Coastal Inundation and its Impacts on Ecology and Human Communities in the Yukon-Kuskokwim Delta, West Alaska

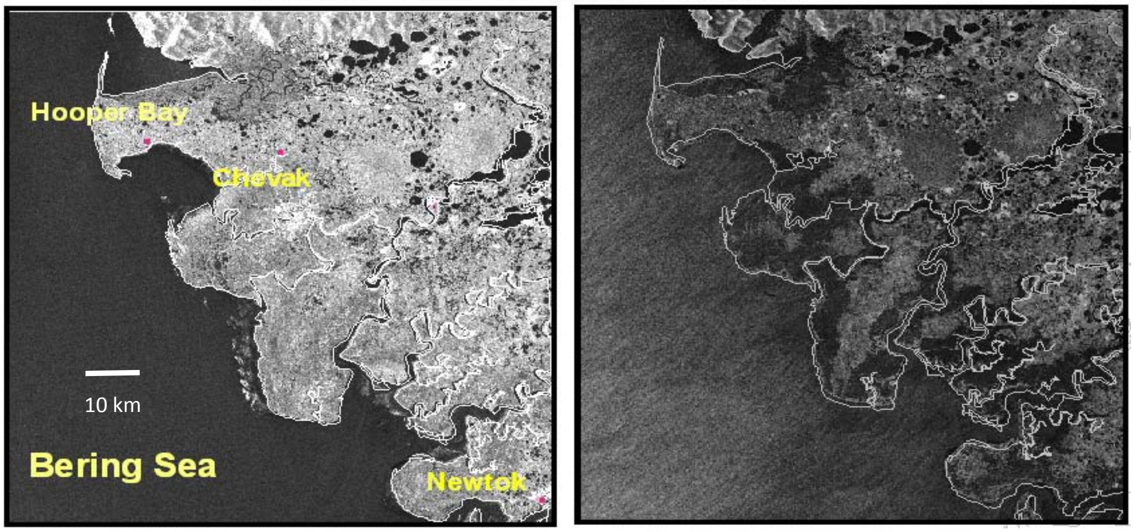
By

Tom Ravens
Professor, Dept. of Civil Engineering
University of Alaska Anchorage
tmravens@uaa.alaska.edu

Introduction

The Yukon-Kuskokwim Delta is home to 40,000 rural Alaskans – most of whom are Native Alaskans. It is also home to the Yukon Wildlife Refuge which is a world-class site for nesting birds including the endangered Spectacle Eider. However, because of the Delta's low elevation (2 m above sea level), the Delta's residents and its ecology are vulnerable to storm surges (Figure 1), and the vulnerability will grow with increasing sea levels. In this paper, we report on research to study storm surge-induced inundation under the current climate and to project inundation under a future climate with selected sea level rise scenarios. In addition, we determine the likely change in the Yukon Delta ecology due to storm surges enhanced by sea level rise.

RadarSat1 - Cloud penetrating satellite imagery



July 2005 - normal high tide

September 2006 - extreme flood event

Figure 1. RadarSat1 view of the Delta during a normal high tide and during a storm surge event.

Methodology and Results

Several tasks were undertaken in order to meet the project’s goals:

- Develop and validate a storm surge model
- Identify a number of representative storms from the past 40 years
- Model these storms and their inundation under present climate conditions
- Re-model these storms assuming one or more sea level rise scenarios
- Compute an inundation index from each model run
- Compute an annual inundation index based on inundation indices from selected storms
- Establish the relationship between annual index and ecological parameters (e.g., vegetation type) under present climate
- Infer changes in ecological parameters (e.g., vegetation type) under a future climate based on projected changes in inundation index

Storm surge modeling

Storm surge modeling was achieved by combining output from an existing course-grid model and by developing a fine-grid model which focused on the Yukon Kuskokwim Delta. The course-grid model was developed by the US Army Corps of Engineers using ADCIRC software and it covered the Bering and Chukchi Seas (and beyond, Figure 2a). The fine-grid model was developed using Delf3D software and it was centered on the mouth of the Kashunuk River in the heart of the Yukon Kuskokwim Delta (Figure 2b). The fine-grid model was “forced” on its ocean boundary by water level data provided by the course-grid model.

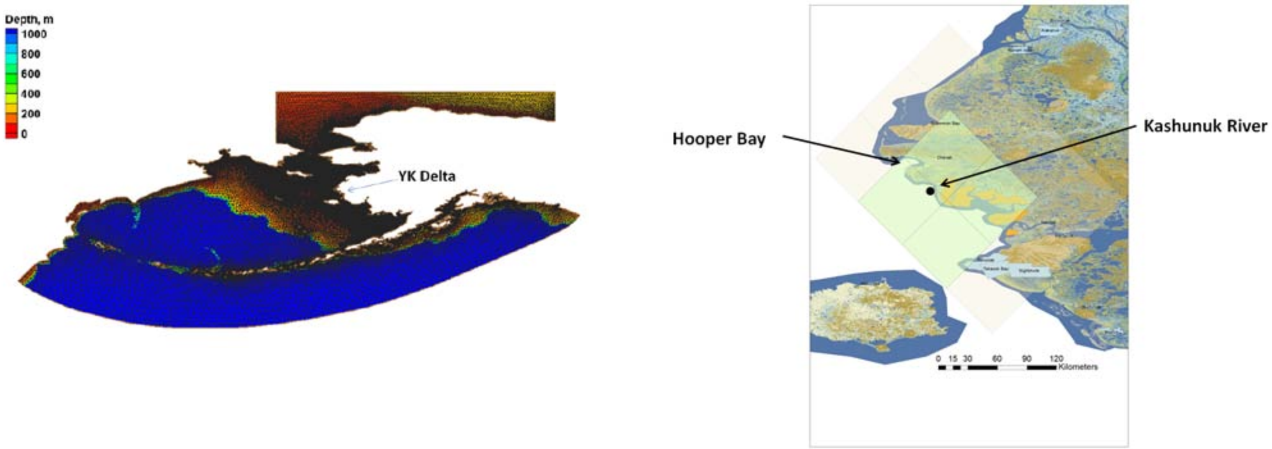


Figure 2. Domain of the (a) course-grid and (b) fine-grid models.

The storm surge model is being validated based on its calculation of water level at the coast as well as extent of inundation. Figure 3 (below) shows a plot comparing model-calculated and measured water level at the coast during a small ("one-year") storm during 2009. The data shows that the model does a reasonable job of representing nearshore water level during a small storm surge event.

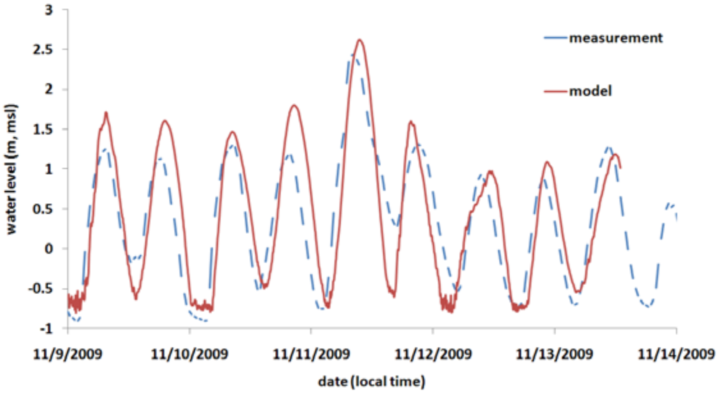
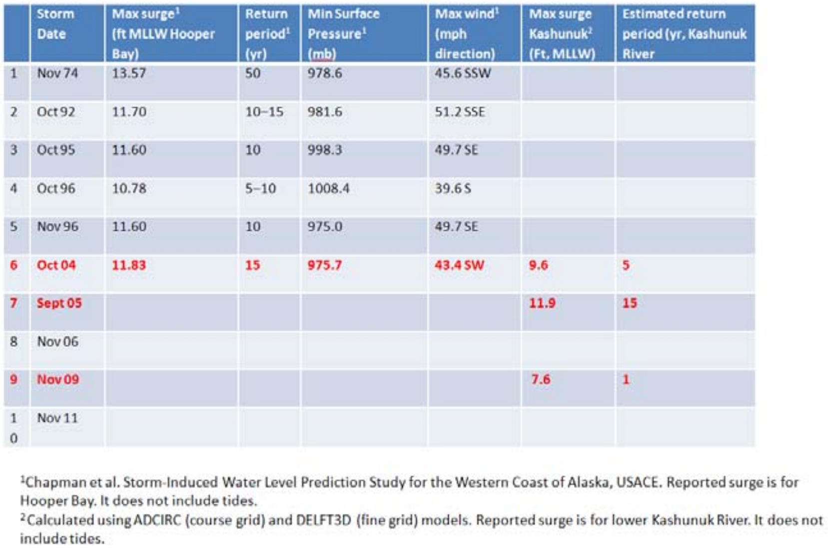


Figure 3. Plot of measured and calculated water level at the coast during a one-year storm in November 2009.

Identification of representative storms from the past 40 years

We identified 10 historic storms to study in this project (Figure 4). These storms had previously been studied by the US Army Corps of Engineers using their ADCIRC model (Chapman et al.



	Storm Date	Max surge[1] (ft MLLW Hooper Bay)	Return period[1] (yr)	Min Surface Pressure[1] (mb)	Max wind[1] (mph direction)	Max surge Kashunuk[2] (Ft, MLLW)	Estimated return period (yr, Kashunuk River
1	Nov 74	13.57	50	978.6	45.6 SSW		
2	Oct 92	11.70	10–15	981.6	51.2 SSE		
3	Oct 95	11.60	10	998.3	49.7 SE		
4	Oct 96	10.78	5–10	1008.4	39.6 S		
5	Nov 96	11.60	10	975.0	49.7 SE		
6	Oct 04	11.83	15	975.7	43.4 SW	9.6	5
7	Sept 05					11.9	15
8	Nov 06						
9	Nov 09					7.6	1
10	Nov 11						

[1] Chapman et al. Storm-Induced Water Level Prediction Study for the Western Coast of Alaska, USACE. Reported surge is for Hooper Bay. It does not include tides.

[2] Calculated using ADCIRC (course grid) and DELFT3D (fine grid) models. Reported surge is for lower Kashunuk River. It does not include tides.

Figure 4. Data on 10 historic storms selected for analysis.

2004). Column 3 above provides the calculated surge height at Hooper Bay about 50 km northeast of the Kashunuk River mouth (Figure 2). The Kashunuk River area is the focus of the current study. Column 4 provides approximate return period for each storm based on extremal analysis conducted by Chapman *et al*. for the Hooper Bay site. For our study, focusing on the mouth of the Kashunuk River, we selected three storms (storms 6, 7, and 9 in Figure 4). The 2004, 2005, and 2009 storms at the Kashunuk River have provisionally been assigned return periods of 5, 15, and 1 years based on the calculated surge at the Kashunuk River mouth and based on the relationship between surge height and return period seen at the Hooper Bay site.

Computation of the inundation index for individual storms and computation of the annual inundation index

An inundation index was computed to account for the frequency and intensity of inundation on the Delta during a given storm surge event. The inundation index is a spatially variable index and is formulated as the time-integral of the water depth on the Delta during the storm event. The inundation index for the one-year storm (2009 storm) is shown in Figure 5 below. The index has units of m-days and it is maximal on the coast. The inundation index for the 15 year storm (i.e., a storm that is expected to return once every 15 years on average) is shown in Figure 6 (below). The inundation index for the 15 year storm is, as expected, much higher than that of the 1 year storm. The inundation index also shows the spatial extent of storm's inundation. Again, not surprisingly, the 15 year storm inundates a much larger area than the 1 year storm.

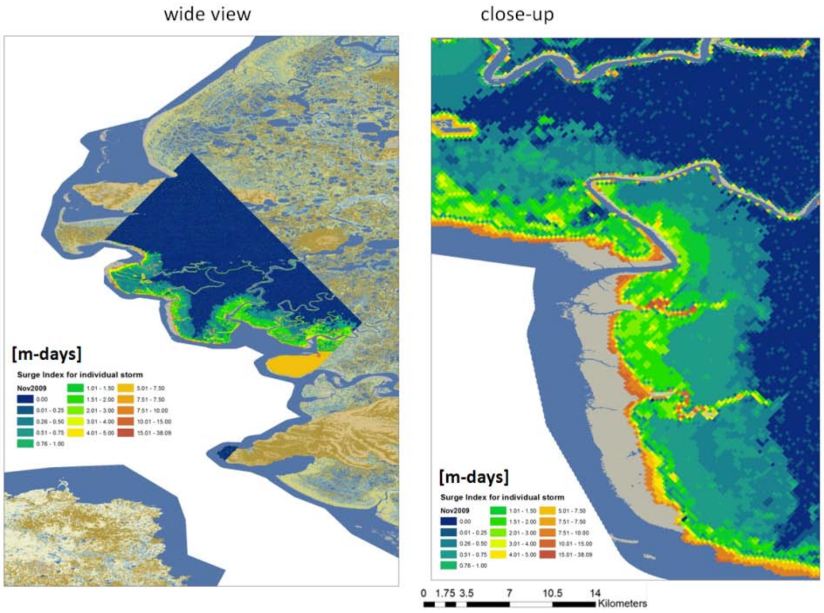
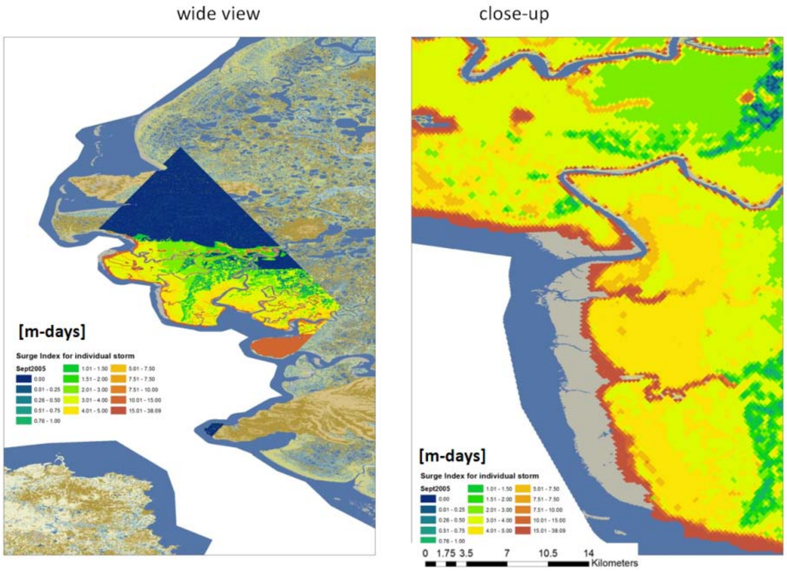


Figure 5. Computed Inundation Index (wide view and close up) for a one-year storm (i.e., 2009 storm).


wide view

close-up

Figure 6. Computed Inundation Index (wide view and close up) for a 15-year storm.

An estimate of the annual inundation index was calculated based on a weighted average of the inundation indices for the 1, 5, and 15 year storms (Figure 7a). The annual index is a measure of the expected amount of inundation in any given year. Examination of the annual inundation index alongside a vegetation map (Figure 7b) shows a remarkable correspondence between index and vegetation type. For example, brackish wet sedge meadow is clearly found where the annual inundation index is in the range of 1 to 2 m-days/yr.

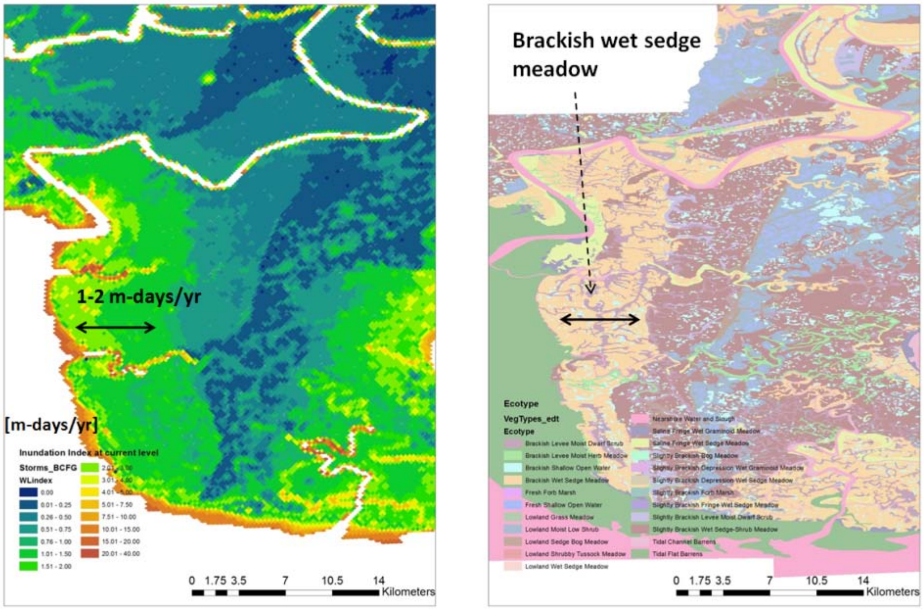


Figure 7. (a) annual inundation index and (b) vegetation map.

Projected changes in inundation index and vegetation type in a future with a 40 cm sea level rise

Assuming an increase in the baseline sea level of 40 cm, the individual storms were re-modeled and the inundation indices for the individual storms were re-calculated. Further, based on the individual storm indices, the annual inundation index for the 40 cm sea level rise scenario was recomputed. Examination of the annual inundation index for the present climate and for the future climate with the 40 cm sea level rise (Figure 8) shows that the region with the 1-2 m-days/yr annual inundation index shifts 7 km inland in the future scenario. Assuming that this index level continues to correspond to brackish wet sedge meadow, we can infer that this vegetation type would also shift 7 km inland.

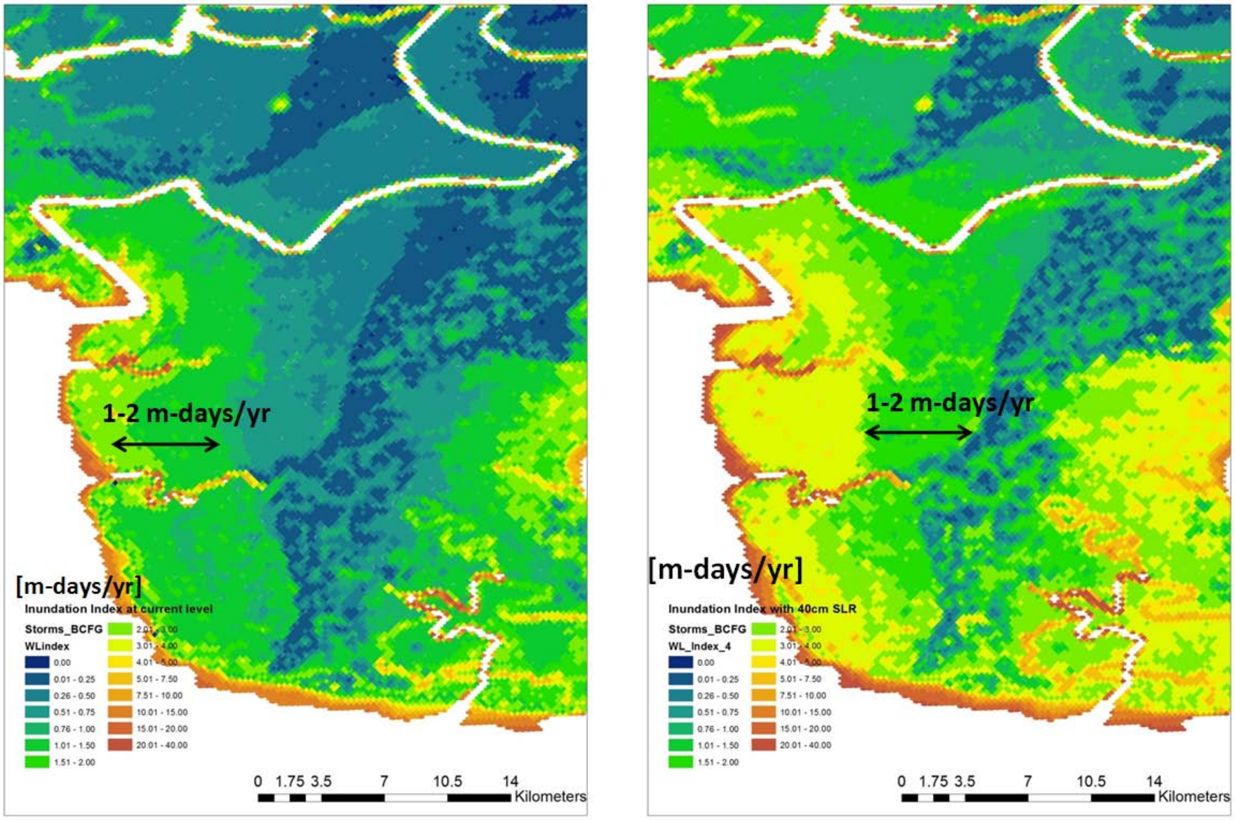


Figure 8 (a) annual inundation index for present climate and (b) annual inundation index for a future climate with a 40 cm sea level rise.

Conclusions

The above calculations indicate that the frequency and intensity of inundation on the Delta – quantified by the inundation index - are very sensitive to sea level changes. A 40 cm sea level rise would lead to large changes in the annual inundation index. In particular, the simulations show that a 40 cm sea level rise would lead to a 7 km inland shift in the 1-2 m-days/yr index band. Assuming vegetation types continued to correspond to inundation exposure, we could expect that brackish wet sedge meadow which corresponds to the 1-2 m-days/yr index range would similarly shift inland 7 km.

Although we have not yet explicitly addressed these issues in our research, we expect other large scale changes in ecology due to sea level rise in this area. First, river salinity will certainly increase significantly due to sea level rise. Among other things, this will lead to changes in the spatial distribution in fish. Fresh water species such as white fish will migrate inland behind the encroaching salinity. Also, the Delta's myriad ponds which support many of the Delta's water fowl, particularly in the juvenile life stage, will become more saline due to the more frequent and intense inundation. The increase in salinity of these ponds will degrade their ability to provide quality for water fowl.

In addition to these ecological impacts, there will be major impacts to human communities due to sea level rise. First, there will be a rise in coastal erosion rates due to the higher water levels. Higher water levels allow the aggressive action of waves to propagate further inland. Coastal erosion will be compounded by the reduction of sea ice which will enable storm waves to reach the shore. Coastal erosion rates will also be exacerbated by permafrost thaw along the coast. In many areas (e.g., on the north coast of Alaska), permafrost is the only thing holding sediments in place. Second, the water resources systems of coastal communities will be threatened. Communities which rely on wells or surface water for drinking water – which is all of the coastal communities – will be threatened. Groundwater and surface water sources for drinking water will be degraded as they become more saline. Expensive rehabilitation of drinking water infrastructure will be necessary. Similarly, waste water treatment systems will be affected. In many instances, these waste water treatment systems consist of sewerage ponds that are flushed periodically. Large storm surges could disperse waste and toxins creating a public health hazard.

Recommendations

The tools that have been developed in this and other research projects would provide a solid basis for comprehensive hazard assessment. However, we are not aware of a comprehensive approach toward assessing hazards in coastal Alaska.