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**Executive Summary**

The Alaska Ocean Observing System, Western Alaska Landscape Conservation Cooperative (Western AK LCC), and the USGS Alaska Climate Science Center jointly conducted a Coastal Hazards Workshop May 30-31, 2012. Participants included a broad array of subject matter experts and stakeholders involved in coastal issues from a variety of perspectives, which included:

* coastal residents,
* those collecting coastal or marine information,
* local, state and federal agency managers,
* University researchers, and
* participants representing other information sharing and collaboration efforts.

Workshop participants reviewed the current state of the coast and the state of understanding of the coast from a systems perspective, discussed stakeholder information needs and developed the framework for a conceptual model focused on natural-human system impacts due to coastal erosion and inundation.

An overview of new sea ice modeling coupled with local observations, coastal landforms, and weather patterns provided a backdrop for evaluating coastal hazards. Adjacent marine studies in the Bering Sea through the BSIERP/BEST programs also provided insights for evaluating coastal issues. Ultimately, the ongoing project to digitally map Alaska will provide an important base layer for evaluating coastal issues.

Part of the workshop focused on the Coastal Hazards section of a proposed 10-year build out plan for AOOS (see <http://www.aoos.org/aoos-drafts-10-year-build-out-plan/> for link to draft plan). Workshop participants identified specific types of information needed to improve forecasts of extreme weather events. Recommendations called for identification of those gaps in both information types and geographic areas, which currently limit a more complete assessment of vulnerability.

Workshop participants developed framework elements for a conceptual model of the coastal ecosystem that ties together near-shore and marine processes that form and affect coastal landforms and human and biological use of this region and their resources. With further refinements, the conceptual model can be utilized to identify vulnerable locations and weather events that may affect coastal stability and near-shore function, and with further work, to assess relative vulnerability of coastal facilities and systems.

Developing the conceptual model allowed participants to identify specific information needs and gaps in current research and monitoring efforts. These were then prioritized based on perceived importance and feasibility. Of note, all recommendations carried high importance but varied in feasibility; the highest importance needs included:

* Evaluate existing coastal models linking nearshore and terrestrial components (relevant data and existing data) for applicability to Western Alaska Ocean
* Collect vertical datum with tidal benchmarks
  + Terrestrial benchmarks tied to water level measurements particularly related to mean sea level
  + This information provides a “Rosetta Stone” for linking bathymetry and topography and thus near-shore and on-shore processes
* Utilize community observations for storm surge, tide height, and general ice observations (such as ice-berm formation)
* Establish coastal “Sentinel Sites” for co-located collection of chemical, physical, and biologic parameters, providing a basis for elucidating the relationships among them.
  + Example of Bristol Bay pilot program (Nushagak Bay Diversity Project, UAF Bristol Bay Campus, Environmental Science Laboratory) as a mechanism for site establishment that employs scientists, students and local residents to conduct baseline studies and long-term monitoring of physical parameters.

Table of Contents

Introduction 1

Research and Collaboration Opportunities 2

State of the Coast 2

AOOS 10 Year Build-out Plan Review 6

Coastal Processes in Western Alaska 7

Stakeholder Needs 7

Information Inventory 8

Conceptual Model Development 8

Marine Open Water 9

Sea Ice 12

Nearshore Condition 13

Terrestrial 15

Ocean to Shore Data Needs 17

Key Recommendations and needs 19

Appendices 22

# Introduction

Alaska’s extensive coastline ranges from the temperate rainforests of southeastern Alaska to the permafrost dominated landscapes of the arctic. The majority of Alaska’s population lives along or near the coast. Most residents depend upon coastal access for a variety of reasons such as, transportation of goods and services, subsistence, recreation and resource development. Climate change is affecting coastal processes and potentially the pattern and scope of coastal hazards. Three organizations with specific interests in coastal issues collaborated in organizing this Coastal Hazards Workshop and while each organization has specific interests, all shared a general goal for the workshop to review the state of knowledge of the coast with an emphasis on Western Alaska and identify gaps in our knowledge of and ability to monitor processes that affect coastal resources and their use.

The Western Alaska Landscape Conservation Cooperative (Western AK LCC) and USGS Alaska Climate Science Center (AK-CSC) are both interested in developing coastal models that tie together those near-shore and related marine processes. In particular the WALCC and AK-CSC have identified a need to better understand ecosystem stressors in coastal areas, as well as understanding the processes that form and may affect coastal landforms. Moreover, the WALCC and AK-CSC have recognized a pressing need to link human and biological use of coastal resources to these physical processes. Their intent is to facilitate development of a model to help identify vulnerable locations, and to determine how different weather and climate events (with particular emphasis on coastal storms) may affect coastal stability and near-shore function. In turn, they hope to assess relative vulnerability of coastal biological and ecological resources, and delineate the gaps in current research and monitoring efforts. The model would be used to guide Western AK LCC and AK-CSC activities related to coastal systems.

The Alaska Ocean Observing System (AOOS) has a long-standing interest in coastal issues and this workshop builds on a similar workshop held in May 2010 that discussed data and modeling needs for dealing with coastal hazards in Alaska (<http://www.aoos.org/workshops-and-reports/>). The purpose of the 2010 workshop was to identify priority ocean observing activities (*e.g.* weather, waves, currents) needed to help stakeholders make decisions relative to coastal hazards. Participants included users of the data, decision makers, and information providers. A specific goal for AOOS was review of recommendations from the initial workshop in light of the draft AOOS 10-year build-out plan and to identify further implementation strategies.

Recognition of the significant overlap between participants in the AOOS efforts, the interests of the AK-CSC, and those that would be involved in evaluating needs and model development for the Western AK LCC geographic area resulted in the combined workshop. The AK-CSC also joined as a partner in the workshop as understanding coastal process dynamics under changing climate conditions is a key area of uncertainty related to climate change.

Expected workshop outcomes included:

* Review of the AOOS coastal hazard information gathering strategy.
* Refine stakeholder needs assessment to clarify Western Alaska concerns.
* Initial development of a coastal model linking near-shore and appropriate marine functions to impacts on coastal landforms and associated human and biological uses of that area.

# Research and Collaboration Opportunities

Workshop organizers identified new research and collaboration opportunities that included initiation of the Western Alaska Landscape Conservation Cooperative (Western Alaska LCC) and the Alaska Climate Science Center (AK-CSC). The Western AK LCC, established in 2010, is a public and private partnership focused on identifying and addressing shared scientific information needs associated with landscape-scale processes affecting natural resource conservation under a changing climate. USGS established an Alaska Climate Science Center (AK-CSC) in 2010, in partnership with the University of Alaska, Fairbanks. The AK-CSC mission is to provide scientific information, tools, and techniques to anticipate, monitor, and adapt to climate change. AOOS and partners received funding from NOAA for a project to develop data integration and visualization tools for Alaska’s Arctic (Spatial Tools for Arctic Mapping and Planning – STAMP). Implementation strategies for the National Ocean Policy (signed in 2010) are under development to address environmental stewardship needs in the face of climate-induced and other environmental changes. The Local Environmental Observer (LEO) Network, facilitated by the Alaska Native Tribal Health Consortium, is a network of local experts who share their knowledge and experiences to describe environmental events in their communities through a map-based system to raise awareness about changes conditions in the north. (See Appendix 3 for additional details).

# State of the Coast

The workshop began with presentations that gave an overview of some of the known information on coastal processes and the documented or suspected changes related to climate change. This section summarizes those presentations and provides some of the discussion topics that were influential in later discussions for developing conceptual models. When there were key recommendation or discussion topics that came from the workshop participants, they are described in paragraphs titled ‘Discussion’.

USGS developed region specific sea ice projections for the Bering and Chukchi Seas based on 18 general circulation models (http://pubs.usgs.gov/of/2010/1176/). Based on an analysis of the past three decades, historical changes in ice cover compared to current conditions differed throughout the year. June is projected to experience the least amount of sea ice loss among all months. For the Chukchi Sea, projections show extensive ice melt during July and ice-free conditions during August, September, and October by the end of the century, with high agreement among models. High agreement also accompanies projections that the Chukchi Sea will be completely ice covered during February, March, and April at the end of the century. Large uncertainties, however, are associated with the timing and amount of partial ice cover during the intervening periods of melt and freeze. For the Bering Sea, median March ice extent is projected to be about 25 percent less than the 1979–1988 average by mid-century and 60 percent less by the end of the century. The ice-free season in the Bering Sea is projected to increase from its contemporary average of five and a half months to a median of about eight and a half months by the end of the century. A 3-month longer ice- free season in the Bering Sea is attained by a one-month advance in melt and a two-month delay in freeze, meaning the ice edge typically will pass through the Bering Strait in May and January at the end of the century rather than June and November as presently observed. More details are available in Appendix 9.

Steve Ivanoff, a resident of Unalakleet on Norton Sound, provided local perspective on how sea ice conditions affect many subsistence activities. In the winter, locals harvest king crab through the ice when it is thick enough and stable enough to support this activity. In the early 1990s, ice condition was excellent as it was extensive, stable and not too thick. Locals could cut holes through the ice with a 3.5 to 4 foot auger. In contrast, ice in recent years is less predictable; in 2010, ice cover was extensive, but this past winter, ice was not as extensive but was too thick to cut through with the augers. Also, ice is melting more quickly now than twenty years ago. Previously, April was the only time for hunting marine mammals, traveling and hunting on the ice. Now, earlier breakup allows boating to begin in June and access to marine mammals on the broken ice.

Weather patterns appear to be changing, with implications for coastal vulnerability as the major on-shore drivers of change are affected by wind direction, fetch and tide cycle. As an example, the large November 2011 storm had 40-foot seas, wind gusts to 93 mph, blizzard conditions and an accompanying storm surge. The storm affected over a thousand miles of coastline and at least 35 communities sustained damage to facilities or other infrastructure. For example, in the community of Golovin, much of the infrastructure (notably the power plant) is in the inundation zone. The community faced difficult decisions about evacuating residents to buildings on higher ground due to an ongoing blizzard conditions and insufficient power at the evacuation site. Golovin, unlike most other coastal villages, did have tide predictions, which provided important information. Substantial damage occurred at a nearby fish camp (with cabins etc.) but considerable damage could have taken place within Golovin and other communities given the size of the storm. Fortunately several factors lessened the storm severity. The day that the storm hit the coast was one of the lowest tides of the month and the storm hit at low tide rather than high tide. Also, the strongest winds were offshore when the storm hit the coast; when the wind switched directions, the magnitude dropped significantly.

Discussion: Tidal information is needed to forecast time and height of high water. It is unrealistic to install gauging stations set to national standards (National Water Level Observation Network – see: http://www.co-ops.nos.noaa.gov/nwlon.html) in all villages; however, the information is still needed. Less expensive platforms with data standards designed to meet regional needs should be employed. The primary issue is that the cost of data recording stations that meet national standards is prohibitive, however, useful data for regional forecasting can be gathered within existing or reasonably obtainable resources. While methods exist to spatially interpolate tides for locations in between gauging stations, currently there are too few stations to provide adequate interpolation.

Storm intensity and number is predicted to increase in the Bering/Chukchi region due to increasing temperatures (climate change). Storm frequency and length of storm tracks has increased in the last 20 years. Sea ice can affect storm magnitude and impact; this is a complex relationship that needs further study. Note that a big storm can have a big effect but numerous smaller storms can also cause damage. US Army Corps of Engineers has gathered information identifying storms with greatest impact on each community. (See Appendix 10 and 11 for further details.)

Discussion: One of the data needs that limit forecasting storms in western Alaska is the lack of a good tidal circulation model. It is possible to build a model of tidal circulation for Bering and Chukchi (Tom Ravens) that is forced by tidal observations. Oregon State has created a worldwide model but Alaska is a special case (complex coastline and unused data sources), therefore development of an Alaska specific model would be beneficial.

A key factor in determining coastal landforms and coastal stability is surficial geology, basically rocky versus non-rocky substrate. The north and west coasts of Alaska are non-rocky and therefore subject to erosion, particularly in permafrost rich areas such as the North Slope where erosion rates can be as much as 15-20m/year. The Chukchi coast southwest of Barrow has a short beach that provides a buffer and the erosion rate averages less that 0.5m/year, although niche erosion occurs during storm events. Volcanic rock armors some parts of the coast in Western Alaska. “Living with the Coast of Alaska” (Mason et al. 1988) identifies coastal communities in which bluff erosion and coastal flooding were major hazards. All of these communities occurred in the Arctic, Bering, or Cook Inlet regions.

Several new information and analysis tools are available for understanding and interpreting coastal landforms. Lantuit, et al., 2011, ‘The Arctic Coastal Dynamics Database: A New Classification Scheme and Statistics on Arctic Permafrost Coastlines’, (Estuaries and Coasts DOI 10.1007/s12237-010-9362-6) presents a geomorphological classification scheme for the arctic coast to assess the sensitivity and erosion potential of arctic coasts. Arctic permafrost coasts are sensitive to changing climate due to the lengthening of the open water season and the increasing open water area. New information tools include the Alaska ShoreZone coastal mapping work, which catalogs both geomorphic and biological resources and has low-tide oblique aerial imagery for all mapped areas (http://www.fakr.noaa.gov/shorezone/default.htm). Some high-resolution digital elevation data sets are becoming available. Gathered using LIDAR (Light Ranging and Detection) technology, USGS has data from Icy Cape to the Canadian border (under review prior to release) and NOAA has data for coastal areas adjacent to Kotzebue Sound (http://www.csc.noaa.gov/dataviewer/#). Useful and new technology for monitoring coastal conditions and changes include time-lapse cameras; paired weather and tide gauge station (example at Teshekpuk Lake field site, the weather station is solar powered and costs under $10k); and potentially, unmanned aerial vehicles (new light-weight, range 10km) that could be used to fly over and photograph coastal areas (an example of use would be to rapidly survey an area following a major storm event). (See Appendix 12 for further details)

Bering Sea dynamics can influence coastal processes and resources. A major study effort is the Bering Sea Integrated Ecosystem Research Program (2007-2013) whose primary goal is integration of the effects of physical forcing through the trophic ladder to people. Results to date show the Bering Sea remains cold and has a cold pool, which extend farther south in cold years. Models predict the Bering Sea will remain cold, recent data supports this, and the cold will remain a barrier to species moving north. Upwelling winds were prevalent during the study period and resulted in predominantly southerly flows. Wind induced mixing was associated with increased productivity, rather than ice or vertical stratification. Fish and epi-benthic communities change with latitude with fish dominant in lower latitudes. Temperature determines the spatial pattern of forage fish with pollock extending farther north in warm years and capelin extending offshore. The program has many other insights on pollock and likely outcomes relative to changing temperature regimes. Interviews with people who live in the region documented the regional aspect of people’s perceptions. Harvest activities are a local activity and residents are focused on conditions in their immediate vicinity and not conditions integrated over large areas. In summary, changes in temperature affect wind, ice and ocean productivity – all will likely affect communities. (See Appendix 13 for further details.)

A major barrier to improved local-scale investigations of coastal processes and change is the limited availability of adequate resolution maps, aerial photography, and digital elevation models. In a major effort to address this need, the State and several Federal partners, are collaborating in the Statewide Digital Mapping Initiative (<http://www.alaskamapped.org/sdmi/>). A significant first step for the project is acquisition of ortho-rectified imagery as baseline data for the whole state by 2014 if funding is secured. This information will be available to USGS for their US TOPO project and to other partners. In addition, SDMI has a variety of mapping services and an extensive data gallery (http://www.alaskamapped.org/data/gallery), note that Aleutians are difficult to obtain due to the prevalent cloud cover. Elevation data (resolution about 1.5 m) will be available soon. There are plans, but no dedicated funding yet, to refresh the program every five years. (See Appendix 14 for further details.)

# AOOS 10 Year Build-out Plan Review

AOOS developed a 10-year build-out plan (<http://www.aoos.org/workshops-and-reports/>) based on four theme areas identified by the national program; Marine Operations; Climate Variability and Change; Ecosystem, Fisheries and Water Quality; and Coastal Hazards. A fifth theme, Integrated Products, was added for issues that cross two or more of the original four themes. For each theme, the build out document identifies the important AOOS issue, priority products and services identified by stakeholders, and information requirements for each product. Key principle is that no single entity can accomplish an effective monitoring system alone; partnerships and collaboration are required.

Input for the Coastal Hazards section of the AOOS build-out plan came from stakeholder input and a focused workshop in 2010. Participants at the workshop included agencies, stakeholders and technical and scientific experts. Recommendations based on an in-depth needs discussion included data needs (harbor observation, ice extent and thickness, shoreline observations); forecasts (storm surge/inundation, ice and wave trajectories and magnitudes); and, data access tools (coastal hazards portal and project tracking system). These recommendations are incorporated in the plan in the identification of desired products (improved forecasts for extreme weather, coastal inundation, wave, and sea ice dynamics) and focal areas where additional instrumentation is needed. (See Appendix 15 for further details.)

Evaluation of the build-out plan was sought as to whether the identified needs were still accurate and how to refine recommendations into implementation plans.

Recommendations included:

* Obtain high-resolution digital elevation model to help predict storm surge. The new statewide mapping initiative will be at 1.5-meter resolution, which is still insufficient detail for community-level decisions during emergencies.
* Incorporate real-time information (such as water levels or pending ice-events) into warning mechanism for villages letting residents know when they are in imminent danger and need to evacuate.
* Develop high-resolution maps for the 30 western Alaska villages that are most vulnerable. (UAA students walking around communities with portable Roberg units, used to collect digital elevation data, could carry this out very cost-effectively; contact Tom Ravens).
* Increase the numbers of wave buoys that can help validate forecast models, which currently are generated with very little real data. (Planning and analysis will be required to determine the most effective numbers, types and locations of buoys.) In the meantime, there is a 9km Real-Time Ocean Forecast System (RTOFS) (better than no data at all).

# Coastal Processes in Western Alaska

The initial scoping efforts for the Western AK LCC identified the need for greater efforts to address climate change related science needs for resource management in western Alaska. Further scoping identified changes in coastal processes as a high priority issue (Reynolds and Wiggins, 2012). Subsequently, the Western AK LCC initiated a two-year Coastal Storms pilot program, a component of which was development of a draft conceptual model of coastal physical processes at the landscape scale. This Workshop provided the LCC a venue for initiating development of the conceptual model and identifying priority information needs related to coastal storms and processes.

## Stakeholder Needs

The Western AK LCC engages in applied science activities that address shared information needs of resource managers and associated stakeholders. The LCC prioritizes among potential activities, in part, in consideration of the needs that each activity would inform (Appendices 16 and 17). These linkages between stakeholder needs and potential science activities were identified from synthesis of the results of the AOOS Coastal Hazards Workshop (May 2010; http://www.aoos.org/wp-content/uploads/2011/05/Coastal-Hazards-Workshop-Summary.pdf), the LCC Science Workshop in 2011 (<http://www.arcus.org/western-alaska-lcc/spring-workshop-2011>), and through information gathered as part of the Western AK LCC’s 2012 request for proposal process. Stakeholder decisions and planning activities that could benefit from additional information sorted into five broad categories: community planning and coastal infrastructure; land management; species management; industry oversight; and, emergency warning and response. A common information need identified across all topics was for better understanding and monitoring of coastal erosion to improve predictive capabilities. The Western AK LCC also engaged with a group of coastal experts who further identified coastal storms as a major driver of coastal erosion and other landform impacts, thus leading to the decision to focus the LCC’s pilot program on “Changes in Coastal Storms and their Impacts”.

## Information Inventory

One of the key recommendations to the Western AK LCC by the coastal experts was to conduct an inventory of current and recent activities in western Alaska coastal areas. The LCC and AOOS partnered to conduct this inventory. AOOS is extending the coverage of the Arctic Assets Map to include the Western Alaska LCC region. The map displays in-situ and transect research and monitoring in the Beaufort and Chukchi Seas. The intent is for the mapped locations of monitoring efforts to be an information source for other researchers and to promote coordination and sharing of information. Mapped assets include in place hardware such as acoustic recorders, buoys, meteorological stations; transects for autonomous underwater vehicles; planes, HF radar, planes, ships; and, include details about the assets such as the instrument type, start/end dates, owner and contact information. Extra effort is focused on including recently completed studies in the Western AK LCC region, such as waterfowl surveys, and fishery monitoring sites. See map at: http://data.aoos.org/maps/arctic\_assets/

USGS is also upgrading their science portal. Currently, the portal is an Alaska USGS application available internally for researchers to enter and maintain their project information (e.g., project metadata). The upgrade is to, in part, bring the site in compliance with Alaska Data Integration Working group (‘ADIwg’) standards with a targeted completion of August 2012. When complete, the site will include reference to all USGS studies in Alaska. Disciplines include geology, hydrology, geography and biology. (See Appendix 18 for further details.)

Similarly, US Fish and Wildlife is developing a publicly accessible database of monitoring studies done on National Wildlife Refuges. The Planning and Review of Inventory and Monitoring on Refuges (PRIMR) database was designed to help NWRS stations develop an Inventory and Monitoring Plan. The PRIMR database contains project metadata on the purpose, methods, and products of Refuge inventory and monitoring activities. In the fall of 2012, PRIMR will move from a distributed database to a centralized version, which will conform to the ADIwg data standards to enable partner access to project metadata.

## Conceptual Model Development

A goal of the workshop was to develop a conceptual model of coastal processes that ties together near-shore and appropriate marine processes and stressors that form and may affect coastal landforms and human and biological use of this region and associated resources. Based on stakeholder needs, the focus of the modeling effort was on coastal flooding or inundation, erosion and changes in nearshore marine conditions. Sub-groups were organized by environmental components (marine ice, marine open water, nearshore marine conditions, and terrestrial) and tasked with developing conceptual model components that summarized current understanding of factors controlling coastal flooding and inundation, and the aspects of coastal erosion relevant to stakeholder information needs. To the extent possible, groups also identified the state of knowledge relative to model components and relationships, with the goal of identifying information needs. (See Appendix 19 for detailed instructions provided to the groups.)

A draft model focused on drivers of change in coastal landscape processes, developed for the Western AK LCC as part of a previous Science Workshop, provided a starting point (Appendix 20). The model presented a landscape perspective and emphasized physical processes. Loss of sea ice, sea level rise and storminess were identified as key drivers that affect the coastal zone through flooding or inundation and erosion. Inundation is an important aspect of coastal wetland dynamics through changes in salt-water intrusion that may be further influenced by disruption of sedimentation patterns. In turn, these changes affect the freshwater and terrestrial habitats that form important habitat for fish and wildlife.

### Marine Open Water

The open water season is becoming longer, resulting in changing ocean dynamics that will impact weather systems, among other things. Notably, changes in storm patterns will likely have considerable coastal impacts. The biggest climate change impact on storms will be due to sea level rise, which is expected to be significant throughout Western Alaska. There is also a possibility of change in storm tracks, frequency, and intensity. Changes in non-storm conditions, such as wind and waves, will also have effects. Sea level rise will add to all changes, however, it was noted that sea level rise would vary geographically. Factors that locally or and regionally affect sea level rise include isostatic rebound (uplift or rebound of land previously covered by glaciers), thaw subsidence (melt of ice-rich permafrost resulting in downward shift of the surface), and changes in ocean circulation. Sea surface temperature will also be affected by changes in ocean circulation through changes to ice cover and presence, storm tracks and storm formation.

The group identified many data needs. Few water level records are available in Western Alaska and those that exist generally cover only short time frames. Similarly, there is little wave data (e.g., wave frequency and size), which is important to obtain as waves are expected to increase in size as the amount of open water increases due to decreased sea ice, and this potential for larger waves will impact, and be impacted by, winds and storms. Nearshore bathymetry and topography, both of which are lacking at high resolution, are required in order to evaluate or predict flooding and erosion events.

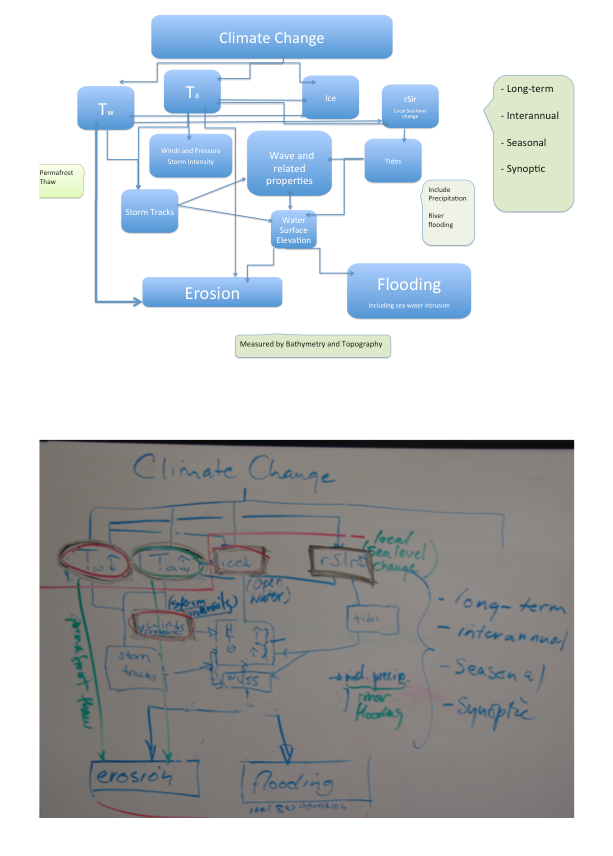
The group’s model identified the types of information and ocean parameters needed to predict the effects of changing ocean conditions on coastal erosion and flooding. These information needs provide the basis for identifying monitoring priorities and guidance for determining and establishing monitoring platforms.

Table . Key model parameters and availability & quality of data for estimating them. Parameter notations refer to the model depicted in Figure 1.

|  |  |
| --- | --- |
| Model Parameters | Data Availablity / Quality |
| Water Temperature (Tw) | poor |
| Air temperature (Ta) | fair |
| Ice (concentration) | fair |
| Ice Thickness (also known as “stage”) | poor |
| Ice floe size and form | fair |
| Dynamics of ice motion and freeze/thaw cycle | poor |
| “wave” hindcast:  Hs – significant wave height  Tp – peak wave period  Wave direction  Directional spectra (angular distribution of wave energy) | fair |
| Water level | sparse and poor |
| Wind speed and directions | sparse and poor |

Marine Open Water Conceptual Model

Figure . Marine Open Water conceptual model (above) and original derivation from workshop (below)



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### Sea Ice

Sea ice is a complex and rapidly changing system with two somewhat distinct components – shorefast ice and floating sea ice. Rather than develop a model, participants specified concerns and needs relative to ice dynamics (risk and condition) and identified further information needs. Seasonality and duration of ice are key aspects that impact coastal environment. Community concerns about the impacts of changing ice dynamics focus on vulnerabilities of village infrastructure and subsistence camps. Two impacts unique to Alaska include: ice shoves due to storms and high tides; and, disruption of delivery routes due to the timing of freeze-up in the fall, which can cut off ship delivery of supplies to villages. Communities are requesting advance notification of these types of ice events.

Shorefast ice, defined as ice that is grounded or ice that is attached to shore, leads outward from the shore and is an important feature for local travel and as wildlife habitat (marine mammals). The lack of shorefast ice, in addition to limiting travel and affecting wildlife, also has physical effects, for example a cold wind (sub-freezing) blowing over open water towards the shoreline resulted in heavy freezing spray on St. Lawrence Island. Shorefast ice can protect areas from ice-scour, which increases with northern winds and storm events and may be affected by tides and southern ice extent. When shorefast ice is not present, floating ice may be blown towards shore into shallower water and the keel under pressure ridges can scour or gouge the sea floor. Infrastructure (e.g., docks, sewers, water lines) in the nearshore zone may be affected, depending upon the magnitude and location of the scour event.

Sea ice dynamics are changing dramatically and are increasingly variable. Ice thickness appears to have a 7-10 year pattern in the Bering Sea, which is currently experiencing cold years. Sea surface temperature does not have a linear relationship with ice formation (note that winter ice maximum is still present, but ice freeze timing is changing). An important information source currently under development is a digital, historic sea ice atlas that AOOS is funding UAF to prepare that will cover all Alaska coastal waters out to a distance of 300 miles from shore.

Shishmaref illustrates the effects related to changing sea ice conditions where a fall storm and no sea ice led to major erosion. This occurred in part due to warmer ground temps and associated permafrost thawing, while strong winds and waves also contributed to the erosion. Other types of community impacts included larger scale and earlier erosion events; and associated impacts to infrastructure (housing, power plants). Storms also directly affect species and habitat. Examples include sea otters unable to forage near Port Heiden and Port Moller; musk oxen frozen in ice due to rapid coastal freezing; and, shellfish habitat changes.

Needs associated with a better evaluation of ice-related risk include:

* Ice risk maps along the coast by community (potential for ice-shove events)
* More detailed information on near-shore bathymetry
* Based on ice risk maps, identify vulnerable areas within communities with solutions (funding sources, insurance, relocation costs)
* Determine potential for increasing coccolithifor blooms associated with warmer water (background note: sea bird die-offs, marine mammal redistributions and declines in salmon runs were reported during a high coccolithifor bloom in 1997 but the exact relationship between coccolithifors and higher trophic levels or food-web structure remains unclear).

Needs associated with the ability to predict effects of changing ice conditions include:

* Improving the spatial resolution of models of wind and temperature along the coast, as direction and duration of wind are needed to determine inundation impacts on human and biological communities
* Improving forecasting abilities so that communities have time to be notified and respond
* Hazard assessment maps with associated risk assessment for community infrastructure

Data quality and availability vary:

* Good – weather models (NOAA); Community communication and emergency response (Homeland Security); increasing ice forecasting program (NWS forecasting)
* Fair – Coastline analysis (wave sensitivity); erosion analysis (high risk and habitat risk assessment, e.g., <http://www.poa.usace.army.mil/AKE/Home.html>); inundation maps; nearshore bathymetry at 5 year intervals
* Poor – Off shore bathymetry

### Nearshore Condition

The group felt it was important to distinguish impacts on nearshore condition from those on the terrestrial side of the shoreline, and to recognize the physical, chemical and biological aspects of the nearshore. The main nearshore components of concern include nearshore currents, sediment budgets, water quality and the biological community. There is a lack of understanding regarding the basic relationships between the nearshore physical, chemical and biological characteristics, however, that limited our ability to draft a model of this component, let alone predict precise impacts on of storm surges on these relationships.

Physical changes in shoreline are related to nearshore bathymetry and sediment transport. There is limited understanding of the region’s sediment dynamics (even including whether they are depositional or stable). This is a fundamental need that requires identifying inputs, sinks, and prevailing directions of transport. Developing a sediment dynamic model would involve an overview of the areas of greatest changes; evaluation of sediment budget and hydrodynamic intensity and calculation of the along-shore transport. The scale of sampling for such an effort would depend upon the regional scope and detail of the model being developed. A sediment transport model for the Bering Sea coast was developed in the 1970’s by USGS (<http://www.dggs.alaska.gov/pubs/id/12976> ). This work identifies littoral cells (regions where the sediment transport along beaches is similar) which may be a useful way to focus future work in western Alaska.

Community risk analyses could be used to identify necessary restrictions on development and to allocate response resources, recognizing that decisions related to funding and relocations are daunting.

Nearshore dynamics can be impacted by external factors, such as mining and dredging activities. The impact of such activities can be difficult to predict without detailed knowledge of local sediment budgets and dynamics. Specific anthropogenic effects noted for mining included the example of suction dredging (e.g., gold mining near Nome) and the resulting deconsolidation of sediments and subsequent degradation of water quality.

Changes in the nearshore component’s physical and/or chemical characteristics can also come from changes in the terrestrial component’s landform processes, including hydrology, resulting from storm surge impacts. These changes in the nearshore’s physical and/or chemical characteristics may then cause changes in biological/ecological characteristics. It is known, for example, that changes in turbidity in estuaries can cause changes in estuarine species distributions, and freshwater intrusion into brackish systems can be detrimental to brackish adapted species such as the onion *Allium schoenoprasum v. sibiricum*.

Nearshore Information Needs:

* Systematic benthic sampling (in time and space) as there is limited data available throughout the region
  + Environmental Monitoring and Assessment Program - EMAP has limited data from the Alaska Peninsula (contacts -Doug Dasher and Ian Hartwell in NOAA); Eelgrass bed monitoring program (David Ward, USGS ASC)
  + Existing information on benthic fauna needs to be compiled and made accessible to public to avoid duplication of effort
  + The group discussed the value of establishing sentinel sites for long-term monitoring of nearshore physical, chemical, and biological processes.
* Nearshore currents are not well understood and regional models are needed.
* Existing literature and data need to be compiled and synthesized to provide a foundation for further refining the conceptual model of drivers and impacts on nearshore processes; existing information is widely dispersed and predominantly in government reports. Examples include:
  + Outer Continental Shelf National Environmental Policy Act analyses (http://www.boem.gov/Environmental-Stewardship/Environmental-Studies/Alaska/Index.aspx);
  + Coastal Impact Assessment Program (CIAP) projects (http://dnr.alaska.gov/commis/CIAP/ciap\_Fall.htm);
  + Arctic EIS (http://www.nmfs.noaa.gov/pr/permits/eis/arctic.htm);
  + Steller’s Eider Habitat) (http://alaska.fws.gov/fisheries/endangered/species/stellers\_eider.htm )
  + Longshore sediment transport (http://www.dggs.alaska.gov/pubs/id/12976)
* Specific information needs for developing nearshore baseline parameters:
  + Water quality (pH, temp, salinity, tides, dissolved oxygen, phosphate, nitrate, sulfate, mercury)
  + Inner-tidal zone (baseline analysis – south side of peninsula; algae blooms, tidal cycles, biologic communities – benthic and pelagic)
* Bathymetry out to 20m depth
* A standardized definition of coastline needs to be agreed upon in order to fully develop a digital coast map (e.g., some groups use mean high tide, others use mean low low tide, etc.).

### Terrestrial

Storm surges can impact terrestrial systems physically and chemically, with both paths potentially impacting biological, ecological, and human communities. The magnitude of the surge will be influenced by the presence or absence of nearshore and shorefast ice (through the mechanisms mentioned by the other groups, including moderating or enhancing hydrodynamics, creating protective barriers or enhancing susceptibility to ice shove events, etc.) and by nearshore bathymetry and topography. The surge impacts will be influenced strongly by local landform, topography and substrate (e.g., recall the earlier presentation on Coastal Landforms). Human activities (land use, infrastructure, policy and regulations) can impact landform processes and thus alter the susceptibility to and magnitude of impacts from surges.

Spatial variations in the landform factors (landform, substrate, topography etc.) limited the amount of process detail explicitly incorporated into the terrestrial component model (Figure 2). Two implications that followed from this recognition were that:   
(i) (spatial scale) understanding the expected impacts of changes in storm surges will require refining the model for each *specific area* (combination of coastal landform and substrate) that is of interest;  
(ii) for time scales longer than a few years into the future, understanding the expected impacts of changes in storm surges will require also understanding how the other major landform processes *in that area* will change over that timescale (e.g., expected changes over that time scale in permafrost dynamics, hydrology, isostatic rebound, subsidence, vegetation community change, etc.). Depending on the time scale and area of interest, human activities influencing the landform processes may also have to be accounted for.

Changes in the terrestrial component’s physical and chemical characteristics can impact habitat, and therefore habitat use and subsistence resource availability. Examples mechanisms mentioned included changes in salinity and saltwater intrusion as well as physical changes due to erosion and deposition (which will depend, to a large degree, on along-shore sediment transport processes). As mentioned earlier, changes in the terrestrial component’s landform processes, including hydrology, can also cause changes in the nearshore component’s physical and/or chemical characteristics, and thus biological/ecological characteristics.

Data Needs:

* Existing literature and data need to be compiled and synthesized to provide a foundation for further refining the conceptual model of drivers and impacts
  + Landforms and substrate information are not consistent availability throughout the region
    - Including isostatic condition (geodetic surveys), sediment transport and deposition budgets, soil dynamics (permeability, infiltration conditions, etc.).
  + Elevation and topography – Statewide mapping will be useful but is not yet available; further, its vertical resolution will be too coarse for many applications (1.5 m vertical resolution will not be very useful on the Yukon-Kuskokwim Delta, for example)
  + Fluvial inputs – need river water levels and discharge information
* Lack of understanding of spatial variation in rates of relative sea level rise limits ability to predict future shoreline locations and thus predictions of storm surge impacts beyond current conditions.
  + This is fundamentally due to the region’s lack of both vertical benchmark controls and associated water level observations.

Figure . Terrestrial Conceptual Model



### Data Needs regarding linkages from Ocean to Shore

Following the initial drafting of coastal model components, a group comprised largely of open water experts identified specific data needs for linking the model components and relating specific oceanographic parameters to changes in coastal processes, especially erosion and inundation. They identified both data needs and also potential sources of information (where available). While the data needs identified by the group initially address research needs for developing a greater understanding of the relationship of oceanographic processes to coastal effects, similar information will be needed to monitor key parameters and provide real-time information for prediction and forecasting.

The group identified water level as a basic parameter associated with processes that affect coastal erosion and inundation. The group discussed different techniques for gathering water level information, ranging from stations that meet national standards (<http://www.co-ops.nos.noaa.gov/nwlon.html>) but are prohibitively expensive to install to simple approaches for measuring extreme events. The group discussed the range of needs for this information and the fact that many of those needs/uses do not require the precision guaranteed by national standards.

Waves are another important parameter with potential to influence coastal erosion and inundation. Waves are also directly influenced by the extent of open water versus ice cover and therefore as ice retreat intensifies, the potential for larger waves increases compared to ice covered waters, which dampen wave potential. Bathymetry and topography in the nearshore area influence the potential effects of water level changes and waves and the group identified information needs relative to these parameters as well as information on ice.

The group further clarified that for near-term prediction of surge and inundation, the shoreline can be considered static and immobile and that the key data needs are nearshore bathymetry and topography. Longer-term prediction into the future requires taking into account the effects of shoreline dynamics and landform processes (subsidence, isostatic rebound, etc.) on the shoreline’s location.

Data and information needs:

* Water level information was described as a fundamental data need, as this would be required in all process oriented and predictive models (including both surge models and open water hydrodynamic models).
  + Discussions focused on the measurement tidal data
    - NOAA limited funding – insufficient for standard water level stations (rough estimate of $500,000 to install a NWLON station is outside current budgets constraints)
    - Tide Gauges: 3 months minimum data need for harmonic analysis (min duration for surge record); to be complete, 25 hours (gets us started on the 1-4 cycles per day tides), 29.53 days (1 synodic month, gives us the spring/neap cycles), 1 year (annual and semi-annual tides, and splitting of the daily and monthly tides), and 19 years (the gold standard, includes the lunar node and perigee variations at 8.85 and 18.6 years)
    - Installation of vertical control survey benchmarks – goal is a known set of benchmarks commonly used by all
    - Need to install gauges that are targeted at understanding storm surges and high water events; these instruments could potentially be based on relatively simple and inexpensive technologies.
    - Need to inventory and collate existing data, and make these data accessible through a common or single location.
* Waves
  + National Data Buoy Center (NDBC – part of the National Weather Service) maintains a limited network of buoys in Alaskan waters; other buoys are sources of information, but number of buoys is limited.
  + Different technologies available - Radar (codar-xband), submerged stations (such as Acoustic Doppler Current Profilers - ADCP)
  + 2d spectra best type of measurement
* Bathymetry and Topography
  + NOAA chart surveys – expensive and updates are limited.
  + LIDAR – useful and precise, but expensive, technology. Data can be collected from different platforms and at different levels of resolution.
    - Airborne
    - Shore-based
    - Small-boat hydro
  + Other potential sources of general survey data were identified; these included:
    - Satellite observations
    - Google Earth
    - Inventory studies
  + Consider using littoral cells and sediment budgets as a way to subdivide the coastal region into segments for analysis/study
* Ice
  + Need to research the impacts of ice on wave generation and storm surge
  + Better prediction of ice storms, particularly when ice is driven ashore; this was identified as a significant short-term operational need, as well as a pressing research topic
  + Better prediction of ivus (ice shove – surge of ice from the ocean onto the shore) is a significant need to understand patterns and develop predictive capability.
    - Ice ramparts (mound of earth or stones formed by the action of ice against the shore)
    - Observations from “LEO” – were seen as a potential source of incidental information (See Appendix 3 for information about LEO)
  + Shorefast ice – a subsistence pathway; dynamics of shorefast ice are poorly understood; research topic

# Key Recommendations and needs

Workshop participants listed key information needs in a plenary session. The needs came from the preliminary model development discussions and subsequent discussions of nearshore conditions, ocean to shore discussion and linkages identified among groups.

* Ocean to Shore
  + Identified a fundamental need to collect vertical data tied to tidal benchmarks
    - Terrestrial benchmarks must be tied to water level measurements, particularly as related to mean sea level
    - Linkage is critical to connect topography and bathymetry, and thus link hydrodynamic models to surge impact models.
    - This ‘ocean to shore’ connection was described as a “Rosetta Stone” for understanding related processes and impacts.
  + Increase tidal gauges (3 month duration is the minimum time needed to measure cycle); to be complete, 25 hours (gets us started on the 1-4 cycles per day tides), 29.53 days (1 synodic month, gives us the spring/neap cycles), 1 year (annual and semi-annual tides, and splitting of the daily and monthly tides), and 19 years (the gold standard, includes the lunar node and perigee variations at 8.85 and 18.6 years)
  + Utilize community observation for storm surge and tide height, nearshore and shorefast ice impacts on surge, etc.
  + Discover and synthesize existing information (e.g., nearshore data listed earlier, etc.)
  + Increase number of wave measurement devices (wave spectra)
  + Better understand the relationship between storm surge, wave generation and ice condition (both offshore ice presence and shorefast ice presence)
* Nearshore
  + Evaluate existing models of the nearshore, including relationships between physical, chemical, and biological components, for applicability to Western Alaska oceans. Include review and synthesis of existing sources of relevant data for this region.
  + Establish Sentinel Sites to gather critical parameters including chemical, physical, and biological measurements of these systems
    - Example of Bristol Bay pilot program (Nushagak Bay Diversity Project, UAF Bristol Bay Campus, Environmental Science Laboratory) as a mechanism for site establishment that employs scientists, students and local residents to conduct baseline studies and long-term monitoring of physical parameters.
    - Eelgrass beds may provide key strata of sites.   
      Contact Dave Ward, USGS ASC, to find out existing eelgrass bed monitoring program and sites in western Alaska.
  + Comments emphasized the need to develop and maintain data discovery and access.
* Bathymetry – an underlying need for nearshore bathymetry identified throughout workshop

To provide information for setting priorities, workshop participants scored each identified recommendation or need with respect to both importance and feasibility (cost, technical capability, logistics and other factors). The Importance and Feasibility Matrix for key recommendations and needs used a scale of -5 to + 5. All the recommendations carried high importance but varied in feasibility.

* High importance and high feasibility (score of 4 or 5)
  + Evaluate existing models of nearshore processes
  + Collect Vertical Datum
  + Utilize community observations
  + Establish sentinel sites
* High importance and good (1-3) feasibility
  + Increase tidal gauges
  + *Discover and synthesize information \*\*range of feasibility*
  + *Develop and maintain data access \*\*range of feasibility*
* High importance and low (0 to -3) feasibility
  + Better understand the relationship between storm surge wave generation and ice surge.
  + Increase wave measurement devices (wave spectra; use of buoys)
  + *Discover and synthesize information \*\*range of feasibility related to specific type of information, example of benthic fauna taxonomy scattered throughout museums.*
  + *Develop and maintain data access \*\*range of feasibility*
* High importance and really low (- 4 to -5) feasibility
  + Bathymetry (due to expense of obtaining complete coverage – reasonable if restrict need to important areas [need to be identified])

# Appendices

1. Agenda
2. Attendees

Appendix 1.

**Coastal Workshop Agenda**

**May 30 – 31, 2012**

**Alaska Climate Science Center**

Day 1

8 – 8:30 Coffee, pastries

8:30 – 9 Welcome & local logistics (Steve Gray, USGS)

Purpose of workshop

Round table introductions

9 – 9:30 Ever-changing research and collaboration opportunities

Western Alaska LCC (Joel Reynolds, WALCC)

USGS Climate Science Center (Steve Gray, USGS)

AOOS – STAMP, Arctic Assets Map expansion (Darcy Dugan, AOOS)

National Ocean Policy: Arctic priority (Molly McCammon, AOOS)

Other?

9:30 – 10:45 State of the Coast – Big Picture

Sea Ice (Dave Douglas, USGS; Steve Ivanoff, Kawerak)

Weather patterns (Aimee Fish, NOAA)

Coastal landforms (Ben Jones, USGS)

Highlights of Bering Sea - BSIERP/BEST project (Francis Wiese, NPRB)

Statewide mapping (Anne Johnson, ADNR)

10:45 – 11 Break

11 – 12:30 Statewide perspective (Molly McCammon, AOOS)

Review AOOS 10 year Build-out Plan

Demonstrate accomplishments to date

Review and revise priorities as needed

Dynamic database/website demonstration

12:30 – 1:30 Lunch (provided)

1:30 – 2:30 Focus on Western Alaska (Joel Reynolds, WALCC)

Review Statewide stakeholder needs and needs identified during WALCC organization process

Discuss and refine as necessary

Review Inventory (AOOS; USFWS; USGS)

Map posted on wall – request participant input

2:30 - 3 BREAK

3 – 5 Overview of conceptual model development (Rosa Meehan, AOOS)

Review Goal (Joel Reynolds, WALCC)

Model that depicts the relationships between:   
- decision maker,   
- environmental components, and  
- state of knowledge.

Review draft WALCC Model and Arctic coastal model – potential starting point

**DAY 2**

8 – 8:30 Coffee, pastries

8:30 – 3:00 Conceptual model development (Catherine Coon, BOEM)

Identify model components and linkages (Rosa Meehan, AOOS)

Establish Breakout Group Composition (self select group and a recorder within each group)

Marine Ice – Amy Holman (NOAA)

Marine Open Water – Orson Smith (UAA)

Terrestrial Inputs – Scott Rupp (UAF)

Breakout Session I: State of Science for model components

Draft Component model structure  
Identify ‘state of knowledge’ of elements & linkages   
Identify Gaps or Information needs

Breakouts Report back

Integration Session I (group): Linkages  
 Bring model components together

Breakout Session II: Prioritize based on Stakeholder needs

Review Stakeholder Needs & Integration session results

Identify priorities based on Stakeholder needs

Integration Session II (group): Identify key information gaps within the combined model

12 – 1 Lunch provided

3 – 3:30 Break

3:30 – 4:30 Closing Summary

Priorities for AOOS Build-out Plan (Molly McCammon, AOOS)

Priorities for WALCC (Joel Reynolds, WALCC)

ID potential partnerships to address needs (to extent possible)

Appendix 2.

Coastal Hazards Workshop - Attendees

|  |  |  |  |
| --- | --- | --- | --- |
| Latifat | Apatira | DHSS |  |
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|  |  |  |  |