

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

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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 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, and again in late summer 2010. Higher resolution time-lapse cameras were deployed in collaboration with the Extreme Ice Survey in summer 2010.

WORK COMPLETED

Over the past year, we completed our third field season; we presented five talks and posters at national meetings and several at local symposia; and we submitted two papers to peer-reviewed journals. Our fieldwork in summer 2010 included servicing of our two meteorological stations; re-measuring coastal position relative to benchmarks established in 2007 and 2008; and deploying new high resolution time-lapse cameras in collaboration with the Extreme Ice Survey. These cameras and associated sensors were retrieved late in September 2010, providing us with a record of approximately 1 full month of both water level and temperature data, and coastal bluff retreat in great detail.

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 time-lapse 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.

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 time series 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).

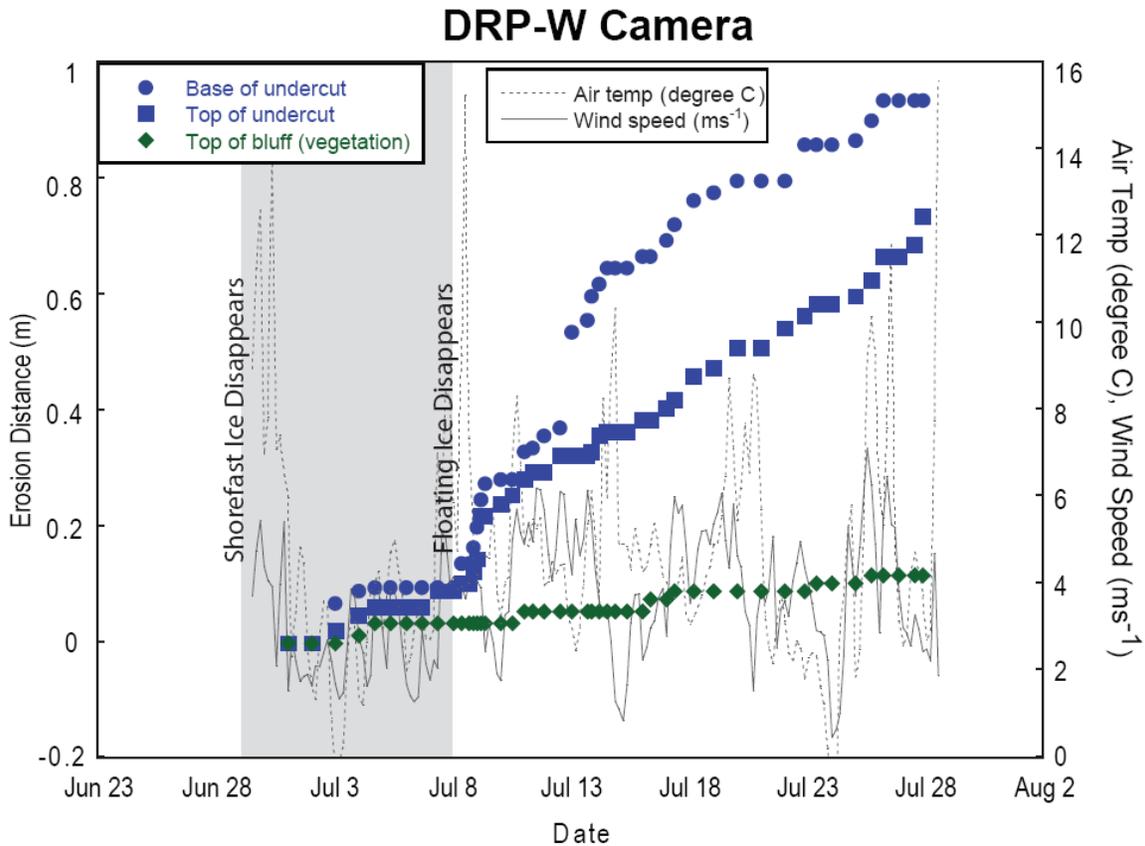


Figure 1. Rate of coastal erosion over July 2008 as reconstructed from time-lapse imagery at Drew Point. Erosion accelerates following retreat of sea ice, and is ongoing even in relatively calm wind conditions.

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 3).

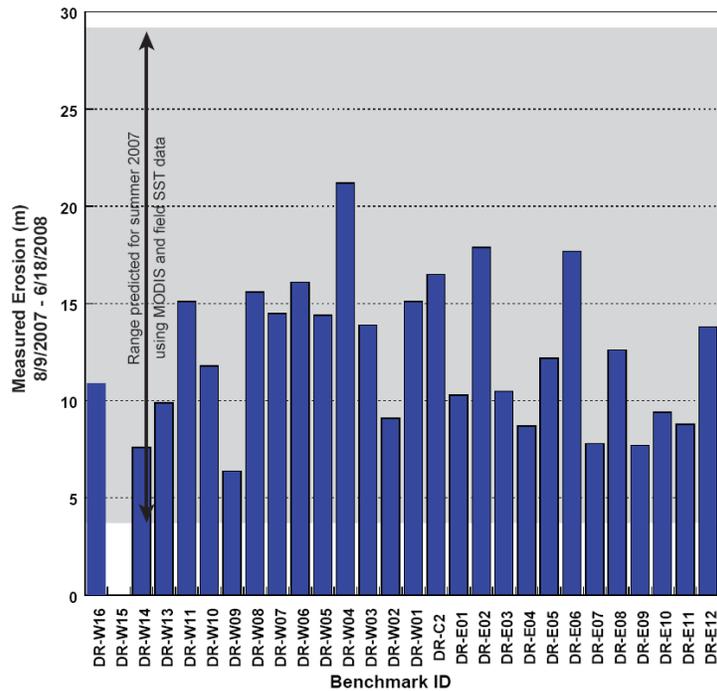


Figure 2. Integrated coastal loss over an entire season (9th of August 2007- 18th of June 2008) as reconstructed from repeat survey transect along Drew Point. Total loss is consistent with thermal erosion potential modeled from MODIS.

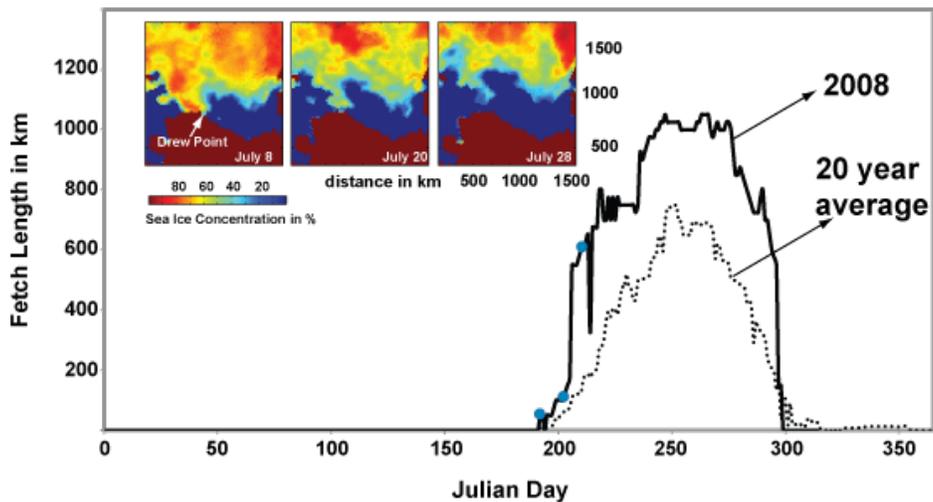


Figure 3. Fetch Length at Drew Point for different stages over the summer season 2008 is reconstructed from Nimbus-7 Passive microwave data, 2008 has open water distances that are 100's of km longer than the 20 year average conditions.

From summer 2009 wave buoy data and the thermal loggers we had deployed with these sensors, we have extracted information about the role of storms in local mixing of shelf waters. The highest ocean temperatures adjacent to the coastal bluffs occur not long after sea ice detaches from the coastline. A single storm event thoroughly mixes the shelf waters over a reach of shelf that is at least 10 km in width normal to the coastline, and they remain well mixed through the remainder of the summer except for several discrete events, all associated with storms.

We have now carefully analyzed the sea ice records from 1979 to present, as this sets the context for coastal erosion. A first order result is the lengthening of the sea ice free period of the summer. We show that for our reach of coastline, the sea ice free period has lengthened considerably, resulting in roughly 2.5-fold increase in exposure to melt by seawater. This expansion of ice-free conditions is asymmetrical, with the majority of the lengthening being into the fall season (0.9 days/yr), and smaller expansion into the mid-summer (0.7 days/yr). This reduces the leverage of the expansion on acceleration of coastal bluff retreat, as the sea surface temperatures in the fall are declining due to decline in direct insolation. A manuscript in which this result is highlighted is presently targeted toward *Science*.

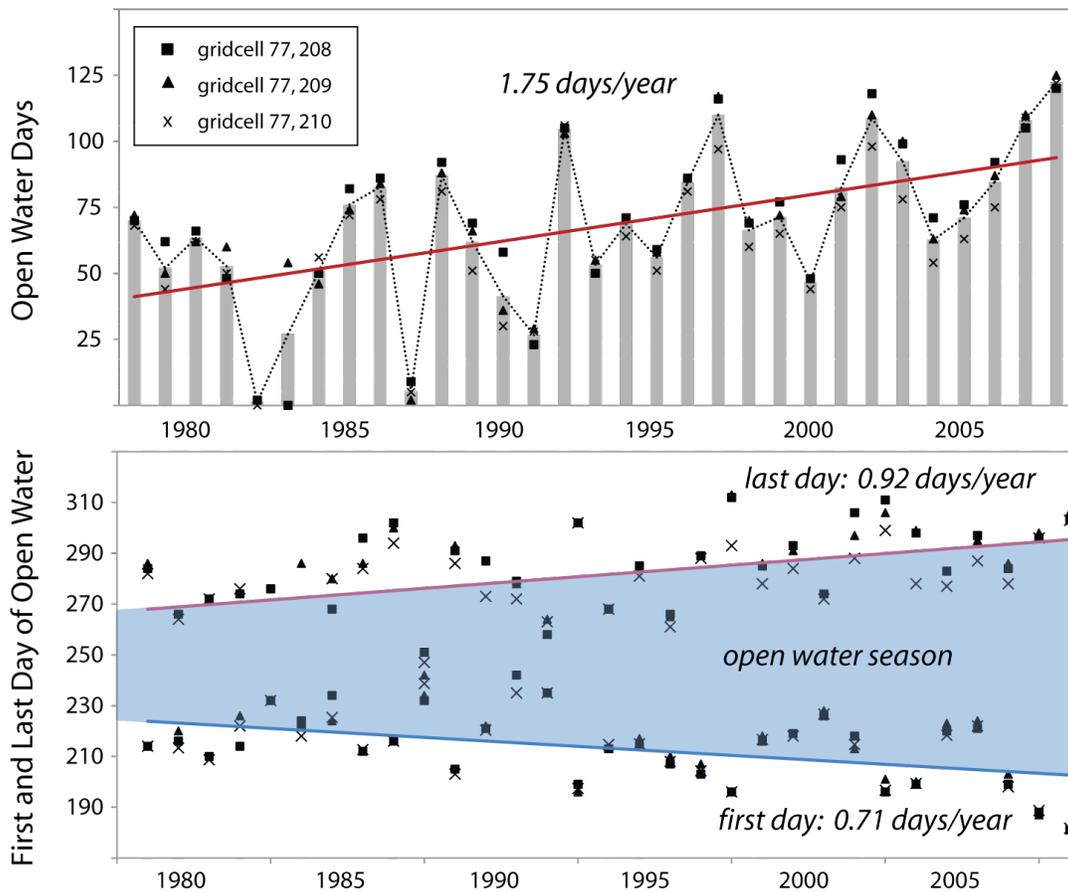


Figure 4. History of sea-ice free conditions (open water) in 3 adjacent cells along Beaufort Sea coastline, centered on our research site.

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.

Summer 2010 field effort

We are excited about the results from the short summer 2010 field effort. This netted us time series of wave level (including contributions from waves, surge and tides), water temperature at several near-shore sites, and coastal erosion patterns from time-lapse photography. We deployed four cameras, two high-end cameras one on land the other attached to a pole embedded in the subsea permafrost; and two lower resolution cameras (hunting cameras) of the sort we have deployed in previous summers. We briefly summarize the results here. In the August 13th-Sept 11th period, the water temperatures were remarkably homogenized in the near-shore zone. Water level shows clearly the role of surge set-up in modulating the location of the water impact with the cliff face, resulting in bluff retreat and block melt rates that vary significantly on short timescales. The demise of the toppled coastal bluff blocks is now revealed by the offshore camera, and happily matches well the patterns revealed by numerical models of this process. The retreat observed in this one-month interval was of the order of 10 m, much of a year's worth of retreat according to our pin-flag measurements from the last two summers.



Figure 5. View from high-resolution land camera upon retrieval in mid-September. Note offshore camera may be seen in the distance beyond the failed bluff block. Documented retreat is roughly 10 m in this view over the month-long period.

Models

We have now submitted for publication in *JGR-Earth Surface* the work of Masters student Nora Matell in which we model the thermal impact of thaw lakes on the permafrost of the North Slope.

With the help of new graduate student Katy Barnhart, we have pushed on the development of numerical models of coastal bluff retreat. The physics embedded in this model includes the growth of a coastal notch by melt, toppling of the block when a torque condition is exceeded, and subsequent melting of the failed blocks. Melting is accomplished by both air and water. Water level is modulated of the water level by waves and surge and tide. Melt rate is governed by an empirically based iceberg melting algorithm that includes explicitly the roles of wave height and water temperature.

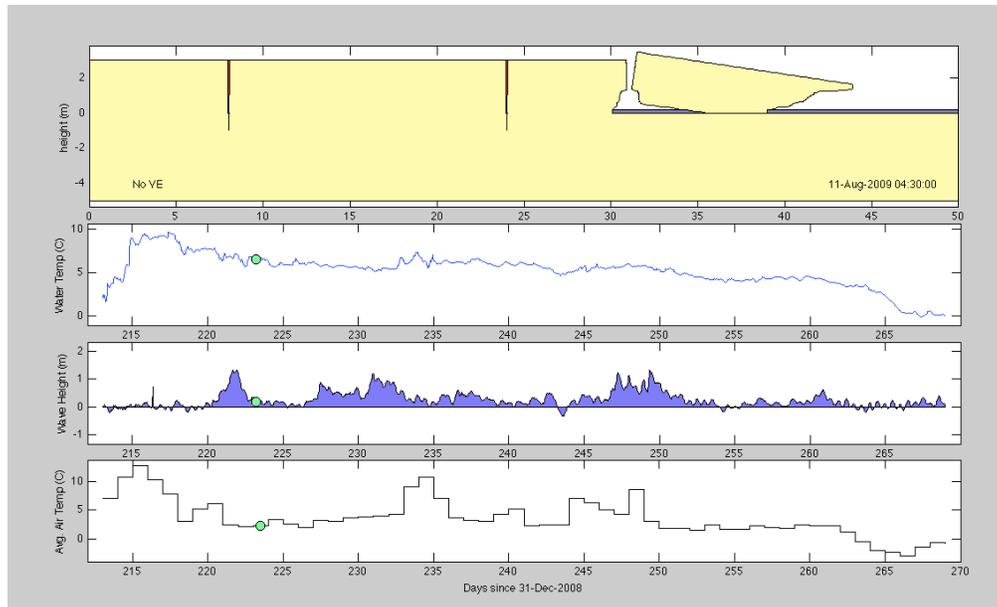


Figure 6. Screenshot of model result from coastal bluff retreat numerical model. Top: coastal bluff in cross-section, showing recently toppled bluff block. Failure occurs on ice wedges. Time series of water temperature, wave height and air temperature. Green dots display where the model is in time, JD 223.

As our goal is to place the coastal retreat problem in a quantitative, even predictive framework, we aim to exercise the model in the following ways. First we will use this and last summer's direct observations to refine and tune the model to our particular coastal conditions. Second, we will attempt to reproduce the rates of coastal retreat over the period for which we have both sea-ice and meteorological constraints. Finally, we will explore various climate scenarios, knowing that these must include i) expansion of sea ice free conditions, ii) models of sea surface temperature, and iii) parameterizations of sea level surge associated with storm systems.

In this endeavor we will mine not only the sea ice data sets, but those of on land meteorological stations maintained by our USGS colleagues. As an example of the weather data now available, we display here a stack of time series of downwelling solar radiation at Drew Point, with air temperatures at the same met station. The pattern shows nicely both the solar-driven direct radiation, but variations about it that reflect both diffuse radiation and storm-driven cloud events. The air temperatures distinctly lag

the insolation pattern, as the presence or absence of sea ice governs the continentality of the site (note high variation in air temperatures occurs in the time window outside the open water season).

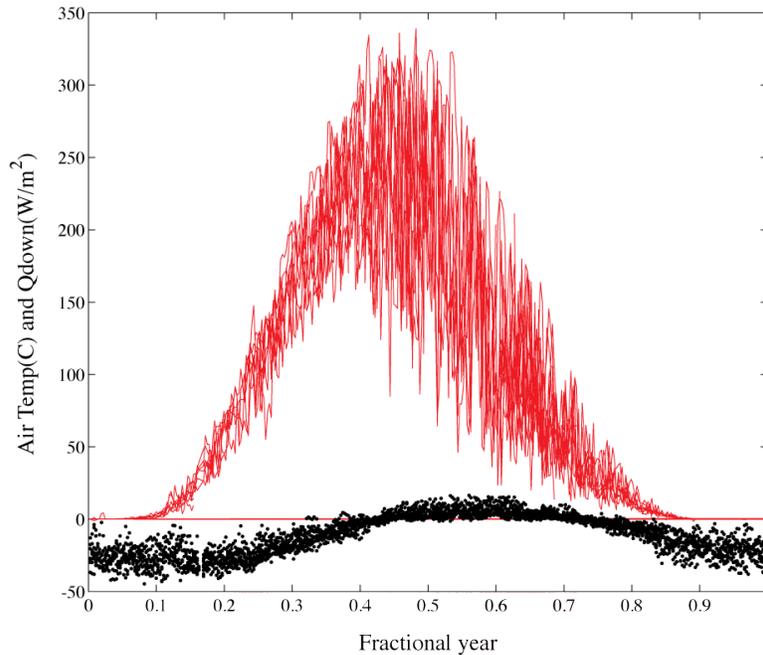


Figure 7. Stacked met records from the Drew Point met station, covering 12 years of record. Red lines = downwelling solar radiation; black dots = air temperature.

IMPACT AND APPLICATIONS

Science Education and Communication

In Fall 2008 we produced a video from our time-lapse photography which was posted on the New York Times “Dot Earth” website. The video, entitled ‘Alaska’s Eroding Coast’, shows the dramatic loss of coastline during a period of relatively calm weather over the middle of the summer of 2007. This video has been viewed more than 30,000 times. In the summer of 2008 we participated in an IPY “Dispatches from the field” event, in which we communicated our daily science activities to a global community of science educators via satellite telephone hookup.

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.

As listed in the end of this report, in FY2010 we were also involved in press conferences, television and newspaper interviews, and have given several talks at both local and national venues.

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.

NOPP Award 2010, July 2009

Our project was chosen to receive the National Oceanographic Partnership Program 2010 Award for Excellence in partnering and outreach. The award was presented to Cameron Wobus at the annual ORRAP meeting in Seward, Alaska, in July of 2010.

PUBLICATIONS

Matell, N., R. S. Anderson, I. Overeem, C. Wobus, F. E. Urban, and G. D. Clow, Subsurface thermal structure surrounding thaw lakes of different depths in a warming climate (submitted to *JGR-Earth Surface* August 2010)

Overeem, I., R. S. Anderson, C. Wobus, G. D. Clow, F. E. Urban, N. Matell, Quantifying the Role of Sea Ice Loss on Arctic Coastal Erosion (submitted to *Geomorphology*, August 2010)

Wobus, C., R.S. Anderson, I. Overeem, N. Matell, F. Urban, G. Clow, and C. Holmes, Calibrating thermal erosion models along an Arctic coastline (in revision with *JGR-Earth Surface*)

Other Contributions

Overeem, I., 2010. Arctic Coastal Erosion along the Beaufort Sea. Contribution to “A Science Plan for Regional Arctic System Modeling”. In: Roberts et al., (eds.), 2010. A report by the Arctic Research Community for the National Science Foundation Office of Polar Programs.

THESES

Matell, N., 2009. Shoreline erosion and thermal impact of thaw lakes in a warming landscape, Arctic Coastal Plain, Alaska. M.Sc. thesis project, Department of Geology, University of Colorado, Boulder.

Holmes, C., 2009. "Focused Temporal and Spatial Study on Sea Ice Location in the Beaufort Sea, Alaska, and its Role in Coastal Erosion". Honors BSc thesis. University of Colorado, Boulder.

ABSTRACTS

2008 AGU

Matell, N., R. S. Anderson, C. Wobus, I. Overeem, F. Urban, and G. Clow, 2008, "Thinking along 2 axes: Lakeshore erosion and subsurface effects of thaw lakes along Alaska's Arctic Coastal Plain", AGU Fall Meeting

Wobus, C., R.S. Anderson, I. Overeem, N. Matell, F. Urban, G. Clow, B. Jones, and C. Holmes, 2008, "Monitoring coastal erosion on the Beaufort Sea coast: Erosion process and the relative roles of thermal and wave energy". AGU Fall Meeting.

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

2009 AGU

Overeem was a Session chair "Arctic Coasts at Risk", AGU Annual Meeting 2009.

Overeem, I., Wobus, C.W., Anderson, R. S., Clow, G.D., Urban, F.E., Stanton, T. P., 2009. Quantifying Sea-Ice Loss as a Driver of Arctic Coastal Erosion. AGU Fall Meeting, San Francisco, December 2009.

Wobus, C.W., Anderson, R. S., Overeem, I., Clow, G.D., Urban, F.E., 2009. Calibrating thermal erosion models along an Arctic coastline. (Invited) AGU Fall Meeting, San Francisco, December 2009.

Overeem, I., Wobus, C.W., Anderson, R. S., Clow, G.D., Urban, F.E., Stanton, T. P., 2009. Quantifying Sea-Ice Loss as a Driver of Arctic Coastal Erosion. AGU Fall Meeting, San Francisco, December 2009.

Anderson, R. S., Wobus, C.W., Overeem, I., Clow, G.D., Urban, F.E., Stanton, T. P., 2009. Rapid coastal erosion on the Beaufort Sea coast: A triple whammy induced by climate change (Invited), AGU Fall Meeting, San Francisco, December 2009.

State of the Arctic Conference

Wobus, C. W., R. S. Anderson, I. Overeem, G. Clow, F. Urban, and T. Stanton. Thermal erosion of an Arctic Coastline: Field observations and Model development. State of the Arctic Conference, Miami, FL, March 17, 2010.

ONR Coastal Geosciences review in Chicago

Wobus, C. W., R. S. Anderson, I. Overeem, G. Clow, F. Urban, and T. Stanton. Thermal erosion of an Arctic Coastline: Field observations and Model development. 2010 ONR Coastal Geosciences review meeting, June 4 2010.

Polar Society

Overeem, I., 2010, Sea Ice Loss Induces Arctic Coastal Erosion. Program and Abstracts of the American Polar Society Meeting 2010, Institute of Arctic and Alpine research (INSTAAR), Univ. of Colorado at Boulder. (Invited talk)

NSIDC

Anderson, R. S., 2010, The triple whammy of sea ice loss on coastal erosion, National Snow and Ice Data Center (NSIDC), University of Colorado at Boulder.

OUTREACH TO GENERAL PUBLIC

Bob Anderson was invited to participate in AGU Press Conference--Climate change discussion for science journalists, organized during Fall AGU 2009 Meeting. The news conference was held with a panel of 3 other Arctic scientists.

Interviews with two national papers on "Eroding Coast of Northern Alaska". Video footage of interviews and supplementary photographic material are posted as well.

University of Colorado Press Announcement in December 2009 resulted in publications in Science Daily, Alaskan News Reader, Hindu Times.

Interview in May 2010, contributed photos to article for Anchore Press: "A fragile past - Archaeologists are scrambling as accelerated erosion sweeps away artifacts on Alaska's Arctic coast"

Overeem gave an interview to be used in a documentary about "Climate Change and its Impacts". The working title of the documentary is 7th Generation.

Data sharing

Our USGS collaborators Frank Urban and Gary Clow are sharing the data streams from our met stations on the North Slope through the Climate and Permafrost Network. <http://data.usgs.gov/akcm/>