Toward a Predictive Model of Arctic Coastal Retreat in a Warming Climate, Beaufort Sea, Alaska

PI: Cameron W. Wobus
Cooperative Institute for Research in Environmental Sciences
Campus Box 216
University of Colorado
Boulder, CO 80309
Phone: (303) 735-2413 Fax: (303) 492-2606 Email: cameron.wobus@colorado.edu

PI: Robert S. Anderson
Institute for Arctic and Alpine Research
Campus Box 450
University of Colorado
Boulder, CO 80309
Phone: (303) 735-8169 Fax: (303) 492-6388 Email: andersrs@colorado.edu

Co-PI: Irina Overeem
Institute for Arctic and Alpine Research
Campus Box 450
University of Colorado
Boulder, CO 80309
Phone: (303) 492-6631 Fax: (303) 492-6388 Email: irina.overeem@colorado.edu

Award Number: N00014-07-1-1017
http://spot.colorado.edu/~camerow/alaska.html

LONG-TERM GOALS

The long-term goal of this project is to build a set of process-based models of Arctic coastal evolution that will aid in prediction of future landscape and nearshore bathymetric change. Our study is focused on the Beaufort Sea coast within the National Petroleum Reserve – Alaska (NPR-A), approximately halfway between Barrow and Prudhoe Bay, Alaska. Our project will help us to identify sites along the Beaufort Sea coast that are at particular risk of becoming eroded in the near future, and to predict future patterns of coastal change as a function of projected changes in sea surface temperature, sea ice conditions, and changes in land surface temperatures. Our approach takes a step beyond the empirical analyses that have characterized past studies of Arctic coastal change by focusing on the development of models fed by new environmental data and retrospective analyses of existing data.

OBJECTIVES

The objectives of the study are threefold: First, we seek to *quantify past rates of coastal change* along the Beaufort Sea coast and to correlate these changes with available meteorological data. These empirical analyses will form a baseline for understanding the how rates of Arctic coastal erosion have changed through time, and what climatic factors correlate most closely with these changes. Second, we plan to *monitor the key environmental drivers* of coastal change through a comprehensive field monitoring program. Field measurements will include monitoring of nearshore conditions including bathymetry, wave fields, and sea surface temperatures; measurement of bluff substrate properties including ice content, ice-wedge polygon spacing, and the evolution of soil temperatures through the summer season; and measurement of fluvial inputs of water, heat, and sediment to the nearshore environment. Finally, we will *develop physics-based models* of coastal evolution that build on our retrospective and real-time data analysis. Ultimately, we hope that these models will allow us to predict future patterns of landscape change

APPROACH AND WORK PLAN

Our technical approach can be divided into three components. The first component is to document past changes in coastal morphology and environmental change so that we can identify both the rates of coastal change through time and the potential correlations between coastal retreat and climatic parameters. Rates of coastal change will be calculated using analyses of orthorectified satellite imagery and aerial photography taken from the same site over multiple time slices. Suitable images have been identified from a variety of interior and defense department sources, spanning from approximately 1955-2007. Imagery is available with a repeat interval of approximately 10 years, becoming denser in the more recent datasets. Difference maps created from these repeat images will be used to quantify changes in coastal morphology through time. Environmental records will be obtained from the same time periods in order to identify trends in sea surface temperature or storminess that might be important in driving the changes in coastal morphology observed in the remotely sensed imagery. Meteorological records will be extracted from both stationary sources and from compilations of mobile sources such as the comprehensive ocean-atmosphere data set (COADS) maintained by the National Snow and Ice Data Center (NSIDC).

The second component of our technical approach is to instrument and monitor coastal dynamics through three summer field seasons. This component can be subdivided into monitoring of offshore conditions, bluff substrate conditions, and fluvial inputs to the nearshore system. The offshore component includes measurement of incoming wave energy using bottom-mounted pressure transducers; mapping of nearshore bathymetry with a compact echosounder; and monitoring of sea surface temperatures in the nearshore environment using small, self-contained thermisters. The onshore component of our data collection includes quantifying the ice content of coastal bluffs; monitoring the dissipation of wave energy to the coast via bluff-mounted seismometers; measuring changes in the temperature profiles of bluff material through the summer season; characterization of ice-wedge polygon spacing along coastal bluffs; and time-lapse photography to document bluff failure processes in real time. Finally, our initial proposal included monitoring of fluvial inputs to the coastal system via the installation of a stream gauging station on the Ikpikpuk River. As described below, we have modified this proposed activity somewhat based on our observations of field conditions during a reconnaissance trip in August 2007.

The third component of our technical approach is to develop physically-based numerical models of Arctic coastal erosion and sediment dynamics. Aerial imagery, environmental data, and field observations will be used to create empirically-based parameterizations of coastal retreat rate as a function of sea surface temperature, wind speed, and offshore sea ice position. Guided by data collected in the field, physics-based models of coastal erosion will be used to describe coastal change driven by thermally driven and mechanically driven erosion of coastal bluffs. Finally, modules describing specific littoral processes will be developed using Delft3D. In particular, modules will be developed to describe the evolution of sea surface temperature as influenced by fluvial inputs and solar insolation; the influence of nearshore barriers and bathymetry on the wave energy reaching the coast; and the fate of eroded coastal bluff sediments in the nearshore environment.

The personnel involved in these data collection activities are as follows: Retrospective analyses of satellite imagery and environmental data will be undertaken by PI Wobus with the aid of a new graduate student (Nora Matell) and an undergraduate student who will be identified in the near future. Field data collection will be undertaken by Matell, Overeem, Anderson and Wobus during the summers of 2008-2010. Wave sensors will be built by collaborator Tim Stanton at the Naval Postgraduate School in Monterey. Numerical modeling will be led by PI Wobus and co-PI Overeem; Overeem will lead the Delft3D modeling efforts, and Wobus will lead smaller-scale modeling of individual physical processes.

We have three major objectives for the coming year. First, we will complete a preliminary inventory of coastal retreat rates from targeted locations using remote sensing, and relate these findings to available meteorological data describing sea surface temperatures and storminess in the nearshore environment. Second, using the data collected from remote sensing and meteorological conditions we will begin to develop process-based models predicting rates of coastal retreat using simple parameterizations of wave energy and thermal notching along coastal bluffs. Finally, during the summer of 2008 we will deploy to the field to measure nearshore bathymetry; install pressure transducers for monitoring wave energy through the summer season; install cameras for time-lapse photography; and collect detailed field observations describing bluff ice content, ice-wedge polygon spacing, and other relevant substrate properties.

WORK COMPLETED

This project was a new award starting late in FY07; as a result, we have just begun the process of obtaining data, planning our logistics for field work, identifying undergraduate assistants to aid in the data collection and analysis tasks, and formulating our preliminary numerical models. We have ordered a first set of satellite and airphoto imagery covering the coastline at Drew Point between 1955 and 1979. We have also begun familiarizing ourselves with the process of extracting packed binary meteorological datasets from the COADS database into useful spatially referenced data. We have advertised for undergraduate assistantships to aid in data collection and analysis. We have begun the background research that will allow us to formulate our baseline numerical models for describing both the thermal erosion of coastal bluffs and sediment transport in shallow estuaries.

PI Wobus also traveled to Alaska for a brief reconnaissance trip in August of 2007. During this trip, temperature sensors were installed in the Ikpikpuk River and in the shallow soil near the Drew Point field site; instantaneous temperature measurements were obtained from four sites along the Ikpikpuk River and seven sites in the shallow Beaufort Sea; oblique aerial photographs and on-the-ground photos were obtained from much of the study area coast; a survey line was established at Drew Point that can be revisited throughout the course of the project; and visual estimates of bluff ice content, dimensions, and substrate grain size were obtained.

This reconnaissance trip was also useful in familiarizing ourselves with Arctic field work, establishing contacts with collaborators and logistics providers, and identifying suitable sites for setting up our summer field stations and monitoring sites. An additional benefit of this reconnaissance trip was the ability to assist our USGS collaborators with building their environmental monitoring stations and connecting them to their existing telemetry network. Future field seasons will be considerably more effective with the knowledge gained from this reconnaissance trip.

RESULTS

Although our project has just begun, the August 2007 reconnaissance trip by PI Wobus provided a number of surprising results that changed our thinking and our plans for future work. Most importantly, sea surface temperatures in the shallow Beaufort Sea were substantially warmer than we had anticipated, even in coastal environments that were far removed from any significant fluvial inputs. Figure 1 shows the distribution of Ikpikpuk River and Beaufort Sea water temperature measurements obtained during the week of August 8-August 15, 2007. The average of four water temperature measurements along the Ikpikpuk River was 14.9°C, and the average of seven

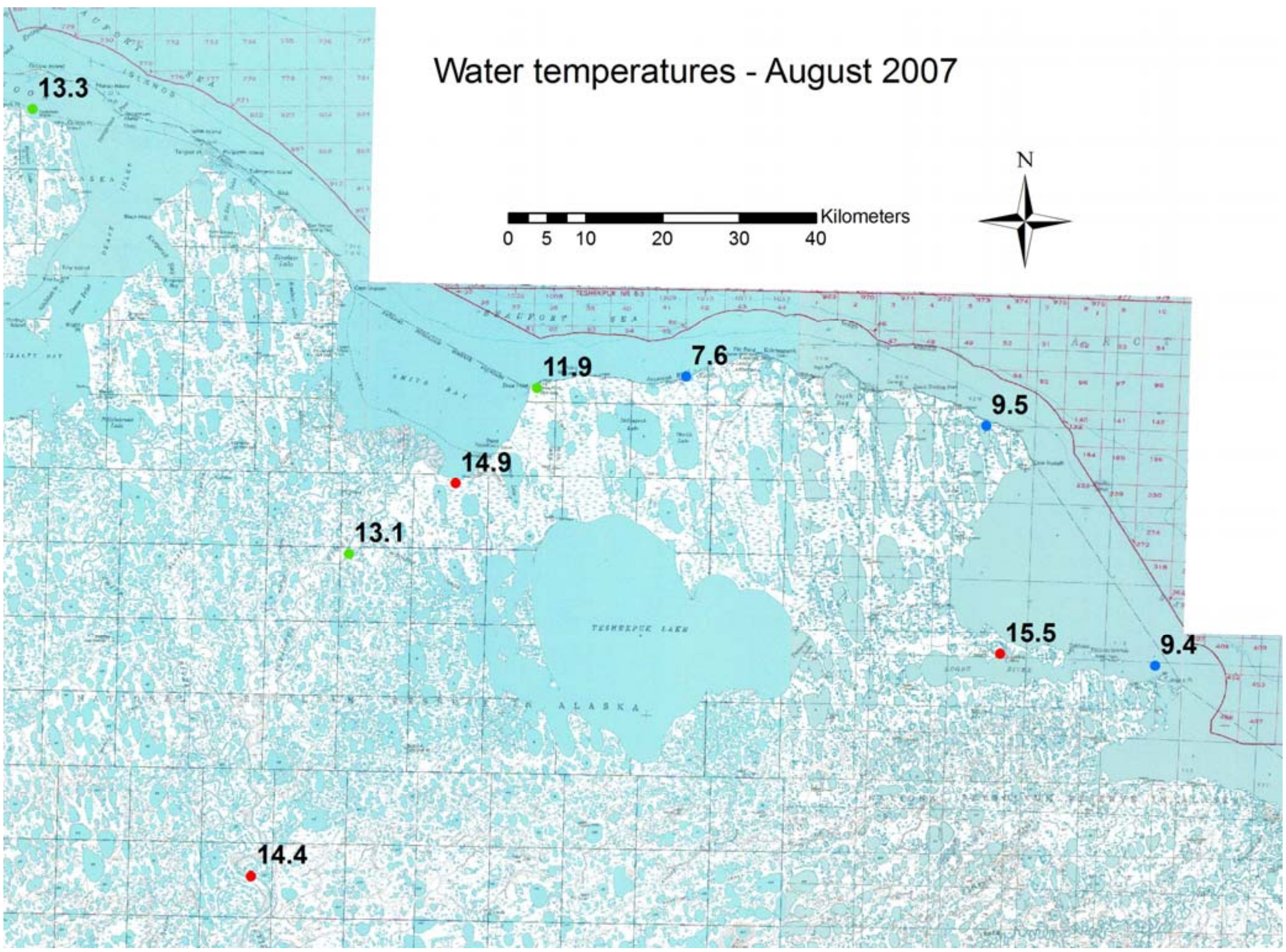

Figure 1. Point measurements of water temperatures during August 2007 reconnaissance trip to the study area.

measurements in shallow waters (< 1 meter depth) in the Beaufort Sea was 11.7°C (Figure 1). Our anticipation prior to this field season was that shallow coastal waters would have been substantially colder than this, since these waters remain in direct contact with sea ice for much of the year. Instead, these field measurements suggest that there may be a narrow zone along the Beaufort Sea coast that efficiently absorbs summer insolation and remains thermally buffered from colder, deeper waters offshore. This observation suggests that erosion driven purely by thermal processes may be considerably more efficient than originally anticipated, and may in fact be the primary driver of coastal retreat where coastal bluffs are ice-rich.

Our reconnaissance trip also gave us a first-hand look at how rapid this purely thermally-driven coastal retreat can be. PI Wobus visited Drew Point, in the northwest corner of our field area, twice during this reconnaissance trip. Although the trips to Drew Point were separated by only five days, the morphology of the coastline changed substantially during this interval, with a very large (~10-meter) block of coastal bluff slumping into the sea (Figure 2). Importantly, there were no storms during this interval that would have contributed any mechanical energy to the coastline in the form of wave attack. However, the weather was very warm over this period, suggesting that there might have been substantial melting of the ice-rich bluff substrate.

Figure 2. Two views of the Drew Point coastline. Left image: August 9, 2007. Right image: August 14, 2007. Note the substantial coastline change in the intervening period, during which time there were no significant storm events. Arrows point to the same features in both photos for reference.

One of our preliminary hypotheses when we designed this study was that inputs of warm freshwater from fluvial systems might be an important source of thermal energy to the coastal system. With this in mind, we had planned to monitor fluvial inputs by setting up a stream gauging station on the Ikpikpuk River. Two observations from our reconnaissance field season suggest that this will not be practical. First, after flying nearly the entire length of the Ikpikpuk River downstream of an existing USGS stream gauge, it is clear that there is not another suitable site for gauging this river; the river is sand-bedded and simply too dynamic to construct a reliable rating curve for any cross-section. In addition, our temperature measurements along the Beaufort Sea coast suggest that shallow coastal waters may reach high temperatures even in the absence of substantial freshwater inputs. Quantifying the thermal inputs to the coast from river systems may therefore be less important than monitoring and modeling direct solar radiative inputs to the shallow sea. We have revised our plans for Ikpikpuk gauging to include only a comprehensive thermal monitoring program, installing a number of self-contained temperature sensors along the course of the river to monitor the downstream change in temperature as the river flows over the coastal plain. We will combine these data with discharge records from the USGS gauging station to estimate the total thermal inputs to Smith Bay.

A final lesson learned from this reconnaissance field season was the observation that coastal bluffs along much of the Beaufort Sea coast between Drew Point and Cape Halkett are extremely poor in clastic material. In particular, many of the bluffs we visited are characterized only by massive ground ice overlain by a fine-grained organic mat (Figure 3a). This lack of clastic material suggests that the potential negative feedbacks on coastal erosion rates – buffering of the shore by local redeposition of clastic material – may be considerably weaker than we had anticipated. In addition, in many of sites we visited the coast is composed almost entirely of organic mats that formed the floors of thaw lakes that have since drained. These organic mats appear to be substantially more resistant to coastal retreat than adjacent portions of the shoreline (Figure 3b). As anticipated during the preparation of our proposal, along-shore spatial variations in bluff substrate composition may be extremely important in modulating the evolution of the coast itself.

Figure 3. Coastal morphology in two endmember bluff substrates. Photo at left shows ice-rich coastal bluffs at Drew Point, with organic-rich mat overlying massive ground ice. Bluff height is approximately 2 meters. Photo at right shows the coast along the former shore of a drained thaw lake. Resistant organic mat here forms a promontory projecting into the Beaufort Sea. Both environments shown here are very poor in clastic material.

IMPACT/APPLICATIONS

Our preliminary observations suggest that the feedbacks between Arctic climate change and coastal evolution might be more direct than we had anticipated. In particular, if purely thermal erosion of ice-rich coastal bluffs is primarily responsible for coastal retreat, then warming sea surface temperatures might directly drive coastal evolution rather than simply modulating the storms that drive physical erosion processes. In areas where coastal retreat is primarily a thermal problem, this might also have important implications for our ability to predict future rates and patterns of coastal change. For example, while coastal weather is inherently stochastic, future changes in nearshore seawater temperatures may be more predictable. These hypotheses about how coastal evolution proceeds will of course be tested with the new remote sensing and environmental monitoring data that will be collected in the subsequent years of this project.

RELATED PROJECTS

PI Anderson and co-PI Overeem are both members of the Community Surface Dynamics Modeling System (CSDMS) terrestrial working group (http://csdms.colorado.edu/index.html). We anticipate that our project will tap the broader expertise of the CSDMS consortium as we move into the modeling component of our study.