ports responding to sea level rise. We discuss the methodology for our study of known engineering solutions later in this section.

At the time of publication, our research of *Future Solutions* is ongoing. Future solutions should allow coastal and port cities some flexibility in approaching and responding to sea level rise. The SUPERSLR team works at the forefront of this issue to investigate new solutions to sea level rise through innovative uses of technology, materials, and knowledge.

[2] For more information, please visit the SUPERSLR website: www.groupspaces.com/seaports2100

II. A. Why Ports?

Using seaports as a unit of study sets boundaries for analysis, since ports have fixed locations and simple measures for determining economic value in the form of shipping volume. Ports also serve as an example of infrastructure that relies explicitly on coastal locations. Unlike other coastal uses, ports must be situated in areas that are vulnerable to the impacts of climate change. As 80% of the world's freight moves by ship, ports serve a critical and central role in the global economy (International Maritime Organization (IMO) 2008). National and international organizations have identified that climate impacts on maritime infrastructure is an area of great concern in which little work has been completed (USCOP 2004; PIANC 2008; UNCTAD 2008; USEPA 2008).

Ports require special treatment because of their economic importance as essential links in supply chains, their locations in the heart of sensitive estuarine environments, their reliance on waterfront locations, and the significant existing infrastructure that links them to inland transportation networks. Unlike other coastal uses like residential or retail, ports cannot be relocated to safer locations. Lacking practical options for retreat, engineered solutions such as armoring must be seriously considered if ports are to continue operating as they have in recent history. Most studies that address climate change impacts on seaports conclude that more information about impacts and tools to reduce vulnerability would help decision makers to better plan for adaptation (Heberger, Cooley et al. 2009; PIANC 2008; Savonis, Burkett et al. 2008; UNCTAD 2008; USEPA 2008; Orbach 2010).

A recent United States Environmental Protection Agency (USEPA 2008) report on climate impacts on seaports states, "most [U.S.] ports do not appear to be thinking about, let alone actively preparing to address, the effects of climate change" (USEPA 2008). Results of a survey conducted by the SUPERSLR team confirms this trend on a global scale (Becker in review). In order to properly prepare, decision-makers must understand the nature of the problem, how risks impact local conditions, and what options may be considered. Policy makers, insurers, the international community, and the ports themselves will all play a role.

II. B. Credible Minimum-criteria Coastal Protection Design Frameworks

We are developing a series of designs for coastal protection structures with the goal of reaching global-scale estimates that provide a sufficient level of credibility for the purposes of an order-of-magnitude study. Our most complete design to date is the dike structure that we use in the Sebastian GeoData System

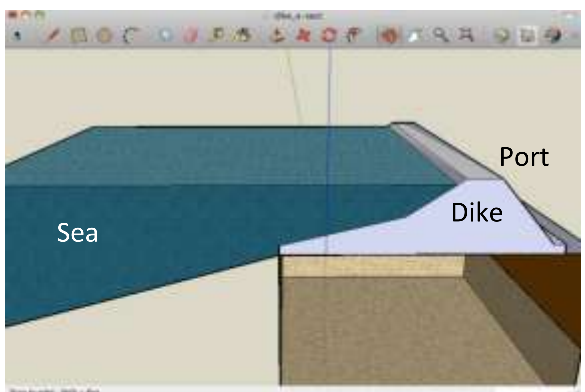

Figure 1. Typical Credible Minimum-criteria Dike Design.

(*pictured in Figure 1*). This design adequately generates material requirements to allow global aggregate analysis. While we do not advocate using this particular design for any particular port, it is a solution that could feasibly work at any port and provides useful outputs for planning purposes. Furthermore, it eliminates the substantial time and effort of a full bespoke engineering study.

II. C. Global Construction Industry Capacity

In order to understand the particular limiting factors in responding to sea level rise, it is necessary to determine the current availability of each resource required to implement the solutions. We use data about these factors to initially populate our research database, which is used as part of the Sebastian GeoData System (*described in Section III*). Combining these data with our Credible Minimum-criteria Designs, we can gain perspective about which factors are most limiting. We describe our methodology for understanding the global construction industry's capacity, as well as some of our preliminary results, in the following sections.

II. C. i. Materials

Data for our estimate of the global supply of materials available for the construction of coastal protection structures was sourced from various public repositories (USGS 2010; UNICSD 2010). The primary construction materials currently used in coastal defenses are concrete and steel. Thus, we have given attention to the known supplies and regional accessibility to cement, coarse aggregate, and fine aggregate. Our preliminary results indicate that the global capacity for producing these materials is insufficient for constructing the protective structures around each of the world's top economic ports in less than 50-60 years. Although fill is also a critical component of most protection structures, it would most likely be available locally and procured through dredging, and is thus not expected to be a limiting factor.

II. C. ii. Specialty Ships

Standard coastal engineering practice requires use of specialty ships (e.g., dredges) to construct coastal protection structures. In the construction of the Oosterschelde storm surge barrier in the Netherlands, a minimum of five dedicated ships were built specifically to meet project requirements (Deltawerken Online 2004). As there are currently an estimated 60 specialty ships in use worldwide today, we anticipate that a project on the scale would require a major new effort in specialty ship construction (Hammel, Student Report 2009).

II. C. iii. Coastal Engineers

We are in the initial stages of determining how many coastal engineers are presently available globally. Our initial estimates for the United States indicate that fewer 5,000 coastal engineers are employed by various firms across the country, and no more than 10,000 worldwide (Greenfield, Student Report 2010). We estimate that a typical dike project would require 800 engineer-hours. Then point to a shortage of coastal engineers in the future.

II. C. iv. Costs & Time to Complete

Using general statistics from RS Means construction costs and labor guides, we calculate the estimated time to complete construction of our modeled designs at each port and the costs associated with this construction. While most of these figures from RS Means are not specified for coastal engineering projects, we found that they are fairly accurate when compared with past dike construction projects. Our preliminary findings suggest that, on average, each port would require 435,000 man-hours (about 11 years using a 20-man team) to construct a modeled defense to protect against 2 meters SLR, and each defense would cost over US$800 million. (R.S. Means Company 2008)

III. Sebastian GeoData System

The Sebastian GeoData System is SUPERSLR's data, visualization, and computer model "hub." Combining open source technologies and free platforms, Sebastian allows a user to view and edit information in a wiki-style manner natively using freely-available Google Earth software. This approach provides similar analytical power to a complex geographic information system (Joint Legislative Committee on Performance Evaluation and Expenditure Review (PEER))[3] model, while retaining the ease-of-use of Google Earth. Within Sebastian, information is directly superimposed on complete satellite coverage of the entire globe, representing spatial elements at an accurate scale. Furthermore, a degree of context outside of a user's own experiences is available. For instance, this enables a researcher in California to begin to understand the local situation in South Africa without requiring a site visit. Geographically-referenced panoramic photos from the popular web service Panaramio take this one step further with freely available images of landscapes and significant features, providing additional information. Furthermore, certain areas include historical satellite imagery, allowing a user to travel back in time and view changes in development and natural conditions.

After learning about the area surrounding a particular port, the Sebastian user may proceed to outline the location of a port using polygons as part of Google Earth's built-in drawing tools. Employing a simple cut and paste methodology, these descriptive features can be added to the SUPERSLR Research Database for use in analysis. After adding the necessary polygons, the user may run our embedded coastal protection design computer model - This model uses a design algorithm[4] to determine the "optimal" credible minimum-criteria design defense path, based on the minimal construction material requirement. The model considers various layouts for the defense structure, accounting for variations in length and depth to match the topography and bathymetry. The resultant material requirements are sensitive to the portfolio of available materials in our estimate of the global construction industry's capacity.

Finally, Sebastian aggregates these calculated data and displays summary information as data tables and graphs, once again inside of Google Earth. Through these steps, a series of ports may be analyzed by users from around the world and the results promptly compiled to inform decision-makers and other stakeholders.

The Sebastian tool is flexible and will grow to incorporate future solutions as they are developed.

Figure 2. Port Completion Status – Darker is more complete – 165 ports fully analyzed.

[3] Geographic Information System, a set of tools that captures, stores, analyzes, manages, and presents data that are linked to location(s)

[4] Modular design algorithms are created by SUPERSLR researchers to simulate a category or type of coastal engineering defense/armor design.

IV. Preliminary Results

As of May 14, 2011, we have successfully analyzed 165 of the prescribed set of 180 ports, shown in Figure 2. At this time, we have incomplete data for the global construction industry's capacity, as noted in Figure 3.

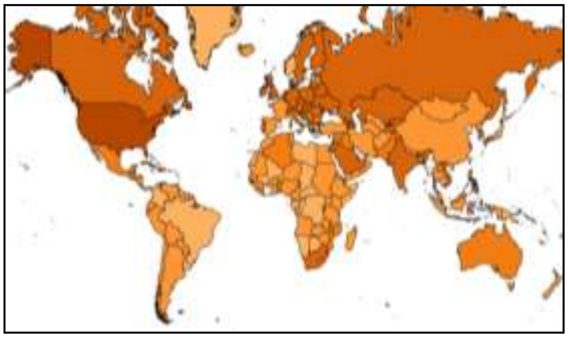

Figure 3. Global Construction Industry Capacity Data Availability – Darker is more available – USA has approximately 82% of the data points in which we are interested. *(Data current as of November 16, 2010)*

Resource	Yearly Production	Estimated Demand	% of Yearly Production
Cement	2,938	184	6%
Sand	1,519	462	30%
Gravel	2,714	727	27%

Table 1. Resource production and demand requirements for the global market in million metric tons *(Data current as of May 14, 2010)*

However, using the data available, we can conclude that sufficient cement, sand, and gravel are not currently produced to successfully meet the enormous increase in demand generated by a need for port armoring structures. In Table 1 and Figure 4, we present the capacity and demand requirements under our scenario, which reveals a need for 6% of one year's current cement production. While not a severely limiting amount, the increased demand would surely increase prices substantially, driving up costs for other construction projects. Furthermore, this number would scale quickly if all of the world's 4,500 ports were to adopt a similar protection strategy, and then cement would become a limiting factor in adaptation to respond to sea level rise.

V. Discussion

SUPERSLR's Sebastian GeoData System combines database, visualization, and modeling technology in a tightly integrated package that allows for great collaboration at minimal cost. By enabling a simplified analysis methodology, we may rapidly come to a conclusion about the feasibility of constructing coastal defenses to protect the 180 economically most important ports worldwide and understand what future research is required to refine the possible solutions for armoring or otherwise protecting coastal and port cities against sea level rise.

VI. Conclusion

No. Known. Future.

In this slogan, we capture the three scenarios SUPERSLR is studying. *No* Solution is not a desirable outcome, given what climate science has revealed in recent years. Sebastian plays a role in the *Known Solutions* category where we wish to determine the feasibility of constructing known engineering solutions to protect and/or armor ports against sea level rise. The implications of our findings indicate that it will be difficult for the global construction industry to meet a demand for the construction of traditional coastal defense structures at current prices to protect ports at a rate that would match the timescales predicted by current climate change researchers (as depicted in Figure 4). New solutions and techniques must be developed that require fewer resources and are cheaper to construct. SUPERSLR also addresses the broader scope of climate change impacts on ports and the shipping industry. For the *Future Solutions* part of our project, we call upon industry leaders to bring their concerns and issues to us to aid in our search for new methods and strategies for ports and shipping to prepare for climate change. The Sebastian tool is flexible and will grow to incorporate future solutions as they are developed. Our current body of work and ongoing projects, including the aforementioned global survey of port administrators, may be found through our website.

Website: http://groupspaces.com/seaports2100

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