Appendix A

A White Paper on Data Requirements and Data Inventory for Alaska SLAMM Analyses

For: Jim Adams
Director, Pacific Region
National Wildlife Federation
Anchorage, AK

And: David Wigglesworth
Coastal Program Manager - Southcentral AK
US Fish & Wildlife Service
Anchorage, AK

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warren
pinnacle
consulting, inc.

Jonathan S. Clough, Warren Pinnacle Consulting, Inc
PO Box 253, Warren VT, 05674
(802)-496-3476

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Overview

In 2008 and 2009 National Wildlife Federation (NWF) and the United States Fish and Wildlife Service (USFWS) Region 7 Coastal Program entered into a cooperative funding agreement (701818J719) to explore the possibility of SLAMM modeling within the state of Alaska. The final study area selected was limited to Anchorage and the Kenai Peninsula, primarily due to data limitations elsewhere. As part of this analysis, a summary of data requirements for the SLAMM model, a general inventory of that data in Alaska, and a prioritized list of data needs for the most effective application of the SLAMM model in Alaska are provided in this white paper. A short discussion of unique Alaska conditions and their impact on SLAMM is included to help guide decisions about where to most effectively apply the model in Alaska.

Summary of SLAMM

The SLAMM model, which has been in development for the past two decades, provides a highly accessible tool to assess how rising seas may impact coastal habitats. As with all models, SLAMM is not a crystal ball. It is not intended to forecast precisely what will happen to the region's habitats in the future; rather, it is a tool to offer a picture of possible outcomes under a range of scenarios. For example, the USFWS has applied the model to over seventy coastal refuges to help evaluate the potential effects of sea level rise within each refuge's comprehensive conservation plan.

To estimate effects of sea-level rise, SLAMM integrates future scenarios of global sea-level rise with data inputs such as area-specific NOAA tidal data, detailed wetland information from the USFWS National Wetlands Inventory, regional light-imaging detection and ranging (LiDAR) data, and United States Geological Survey (USGS) digital elevation maps to project potential habitat changes. One of the benefits of the SLAMM model is that it integrates complex spatial databases in an attempt to maximize realism. For example, it can assess the extent to which sea-water inundation contributes to the conversion of one habitat type to another by looking at elevation, habitat type, slope, sedimentation and accretion, erosion, and the extent to which the affected area is protected by dikes or other structures.

In addition, SLAMM accounts for relative changes in sea level for each study site. Relative sea-level rise is calculated as the sum of the historic eustatic trend, the site specific rate of change of coastal elevation due to subsidence, changes in natural sediment loads, rates of marsh accretion, and the accelerated sea-level rise, depending on the future scenario chosen. Within SLAMM, there are five primary processes that affect wetland fate under different scenarios: inundation, erosion, overwash, saturation, and accretion.

The most recent version of SLAMM (6.0) has a number of upgrades from previous versions. In particular, the model is now able to incorporate dynamic feedbacks in marsh accretion, whereas previous versions assumed linear changes in accretion rates over time. That said, there are likely to be a number of dynamic geological and ecological changes that will not be captured through SLAMM. Furthermore, there are a number of additional impacts associated with climate change that are not incorporated into this model, such as altered hydrology and more-intense coastal storms, and additional anthropogenic stressors that will affect coastal habitats in the future. For detailed technical information about the SLAMM model, visit the SLAMM homepage: http://www.warrenpinnacle.com/prof/SLAMM

Data Requirements

The table below summarizes the principal data needs for the SLAMM model and also summarizes their availability in Alaska. This table is followed by a more detailed discussion of the model's data needs and availability. Finally, the section concludes with a prioritized list of data needs for most effective application of the SLAMM model.

Category	Model Use	Availablilty in Alaska
Elevation Maps	Defines Land Elevations in Relation to Sea Level	High Vertical-Resolution Data Extremely Limited
Vertical Datum Conversion	Ties Elevation Data to Water Levels	More Uncertain than CONUS
Land Cover Categories	Initial Condition for Land Types	Most Coastal Regions Covered by NWI with Some Data Gaps; Additional Horizontal Uncertainty
Vertical Uplift or Subsidence	Converts Average Global SLR to Local SLR Estimate	Horizontal Resolution Varies by Region as does Uncertainty in Estimates
Marsh Accretion Measurements	Vertical Movement of Marshes	Extremely Limited
Erosion Rates	Horizontal Retreat of Beaches and Dry Lands	Fairly Plentiful
Tide Ranges	Defines Water Height	Fairly Plentiful

Elevation Data

High vertical-resolution elevation data is probably the most important SLAMM data requirement. Elevation data demarcates where salt water is predicted to penetrate and, when combined with tidal data, the frequency of inundation for wetlands and marshes. Elevation data also helps determine the lower elevation range for beaches, wetlands, and tidal flats—the elevation at which point they are inundated too frequently and are predicted to convert to a different type of land-cover or open water.

LiDAR data, as derived from laser pulses usually emitted from airplanes, is currently the "gold standard" for elevation data with vertical errors ranging from 4-20 cm. If a larger cell-size is utilized incorporating multiple LiDAR returns, the average elevation for that cell may have a lower vertical error (assuming that normally distributed errors cancel each other to some degree.)

LiDAR data within Alaska is fairly limited in coverage. Areas with large publicly-available LiDAR coverages include:

Kenai Peninsula (Simulated with SLAMM in 2009)
Borough of Anchorage (Simulated with SLAMM in 2009)
2004 LiDar data of coastline near Kotzebue. (Seward Peninsula).
2008 Kachemak Bay coverage (superseded by Kenai coverage)
Northern Resurrection Bay, Seward, Alaska

This list is likely not exhaustive as LiDAR coverages expand quickly and several months have passed since our last attempt to thoroughly inventory these data.

Lacking LiDAR data, ifSAR data also can be appropriate to use in SLAMM modeling though uncertainty due to elevations errors increases to some degree. ifSAR data uses radar rather than lasers and tends to be flown in airplanes at higher heights. Costs of obtaining ifSAR data also tend to be lower than LiDAR data costs which can be significant given the geographical scope of the state. IfSAR data seems to be presently available for the Beaufort Sea region (2001-2005).

SLAMM was designed prior to the advent of LiDAR data, so it can certainly model areas with lower quality elevation data. The model does this by estimating elevation ranges as a function of tide ranges and known relationships between wetland types and tide ranges. However, this tool assumes that wetland elevations are uniformly distributed over their feasible vertical elevation ranges or "tidal frames"—an assumption that may not reflect reality. If wetland elevations are actually clustered high in the tidal frame they would be less vulnerable to sea-level rise. If wetland elevations are towards the bottom, they would be more vulnerable. LiDAR data for any site assists in reducing model uncertainty by characterizing where these marshes exist in their expected range. Additionally, high vertical-resolution data can be used to validate model assumptions regarding the elevation range to tide range relationship for these wetland types.

The SLAMM wetland pre-processor cannot be used to estimate elevations for dry lands or fresh-water wetlands. Therefore estimates of saline inundation for these land-types are subject to considerable uncertainty when low-quality elevation data are utilized.

Within most of Alaska, the best available non-LiDAR Digital Elevation Model is derived from USGS topological maps (National Elevation Dataset). Because of the high elevations that abut many coastlines, contour intervals can range from 15 to 100 feet. These maps provide little-to-no information about elevations below the lowest contour and are therefore not acceptable for modeling the effects of sea level rise.

Below the 60th degree of latitude, Shuttle Radar Topography Mission (SRTM) data are available. However, the vertical errors for these data are too large for SLR modeling (the 90% confidence interval for SRTM error ranges from negative 6.5 meters to positive 6.5 meters).

Vertical Datum Considerations

Elevation data is generally provided with a vertical datum of NAVD88 or in some cases NGVD29. SLAMM requires that vertical data be converted to a tidal datum, specifically the mean tide level (MTL). Within the contiguous United States, such corrections may be derived from the NOAA VDATUM product.

In Alaska, where VDATUM coverage is not available, these corrections must be derived from NOAA gages (Tidal Datums) or the National Geodetic Survey. Given the coarse spatial resolution of these gages, interpolation between gages or extrapolation from existing gages is often required, increasing uncertainty in the relationship between elevation data and water levels.

There is an additional uncertainty in Alaska elevation data due to uncertainty in the vertical control network. Renee Shields of the NOAA National Geodetic Survey writes:

"Heights derived this way [converting from the geoid to NAVD88] are, in areas of the country with significant geodetic control, at best good to about 4 cm. Alaska does not have a good vertical control network, and I'm not sure when the heights there were last leveled, so while GEOID06 is significantly better than previous geoid models, it could be much less accurate than 4 cm."

In other words, due to the sparse data network in Alaska relative to the rest of the country, elevation data uncertainties are increased.

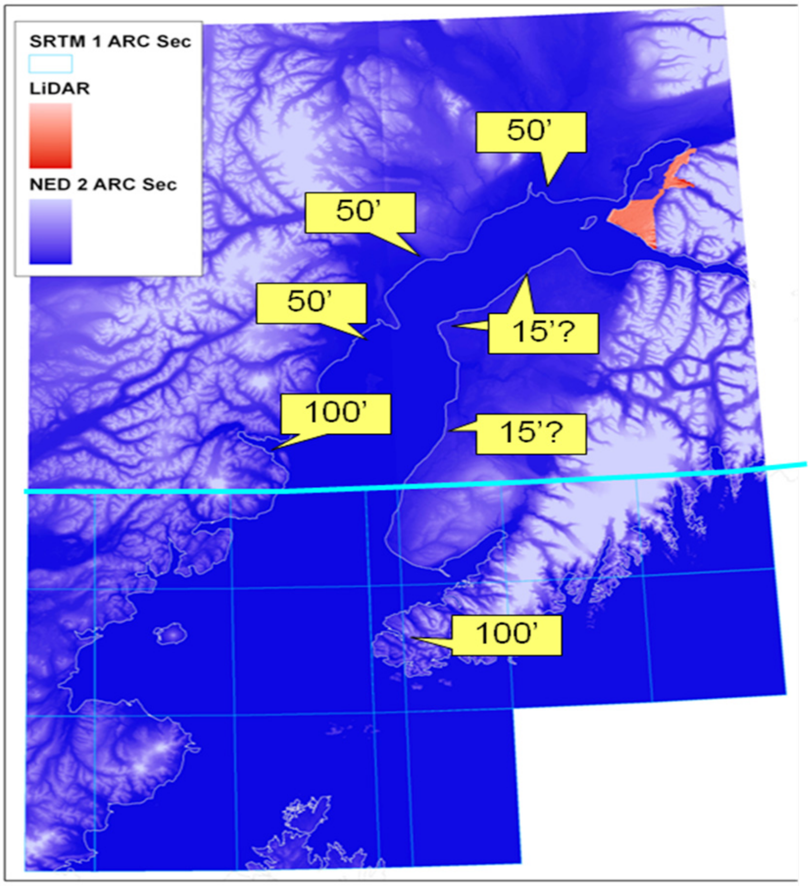

Figure 1: Example of Available Elevation Data for Cook Inlet Region.
Yellow call-out boxes indicate contour intervals for NED data. Light blue line indicates northern boundary for SRTM data This map does not include recently available Kenai Peninsula LiDAR

Land Cover Data (NWI)

Land cover data for the SLAMM model is generally provided by the National Wetlands Inventory (NWI). Land covers are converted from the Cowardin Classification system into SLAMM land-cover categories. Coastal wetland data within Alaska are fairly complete, though there are occasional gaps (Figure 2). However, most NWI maps in the region are based on aerial photography collected in 1977-1986. If land-cover changes have been extensive in the last 20-30 years these changes will not be properly captured in the model's initial condition maps. They may instead occur simultaneously within model results. There also are issues when elevation data is out of phase with land cover data as the relationship between land types and land elevations becomes less clear. More discussions on this may be found in the section Conceptual Model Verification below.

NWI data tend to be of lower horizontal resolution in Alaska than in the contiguous United States. The NWI is based on survey-level mapping at a coarser resolution of 1:60,000. In other areas of the United States, 1:25,000 scale NWI maps are utilized. This means that lines delineating wetland types are more generalized in Alaska. This lack of horizontal precision can lead to further conflicts between NWI cover classes and higher-horizontal-resolution elevation data. Differences are usually resolved in the first year of a model run and may not have significant effects on overall model predictions.

It may be especially costly to update the NWI within Alaska due to the lack of availability of updated aerial photography for the majority of coastal Alaska. There are significant costs to acquiring new imagery in remote locations due to the limits imposed by weather conditions and seasonal windows. Despite this, NWI datasets are constantly being updated so contacting the USFWS directly to determine whether the datasets available on-line are current and whether blank spots may be filled in in a timely manner is recommended.

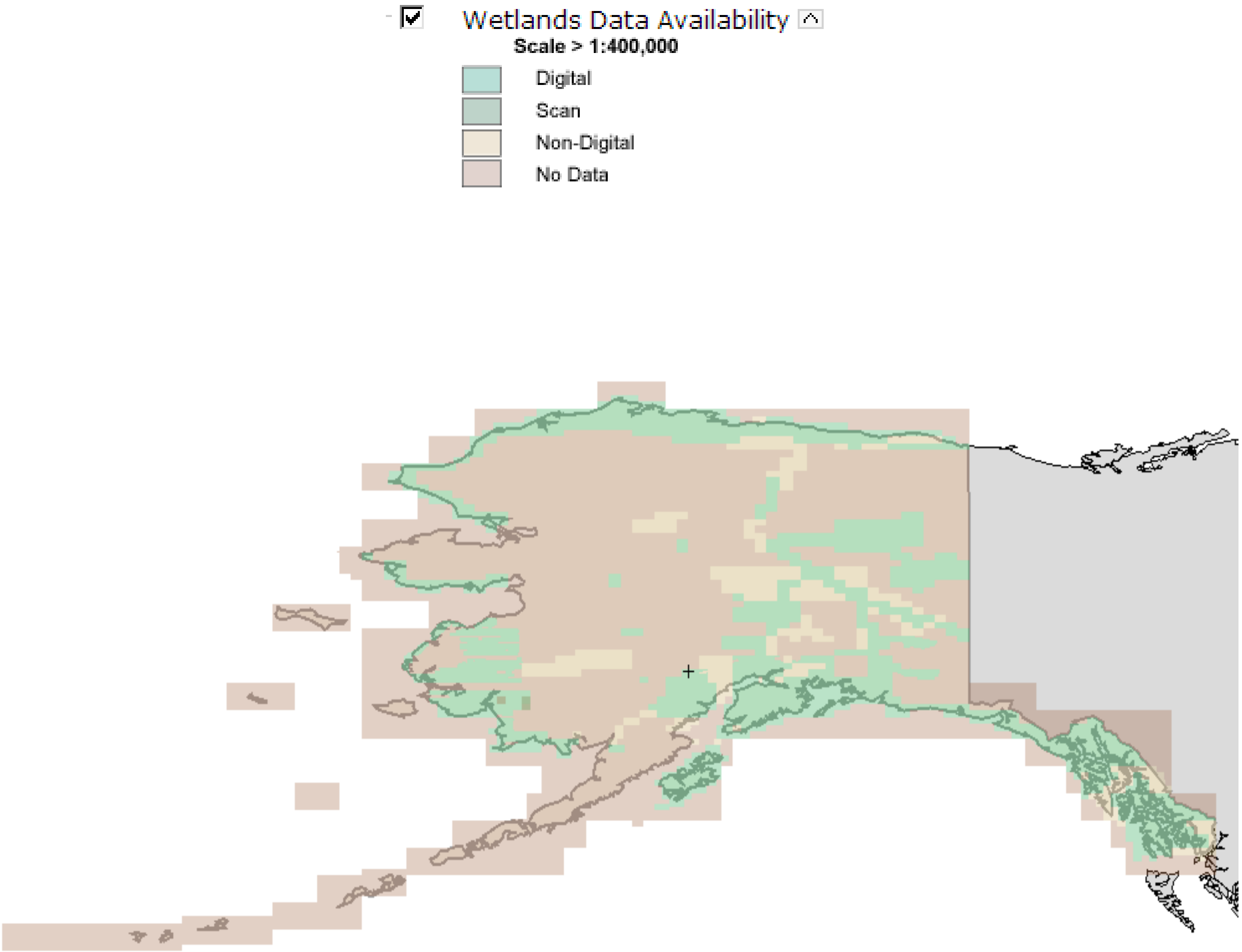

Figure 2: NWI Data Availability within Alaska from Wetlands Data Mapper.

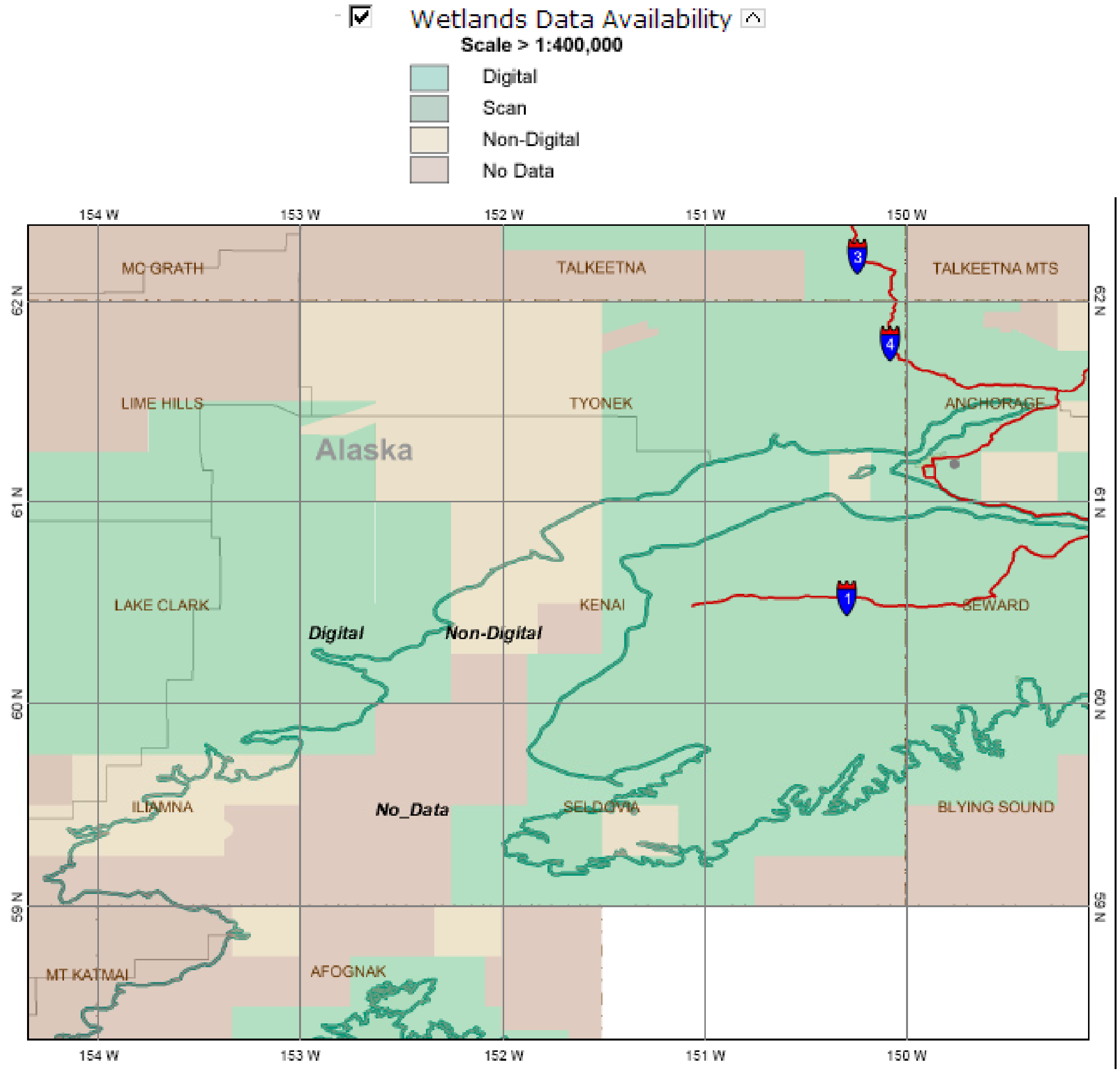

Figure 3: NWI Data Availability for Cook Inlet from Wetlands Data Mapper.

Land Movement / Uplift

Due to the spatially-variable and high-magnitude effects of isostatic rebound within Alaska, an accurate characterization of land uplift is of critical importance. One important source of land movement data within Alaska is the work of Dr. Jeffry Freymueller (Freymueller et al. 2008). Dr. Freymueller has conducted repeated GPS surveys covering the time period from 1992-2007 throughout the state. In our conversation with Dr. Freymueller, he indicated that the projection of these measured rates of change over the next 100 years would likely provide the best available estimate of uplift or subsidence rates during that time period. However, some Alaska locations have a higher point density than others (Figure 4 to Figure 6). In particular, Dr. Freymueller emphasized the lack of data points in western Alaska as very significant—with just a few measurement stations to cover a coastline of thousands of miles (Figure 7).

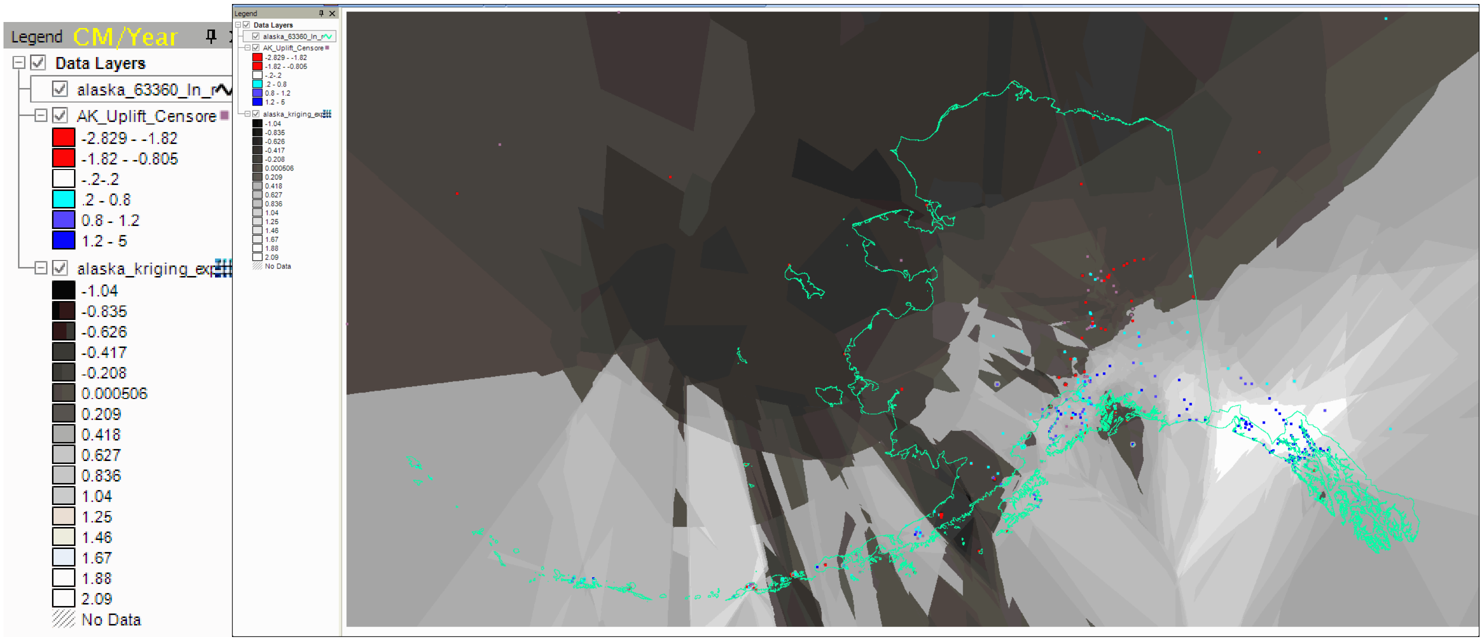

Figure 4: Freymueller Point Data and Results of Kriging Interpolation for all of Alaska.
Lighter gray areas represent areas of 0.4 cm/year uplift or greater and are therefore less likely to be directly affected by sea-level rise.

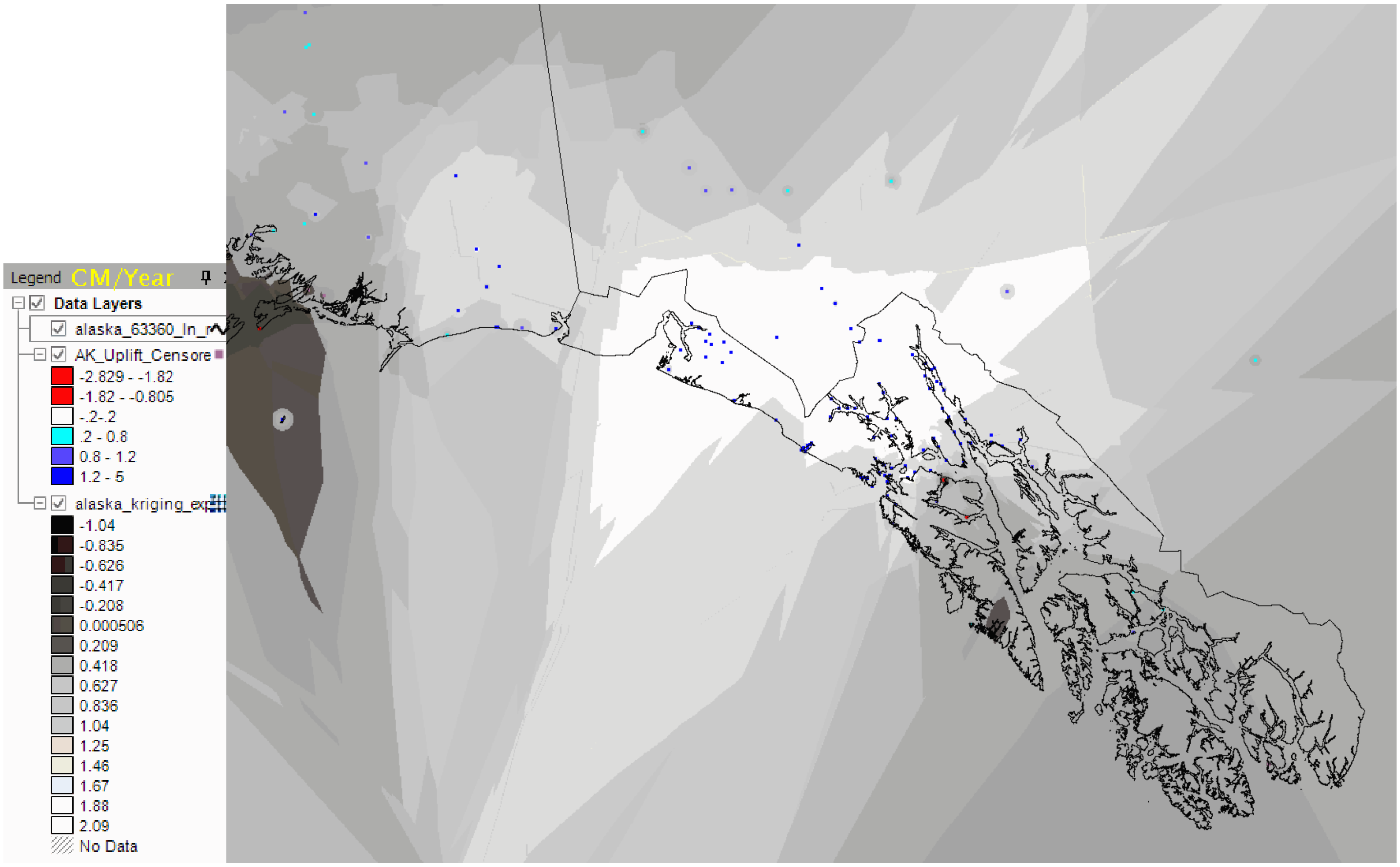

Figure 5: Freymueller Point Data and Results of Kriging Interpolation for Eastern Alaska.
Lighter gray areas represent areas of 0.4 cm/year uplift or greater and are therefore less likely to be directly affected by sea-level rise.

GPS measurements such as these should also be checked against other sources of local data such as historic SLR trends from NOAA gages, data from Alaska CORS stations (continuously operating reference stations), and other literature sources (e.g. Larsen et al. 2005).

Some form of spatial interpolation is then necessary so that uplift can be applied on a cell-by-cell basis. SLAMM 6 allows a user to import a spatial map of uplift and subsidence, a critical capability for Alaska simulations. Using a two dimensional interpolation called “kriging” may be the best solution, though there are complexities to this approach.

Important Note: Maps presented in this paper represent kriging over the entire state of Alaska, though careful quality assurance of results was only performed for the Cook Inlet study area where the point density was much higher. Using different parameters within the spatial interpolation technique will doubtlessly result in different estimates of uplift between measurements.

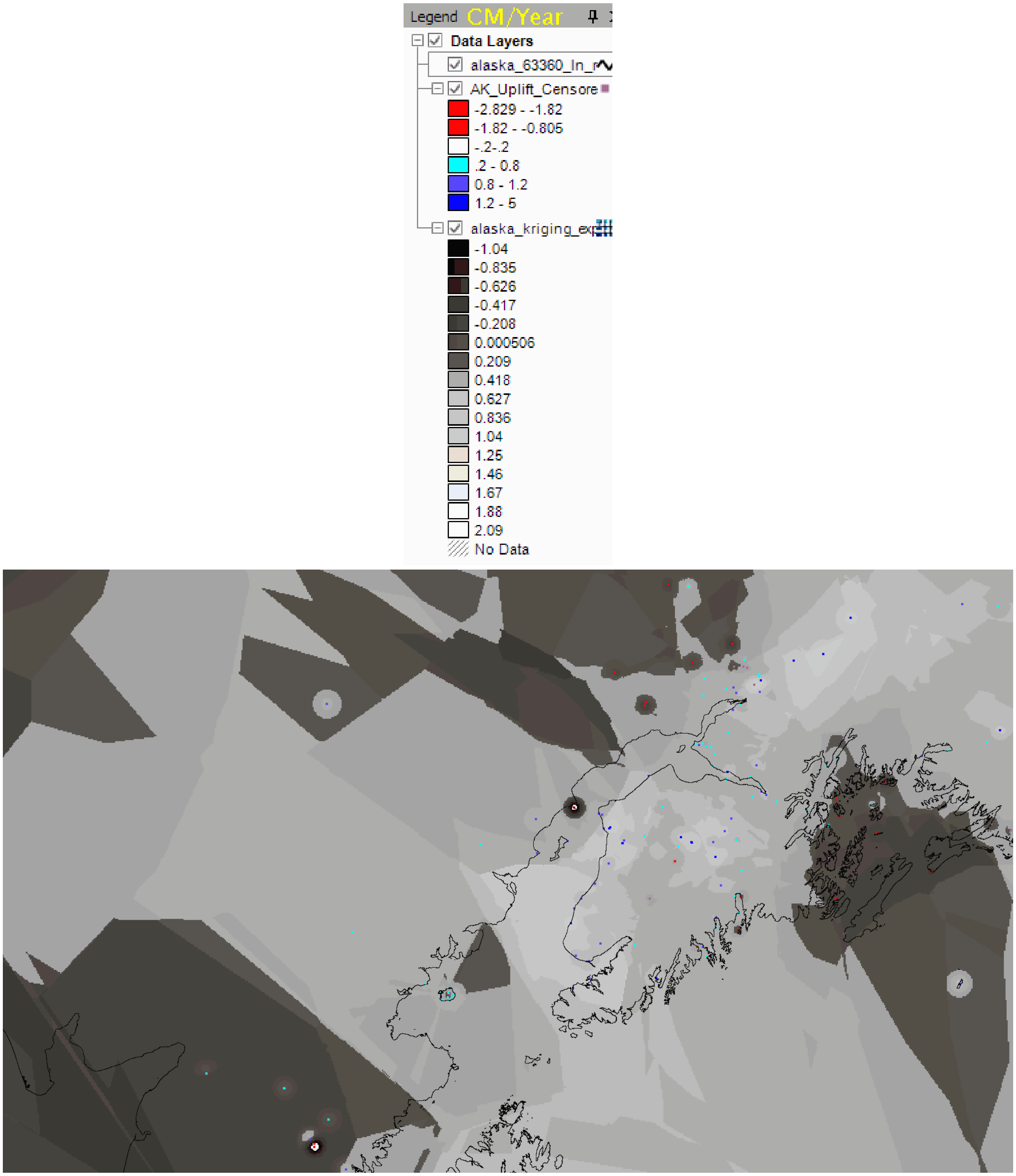

Figure 6: Freymueller Point Data and Results of Kriging Interpolation for Cook Inlet Region
Lighter gray areas represent areas of 0.4 cm/year uplift or greater and are therefore less likely to be directly affected by sea-level rise.

Measurement-error considerations must also be taken into account. Dr. Freymueller's data includes error estimates based both on the number of measurement years and also the variability within measured rates at a particular site. Data points with higher error rates must be given a lower weight or truncated from the data set. The data sets shown above have had errors of greater than 0.4 cm/year truncated.

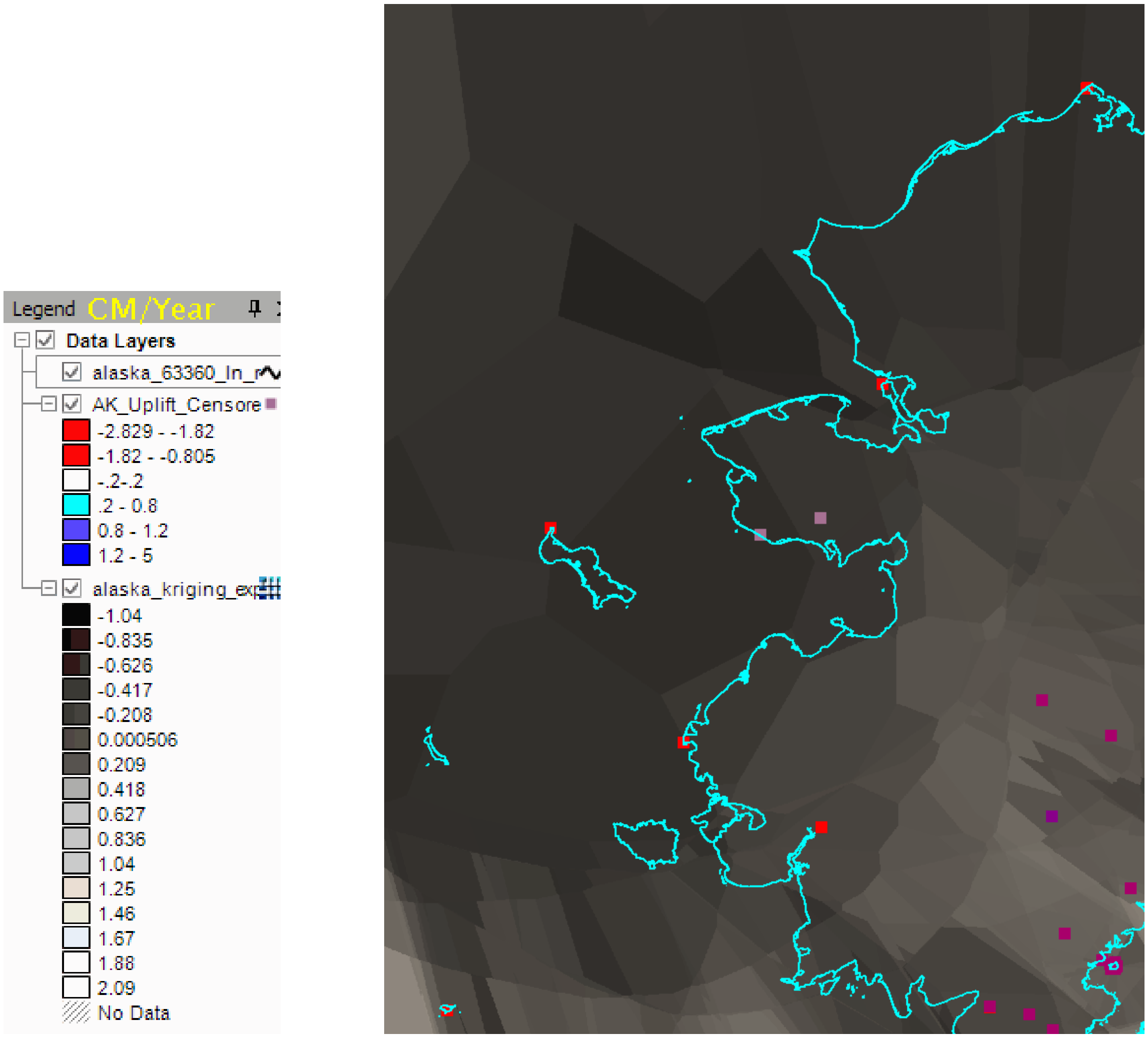

Figure 7: Freymueller Point Data and Results of Kriging Interpolation for Western Alaska
Only seven CORS stations forthousands of miles of coastline

Accretion Data

Within the SLAMM model, sea-level rise is offset by sedimentation or vertical accretion using average or site-specific values for each wetland category. (Accretion rates may also be spatially variable within a given model domain.) Accretion rates are important model parameters. Depending on the rate at which they are vertically moving, wetlands may be much more resilient to or susceptible to sea level rise.

Wetlands accretion studies within Alaska appear to be extremely limited. For Cook Inlet, two studies were found. One was an analysis of Eagle River Flats in Fort Richardson Alaska (Lawson et al., 1995). The other is a set of unpublished marker/horizon data provided by Jerry Hupp of USGS from Cook Inlet (Hupp 2009). Additional published data about wetlands accretion in Alaska were not located in our preliminary literature search. In areas where accretion data are not available, regional averages must be utilized or a range of accretion values may be used to assess feasible outcomes.

An additional source of model uncertainty is the potential for increased accretion rates due to changes in glacial rivers. As glacial coverage potentially recedes, accretion rates may increase as a result of increased rockface exposure. The SLAMM model could be used to estimate the effects of time-varying sediment accretion as a result of this process; however, the effects on accretion rates must first be estimated outside the model.

One significant model simplification within SLAMM has been a temporally constant accretion rate for a given region. This does not account for potential feedbacks that can occur. For example, as frequency of inundation increases, sediment trapping also tends to increase (Morris et al., 2002). The latest version of the model, SLAMM 6, contains flexible variable feedbacks to cell elevation (i.e. frequency of inundation), cell salinity, and the distance between a cell and an estuarine channel. Due to these new relationships, any data gathering exercise for accretion should try to characterize potential relationships between accretion and elevation, accretion and salinity, and spatial location relative to channels. Such data will improve the capability of the SLAMM model to incorporate such feedbacks into its formulation and should reduce overall model uncertainty.

Horizontal rates of marsh or tidal flat erosion are also quite useful for model setup. These data appear to be somewhat more plentiful within Alaska and can be derived from shoreline change maps or direct studies of coastal erosion.

Tide Ranges

Tide ranges are generally gathered from NOAA gages and/or NOAA tide-tables. NOAA gages are often more useful as they can include data regarding frequency of inundation at a given elevation, which can then be used to define the boundary between dry lands and wetlands.

Tide data is fairly plentiful within portions of Alaska, but there are some regions in which long-distance interpolation between gages will be required. In the northern and western parts of the state, for instance, the gap between tidal gages with tidal datum is often 50 miles or more (Figure 8).

Tide ranges can also be more uncertain moving up rivers where a combination of freshwater flows and saltwater usually results in a reduced range of tide.

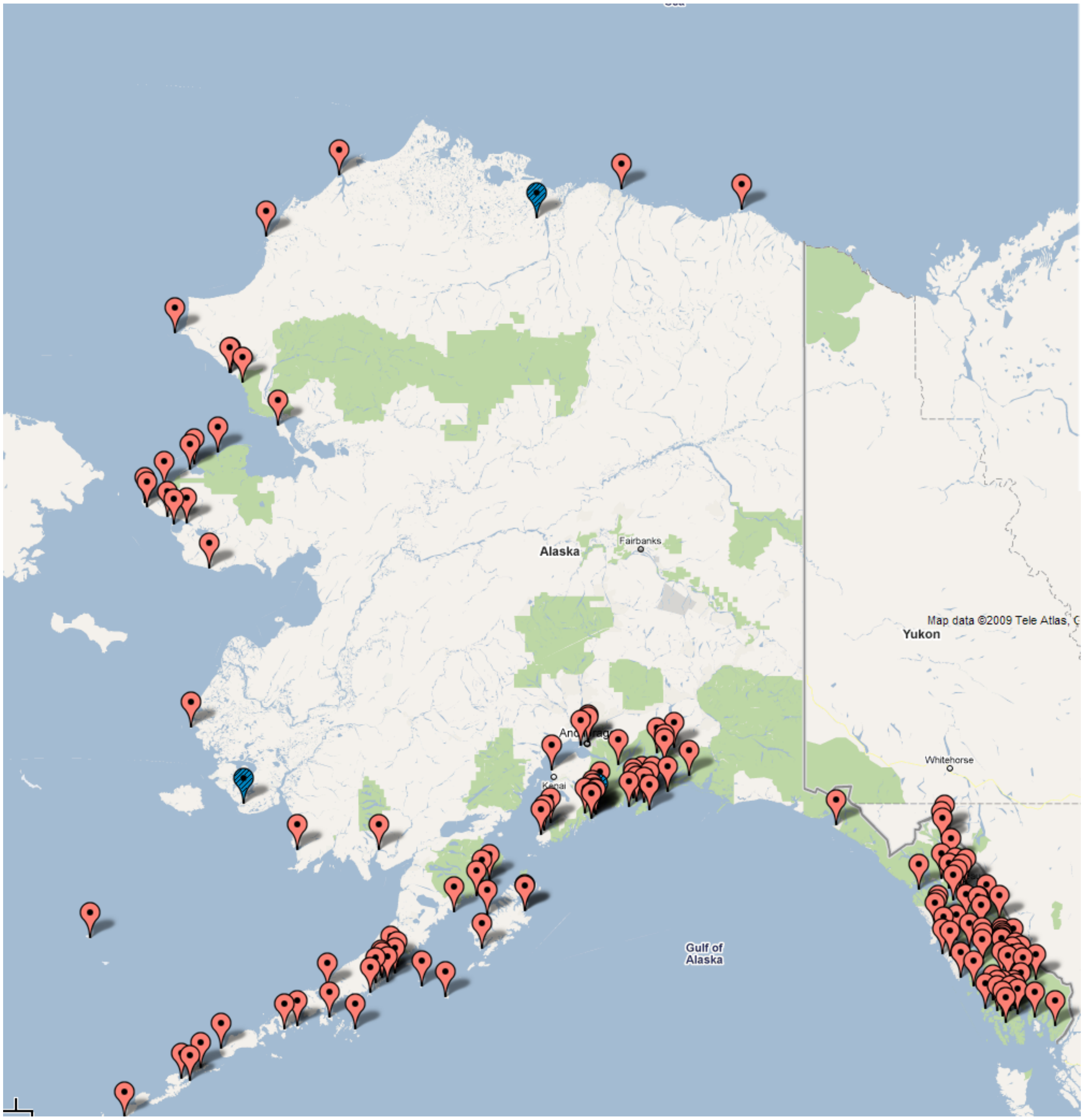

Figure 8: Tidal Gages with Tidal Datum Irrnformation within Alaska

Conceptual Model Verification

The SLAMM model assumes that wetlands inhabit a range of vertical elevations that is a function of the tide range. For example, saltmarshes are generally assumed to persist from Mean Tide Level (MTL) up to an elevation greater than Mean High Higher Water (MHHW). Based on LiDAR data from many sites, this relationship has been generally proven to be true, though there are occasional site-specific differences. For example, in macrotidal regimes, saltmarshes have been shown to persist several centimeters below Mean Tide Level. (McKee and Patrick, 1988).

Within SLAMM 6, an automatic elevation analysis can be undertaken to examine whether the elevation data and NWI coverclass data match the SLAMM conceptual model appropriately. This examination will be most successful when the NWI and LiDAR data have similar dates. Otherwise, statistics will be thrown off by any changes in land cover classes since the date of the NWI photography. High vertical-resolution elevation data is also required. Additional differences can be expected if the elevation data grid has a higher horizontal resolution than the NWI coverclass.

An initial examination of the SLAMM conceptual model within Alaska indicated that the conceptual model does apply in the Cook Inlet region. While marshes in Kenai Peninsula were found to be at a higher elevation than expected, this may have been a function of land-uplift and differences in dates between the NWI and LiDAR coverages (Clough, Larson 2009). However, the model has not yet been tested in areas above the North Temperate Zone.

If a site does not match with the current conceptual model particularly well, the SLAMM model may now be modified to allow a new elevation-range to wetlands-class relationship (new SLAMM 6 capability). However, care should be taken to ensure that the reason for the mismatch is not due to some sort of systematic data error (such as a problem with the vertical datum transformation or an inaccurately quantified tidal range). Any changes to the SLAMM conceptual model should be documented along with hypotheses for why the site appears to differ from other sites that have been modeled.

Prioritized Data Needs

1) Practically speaking, most elevation data in Alaska is too old and/or coarse to be useful in SLAMM modeling. LiDAR or IfSAR data is needed. Collecting these data should be considered the top priority for SLAMM modeling and for many other sea-level rise modeling resources.

2) Because of Alaska's seismic activity and glacial recession, land movement is a crucial player in assessing the impacts of sea-level rise. These data are sparse in western and northern Alaska, including the Yukon-Kuskokwim Delta, where application of the SLAMM model would seem likely to be very useful.

3) Coastal Alaska NWI data coverage is fairly complete but there are a few significant data gaps, especially in the Alaska Peninsula and southern Kotzebue Sound. What's more, the data that do exist have a lower horizontal resolution than sites in the contiguous United States and tend to be 20-30 years out of date. To maximize model precision, additional NWI data should be gathered.

4) Tide data is fairly plentiful within portions of Alaska, but there are some regions in which gages are a significant distance apart.

Most Useful Applications of SLAMM In Alaska

While the SLAMM model is suited to working in a wide variety of situations, managers will generally gain more useful information in areas where the impacts of sea-level rise are likely to be high. Coasts that have high rates of isostatic rebound or wide tidal ranges are less likely to be vulnerable to sea-level rise impacts, as are areas with high vertical coastlines. The model is therefore most likely to provide important information in areas where isostatic rebound is low or non-existent and where tidal ranges are not extreme. One large region that most obviously would benefit from a SLAMM analysis is the western coast of Alaska along the Yukon-Kuskokwim Delta. The erosive forces farther north are not in play, rebound is unlikely to be a factor, and tidal ranges are within normal ranges. However, as with much of the rest of Alaska, the Yukon-Kuskokwim Delta does face some data challenges that should be met to assure the most useful application of the SLAMM model.

North Slope/ Western Arctic Considerations

The northern and northwestern coasts of Alaska are somewhat unique in that erosion rates are dramatically accelerating, possibly due to decreasing sea ice extent (Jones, et al. 2009). The SLAMM model does not currently model temporally variable erosion rates, or erosion as a function of air temperatures. Horizontal erosion rates would need to be entered into the SLAMM model based on external estimates of future rates. Temporal changes in sedimentation rates may also need to be incorporated to account for the additional mobilization of sediment brought forth by such erosion. Based on these considerations, minor model modifications may be required to run scenarios for the North Slope.

Southeast Alaska Considerations

In general, southeast Alaska is uplifting at a fairly high rate—which is to be expected given the prevalence of glaciation and consequent isostatic rebound. However, Dr. Freymueller's uplift data suggests that these uplift rates are quite spatially variable. (A few GPS stations within southeast Alaska even produced data that suggested subsidence, for example, one data station within Port Frederick). The SLAMM model may therefore be very relevant in portions of the region—but uplift data will be an important determinant.

Conclusions

Alaska poses unique challenges for Sea Level Rise (SLR) Modeling. Most importantly, the high quality elevation data required to accurately estimate impacts of SLR are not available for the majority of the state. Other data coverages such as land-cover, tidal ranges, and vertical datum corrections tend to be of lower resolution than those coverages are in the contiguous United States. Accretion studies are few and far between.

When running the model, the elevation data is certainly the most critical data limitation. NWI coverage is fairly thorough though potentially dated and subject to higher horizontal uncertainty. Other inputs can generally be estimated or derived from existing datasets, though uncertainty may be higher in Alaska depending on the assumptions utilized.

When running SLAMM in Alaska, parametric sensitivity and uncertainty analyses may be especially important to determine the manner in which lower-resolution data is affecting predicted model outcomes. For these analyses, parameters are allowed to vary within their feasible ranges and a range of predictions and their percent likelihood may then be derived and examined. The effects of elevation data uncertainty may also be evaluated.

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