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

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LONG-TERM GOALS

The long-term goal of this project is to quantify the environmental drivers of extremely rapid coastal erosion in the Arctic, and to begin developing predictive models of future rates of coastal erosion resulting from climate 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. We are focusing our efforts on collecting empirical data that will help us to develop process-based models of coastal change.

OBJECTIVES

Our main scientific objective is to understand and quantify the relative roles of thermal and mechanical (wave) energy in driving coastal erosion in the Arctic. We are combining high-resolution observations of coastline retreat with meteorological and oceanic monitoring programs. Our planned and completed field data collection includes: 1) measurement of bluff substrate properties including ice content, ice-wedge polygon spacing, and the thermal properties of bluff materials; 2) time-lapse photography to observe coastal erosion processes in real-time; 3) establishment of a meteorological monitoring network to summarize the climatic forcings on the system; and 4) monitoring of offshore conditions including bathymetry, wave fields, and sea surface temperatures. By synthesizing these field observations and remote sensing observations into process-based numerical models, we anticipate that we will be able to predict future patterns of Arctic landscape change in the face of changing climatic

APPROACH AND WORK PLAN

Our technical approach includes direct observation of coastal erosion using time-lapse photography; collection of relevant field data including coastal bluff composition, wave and sea surface temperature records, and meteorological records; and modeling of relevant thermal and mechanical processes.

The personnel involved in these activities are as follows: Analyses of time-lapse photography and meteorological records is being undertaken by Dr. Wobus. Sea ice analyses and wave modeling have been conducted by undergraduate Cori Holmes and Dr. Overeem. Masters student Nora Matell developed thermal models of lake erosion, and compiled remote sensing datasets from the NPR-A. Numerical models and data mining code have been developed by Drs. Anderson, Wobus and Overeem. USGS scientists Clow, Urban and Jones assisted with retrieval of sensors during the 2008 summer season. Wave sensors were built by collaborator Tim Stanton at the Naval Postgraduate School in Monterey, and were deployed during the summer field season in 2009.

WORK COMPLETED

Over the past year, we completed our second full field season; we presented five talks and posters at national meetings and local symposia; we submitted one paper to a peer-reviewed journal; and we had two students complete theses (one masters and one undergraduate). Our field work included servicing of our two meteorological stations; re-measuring coastal position relative to benchmarks established in 2007; and deploying new time-lapse cameras in sandy coastal environments. We also contracted with a private marine services company to deploy wave sensors equipped with autonomous temperature sensors, to catalog the timeseries of thermal and wave energy through a summer season. These sensors were retrieved late in September 2009, providing us with a record of approximately 2 months of both wave and temperature data. During the academic year, we also developed computer codes that dramatically increase our efficiency in processing remotely sensed data describing sea ice concentrations and sea surface temperatures relevant to our study area.

RESULTS

One of our major goals for FY2009 was to use our time-lapse imagery to quantify the relative roles of warming surface waters and wave energy from storms in driving coastal erosion. Toward this end, we have leveraged a timelapse sequence documenting shoreline erosion along an inland lake where we have simultaneous water temperature measurements. Since wave energy is limited in this lake environment, this record has allowed us to calibrate a model of purely thermal erosion along a permafrost coastline. Our simple model suggests that previously published models of bluff erosion predict observed erosion rates quite well. Conversely, temperatures back-calculated from erosion rates mimic measured water temperatures in the lake environment (Figure 1).

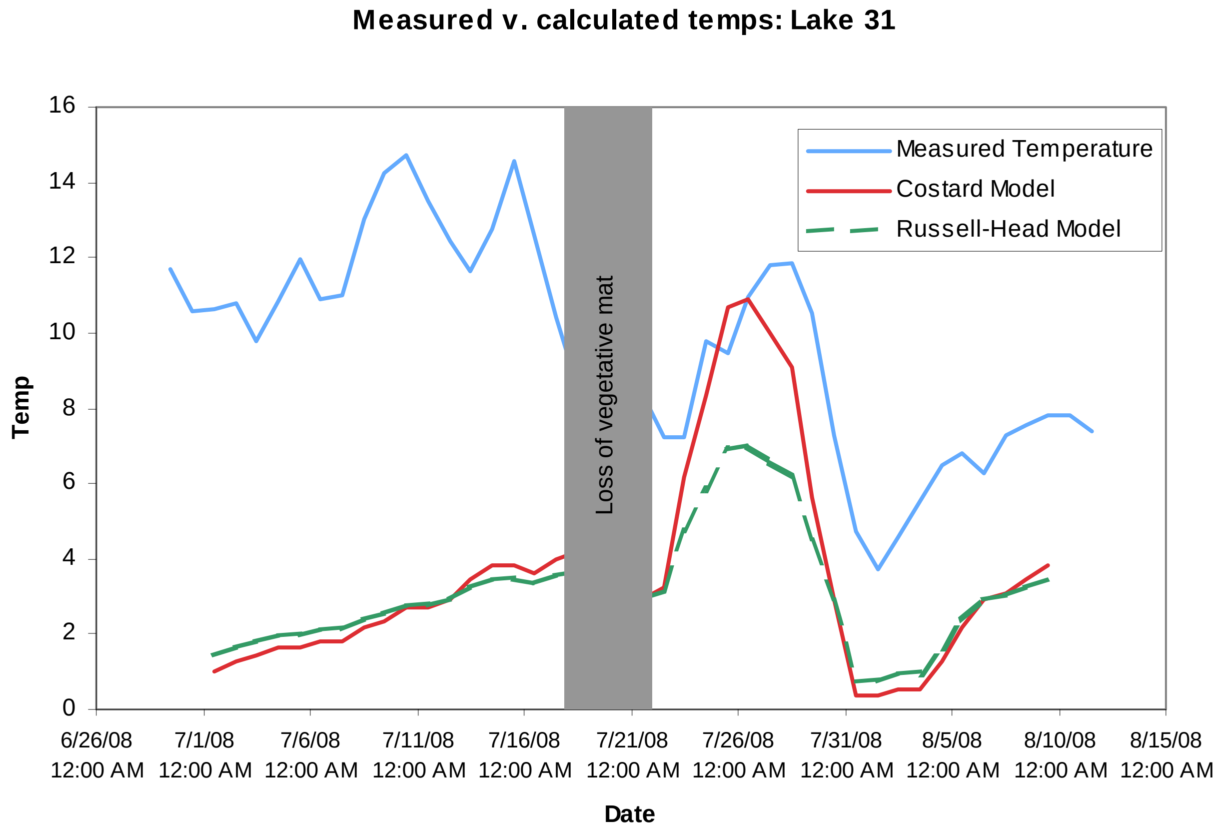

Figure 1 Modeled lake temperatures calculated from shoreline erosion rate mimic measured temperatures in the latter half of the summer of 2009.

The next step is to take these models to the Beaufort Sea coastline. The rapid retreat of the Beaufort coastline after the last appearance of sea ice – even in the absence of substantial wave energy – strongly implicates a thermal driver for the coastal erosion that we have observed (Figure 2). In the laboratory, we measured the ice content of seventeen composite samples collected from bluffs at Drew Point. Ice contents (by mass) ranged from 25-95%, with most of the samples having ice contents in excess of 50%. Combined, these data suggest that thermal processes may be more important than mechanical processes in eroding this coastline. A corollary to this is that continued increases in sea surface temperatures could directly influence erosion rates into the future.

Thus far, we have used remotely sensed records from the MODIS satellite to reconstruct timeseries of sea surface temperature and to evaluate the total thermal erosion potential in this setting. Comparisons of these coarse-resolution data with observations of coastal erosion rates from repeat measurements of onshore benchmarks also indicate that thermal processes could account for the majority of erosion that we have observed over two summers of monitoring (Figure 3).

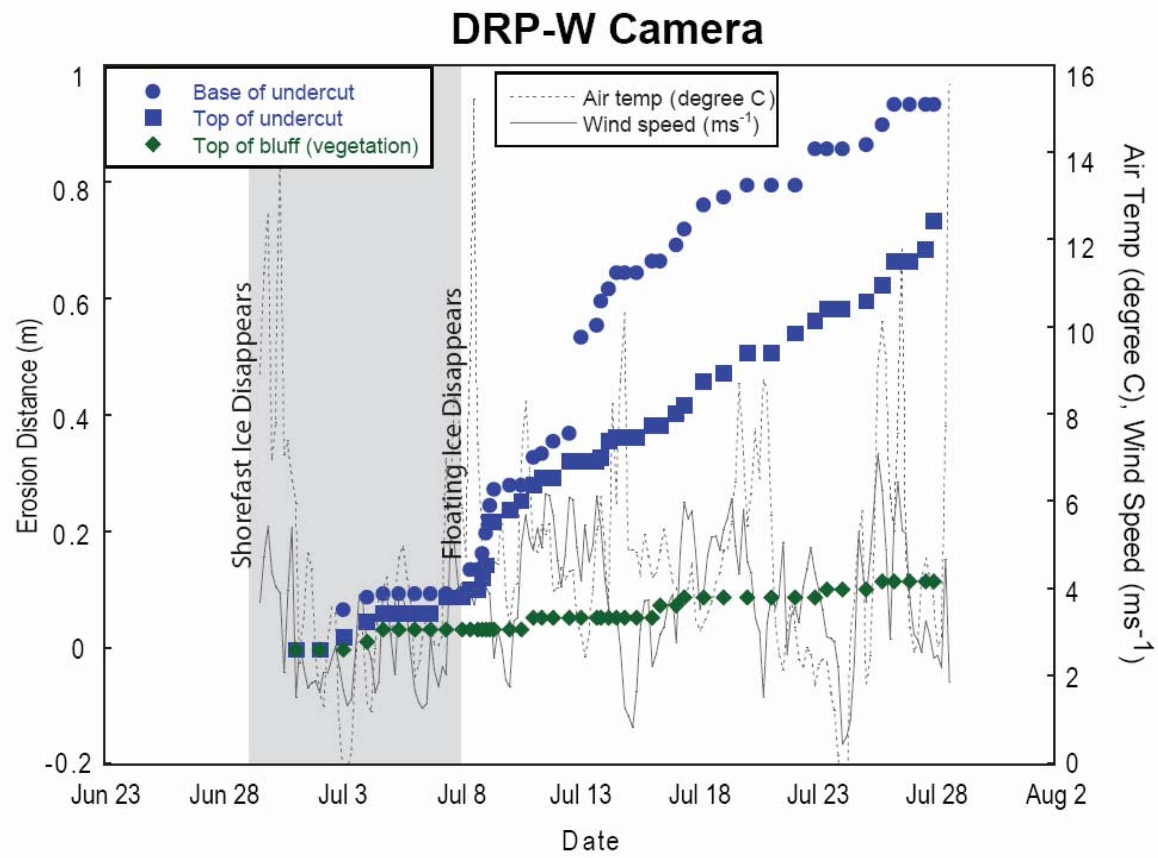

Figure 2 Rate of coastal erosion over July 2008 as reconstructed from time-lapse imagery at Drew Point. Erosion accelerates following retreat of sea ice, and is ongoing even in relatively calm wind conditions.

We have also begun to evaluate the effects of increased fetch on coastal erosion by wave energy. As a first step we used Nimbus 7-SMMR /SSM/I and DMSP SSMI Passive Microwave data to assess sea ice concentration around the Drew Point coast. This dataset runs from 1978 to the present at daily or two-daily time resolution, but has a low spatial resolution (25 by 25km gridcells). We analyzed the data to determine ‘open-water distance’, the distance from a coastal cell towards the sea ice margin where concentration rises above a wave dampening threshold (we used >50% ice). This allows us to show how fetch develops over the year and how it is related to the 20 year average fetch (Figure 4). Analysis of storm records is ongoing to evaluate the role of mechanical (wave) erosion over the same time periods.

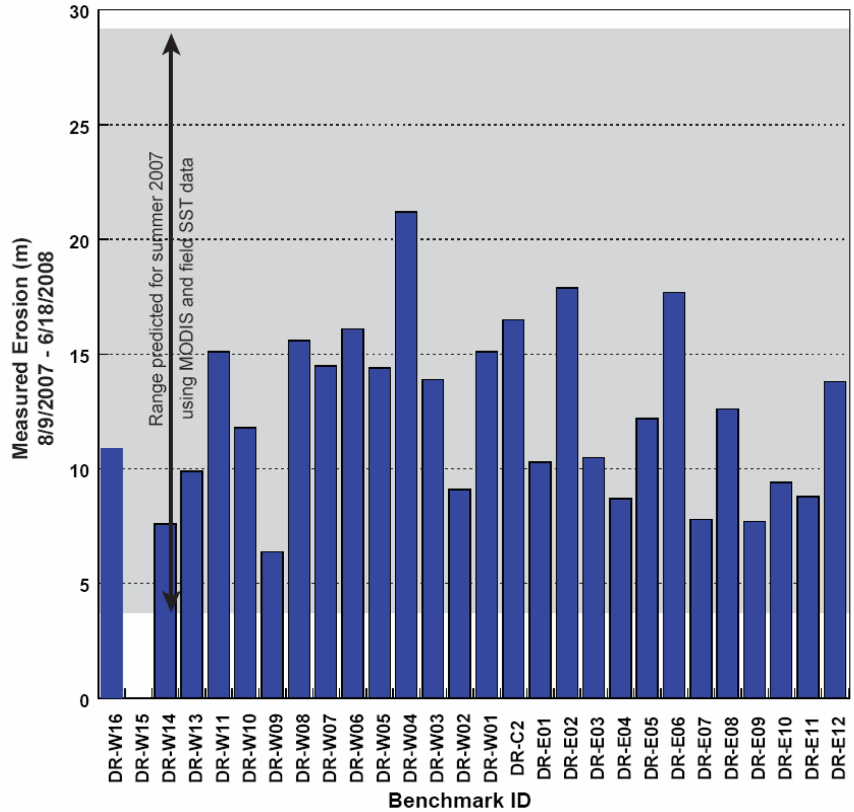

Figure 3 Integrated coastal loss over an entire season (9th of August 2007- 18th of June 2008) as reconstructed from repeat survey transect along Drew Point. Total loss is consistent with thermal erosion potential modeled from MODIS.

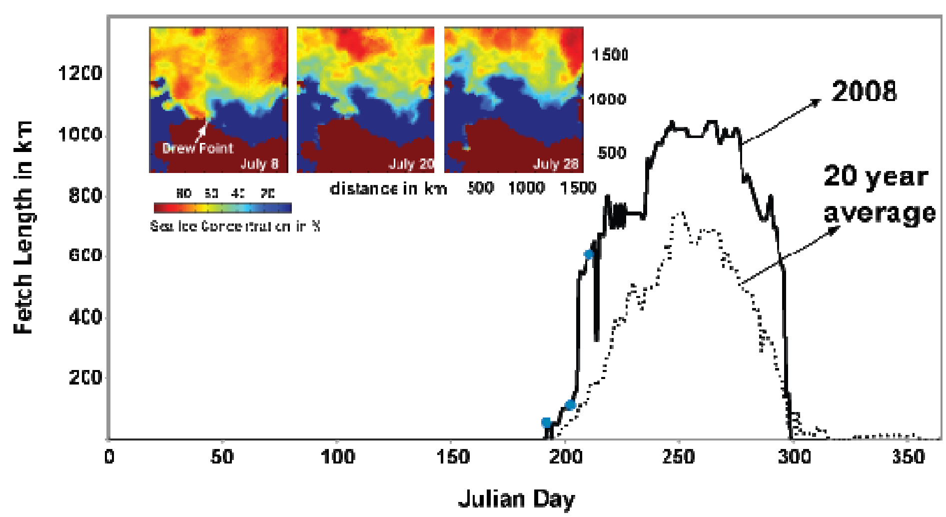

Figure 4 Fetch Length at Drew Point for different stages over the summer season 2008 is reconstructed from Nimbus-7 Passive microwave data, 2008 has open water distances that are 100's of km longer than the 20 year average conditions.

Our offshore work during the summer of 2009 gave us our first look at the detailed bathymetry in the shallow Beaufort Sea. One hypothesis to be tested is that if coastal erosion rates have in fact accelerated over the past century, there should be an inflection in the bathymetry that reflects this acceleration. There are suggestions from our bathymetric surveys that such an inflection exists in the nearshore environment (Figure 5), which would be consistent with the idea that coastal erosion rates have accelerated in the recent past.

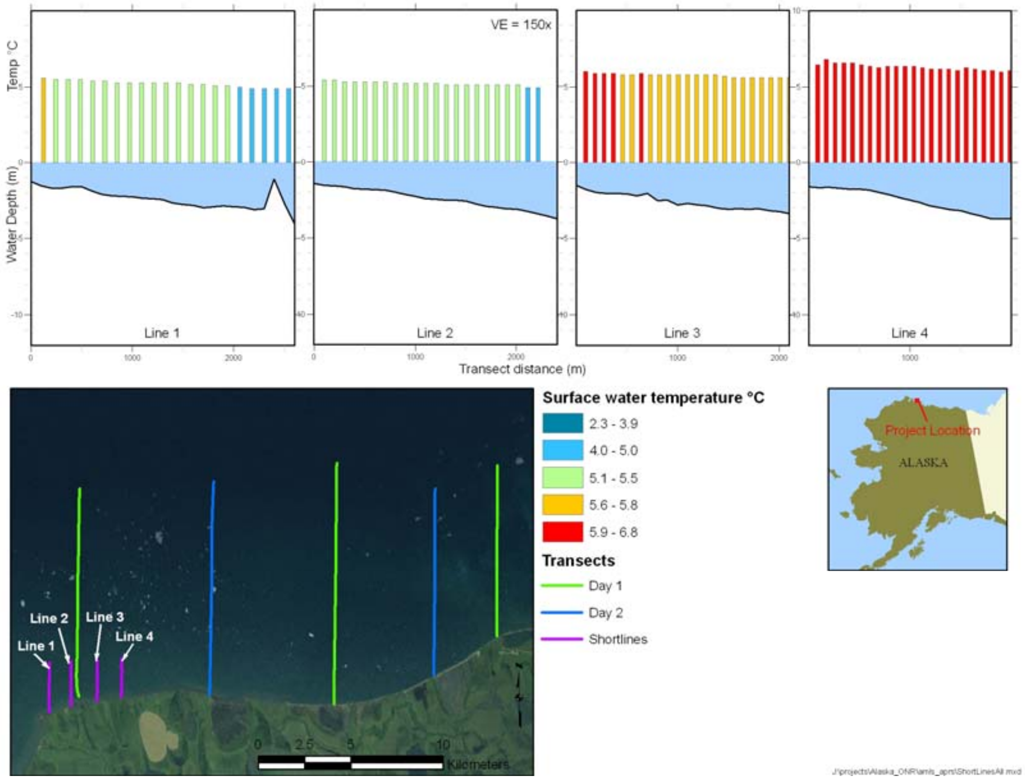

Figure 5 Survey lines of nearshore bathymetry and measured SST temperatures, July 2009.

IMPACT AND APPLICATIONS

Science Education and Communication

Last fall we produced a video from our time-lapse photography which was posted on the New York Times “Dot Earth” website. The video, entitled ‘Alska’s Eroding Coast’, shows the dramatic loss of coastline during a period of relatively calm weather over the middle of the summer of 2007. As of this writing, this video has been viewed nearly 29,000 times.

TRANSITIONS

Science Education and Communication

Our work has been disseminated among other researchers studying Arctic climate change and coastal processes. Our project was featured as an example on ‘Modeling Arctic Coastal Erosion’ in the policy document ‘Arctic Coasts 2009 – a Circumpolar Review’ that will be published by IASC-LOICZ-AMAP. Our coastal erosion video was also shown at the large plenary closing ceremony of the International Polar Year (IPY) in Geneva, Switzerland.

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. Photos and movies of the eroding permafrost coast, as well as thawing lake shores at our field site have been added to the Educational Gallery of the CSDMS: http://csdms.colorado.edu/wiki/index.php/Coastal_GL4
The developed model for 'Lake-Permafrost with Subsidence' developed by graduate student Nora Matell has been added to the Model repository of CSDMS and will thus become available as open-source code for interested earth scientist worldwide.

PIs Wobus and Anderson are both involved in an NSF-sponsored project to understand weathering in alpine environments. Thermal models of ground temperatures as well as technologies developed for monitoring weather conditions, collecting time-lapse photographs, and deploying self-contained temperature probes are creating synergies between these two projects.

PUBLICATIONS

Wobus, C., R.S. Anderson, I. Overeem, N. Matell, F. Urban, G. Clow, and C. Holmes, in revision Calibrating thermal erosion models along an Arctic coastline (Submitted to Nature Geoscience June 2009; in revision for JGR-Earth Surface)

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Peckham, S., Overeem, I., Sediment Transport in a Changing Arctic: River Plumes, Longshore Transport and Coastal Erosion. Arctic Change Meeting, December 10th, 2008. Quebec, Canada.