CONFIRMATION AND CALIBRATION OF COMPUTER MODELING OF TSUNAMIS PRODUCED BY AUGUSTINE VOLCANO, ALASKA

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ABSTRACT

Numerical modeling has been used to calculate the characteristics of a tsunami generated by a landslide into Cook Inlet from Augustine Volcano. The modeling predicts travel times of ca. 50-75 minutes to the nearest populated areas, and indicates that significant wave amplification occurs near Mt. Iliamna on the western side of Cook Inlet, and near the Nanwelak and the Homer-Anchor Point areas on the east side of Cook Inlet. Augustine volcano last produced a tsunami during an eruption in 1883, and field evidence of the extent and height of the 1883 tsunamis can be used to test and constrain the results of the computer modeling. Tsunami deposits on Augustine Island indicate waves near the landslide source were more than 19 m high, while 1883 tsunami deposits in distal sites record waves 6-8 m high. Paleotsunami deposits were found at sites along the coast near Mt. Iliamna, Nanwelak, and Homer, consistent with numerical modeling indicating significant tsunami wave amplification occurs in these areas.

1. INTRODUCTION

Augustine Volcano is the most active volcano in the Cook Inlet region of Alaska (Fig. 1). It erupted at least five times during the 20th century, and began erupting again in December 2005. The activity in early 2006 has included multiple episodes of explosive ash and pyroclastic flow eruptions, as well as lava dome eruptions at the summit of the volcano. The steep summit edifice of Augustine Volcano repeatedly collapsed in giant debris avalanches into the sea around Augustine Island during the last 2000 years, most recently in 1883 (Beget and Kienle, 1992; Siebert et al., 1995). Volcanic debris avalanches into the sea are an important cause of tsunamis (Beget, 2000).

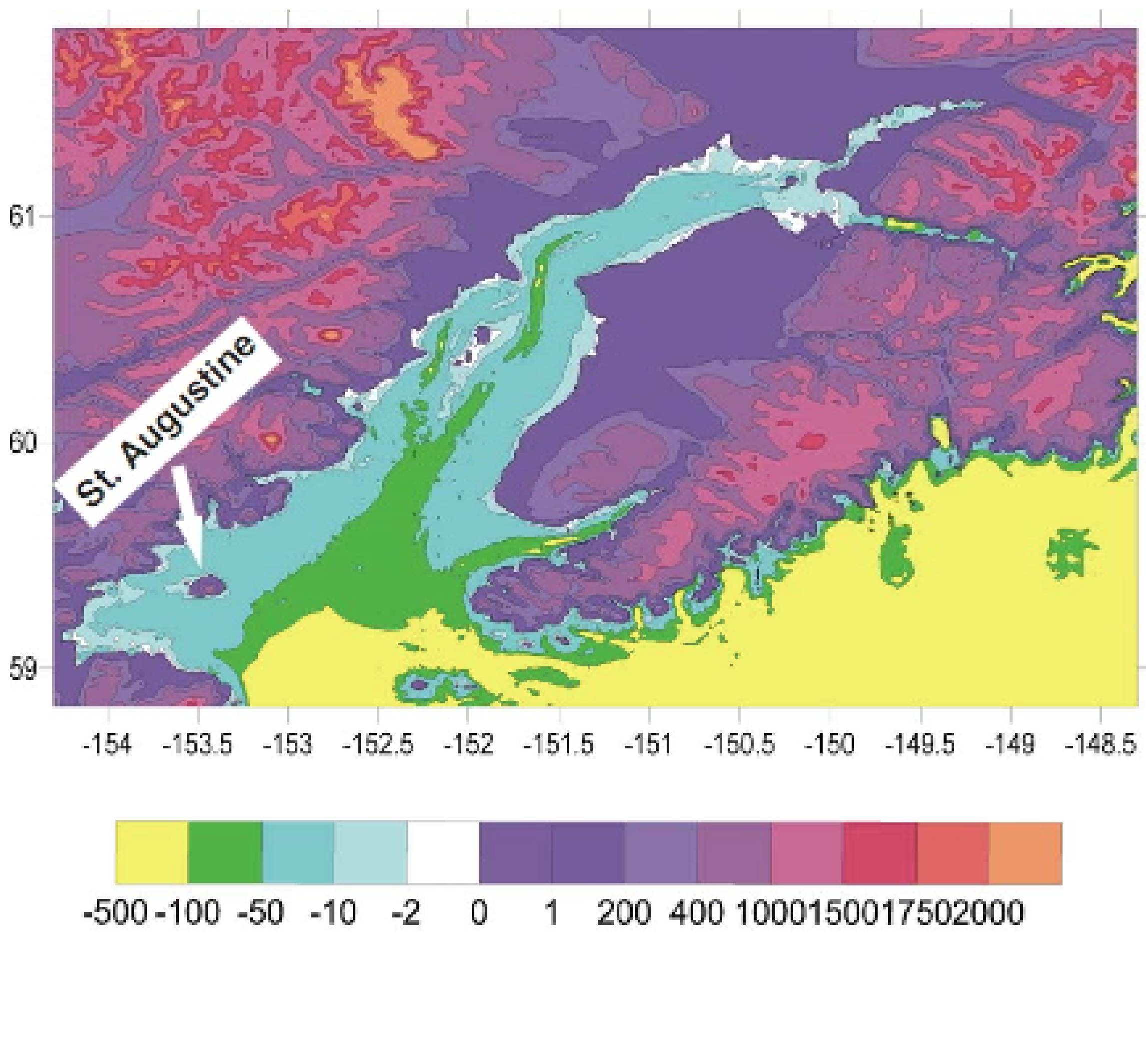

Fig. 1. Location of Augustine Volcano within Cook Inlet, Alaska, and generalized bathymetry of Cook Inlet.

On the morning of October 6, 1883, a debris avalanche from the north flank of Augustine Volcano travelled northward from the summit of the volcano to the shoreline of Augustine Island and then flowed 5 km into the waters of Cook Inlet, generating a tsunami (Kienle et al., 1987; Siebert et al., 1989). A contemporary written account of the tsunami recorded in a log at a trading post at English Bay (modern Nanwalek), about 80 km northeast of the volcano, states (Alaska Commercial Company, 1883):

"At this morning at 8:15 o'clock, 4 tidal waves flowed with a Westerly current, one following the other at the rate of 30 miles p. Hour into the shore, the sea rising 20 feet above the usual level. At the same time the air became black and fogy, and it began to Thunder. With this at the same time it began to rain a finely Powdered Brimstone Ashes, which lasted for about 10 minutes, and Which covered everything to a depth of over 1/4 inch…the rain of Ashes commencing again at 11 o'clock and lasting all day."

Cook Inlet has one of the largest tidal ranges on earth, and the 1883 Augustine tsunami occurred just at low tide. The 20 foot (ca. 6.6 m) waves at English Bay were just slightly larger than the tidal range in this area, mitigating the effects of the tsunami wave on coastal communities. There were no reported fatalities from the 1883 tsunami, but oral history accounts, collected from Alaskan native people affected by the tsunami, tell of flooded coastal dwellings and kayaks washed away by the tsunami.

2. NUMERICAL MODEL OF TSUNAMI GENERATED FROM AUGUSTINE VOLCANO

The numerical model assumes that a portion of Augustine volcano collapsed into the shallow water of Cook Inlet, and is used to calculate a tsunami generated by the landslide from the volcano collapse. The source of debris is assumed to be the northeast side of the volcano's summit.

The model is based on geologically reasonable parameters derived from the extent and characteristics of past debris avalanches at Augustine Volcano determined through stratigraphic studies of the volcanic deposits and geologic mapping of Augustine Island (Waitt and Beget, 1996; Beget and Kienle, 1992). As the slide travelled into Cook Inlet, it's velocity is assumed to diminish from 50m/s to 10m/s, its thickness along the center of the slide also diminished from 30m to 10m, and the slide width increased from approximately 2.5km to 3.5km (fig. 2). The debris avalanche was simulated as progressive flow of the bottom uplift which imparted motion to the water column.

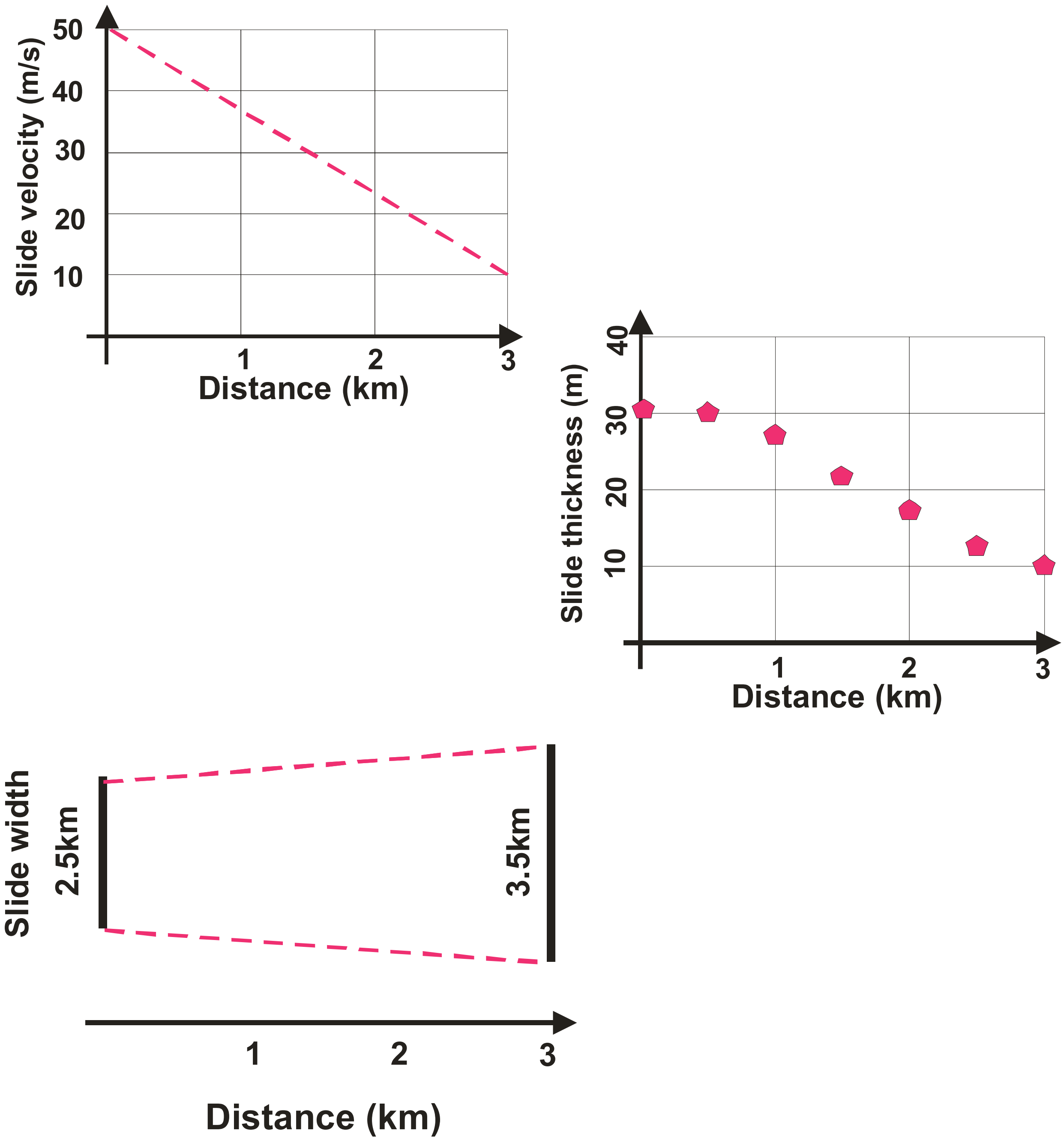

Figure 2. Slide velocity, thickness and width as a function of the distance for an eastern Augustine Volcano slide.

Generation and propagation of the tsunami is calculated by using a set of equations of motion and continuity for the long wave equations. Numerical form of these equations and appropriate boundary conditions for the land/water and water/water boundaries have been described by Kowalik et al. (2005). The finite-difference equations are solved in the spherical system of coordinate with the grid spacing of 1 minute along E-W direction and 0.5 minute along N-S direction. The Cook Inlet domain depicted in Figure 2 span from 58 50'N to 6150'N and from 154 18'W to 148 18'W. A generalized map of the bathymetry of Cook Inlet is shown in figure one.

The first result of the numerical computation are travel times to various locations around lower Cook Inlet (Fig. 3). Tsunami travel time to Homer, the closest major population center to Augustine Volcano, is close to 75min, while travel time to Anchorage is around 4 hours.

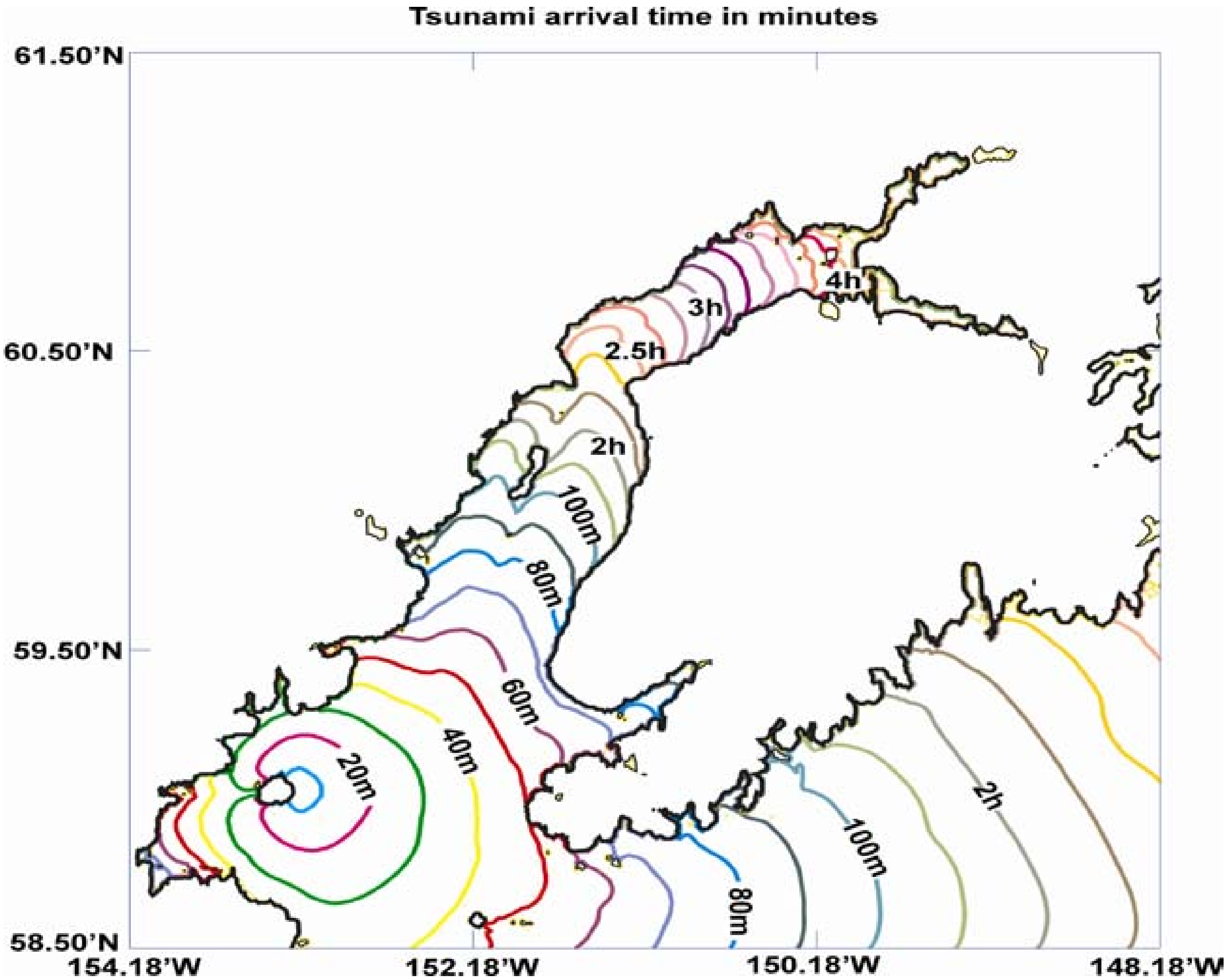

Figure 3. Tsunami arrival time estimated for the modeled slide from Augustine Volcano.

Another result of the numerical model are estimates of maximum tsunami amplitude, i.e. the maximum wave height which occurs during the 5 hours span after the landslide (fig. 4). In general, wave height maximums at the different grid points occur at different time. The spatial distribution of the maximum amplitude defines directional properties of the tsunami source, and therefore the maximum in Figure 4 is initially directed away from St. Augustine towards the east. While propagating towards shorelines the tsunami amplitude is amplified along peninsulas and along ridges. Towards the west from Augustine Island tsunami amplitude is reduced through bottom friction in the shallow waters of Kamishak Bay. The strongest amplification occurs along the Seldovia-English Bay shoreline, up to approximately 2.5 m above the mean sea level (Fig. 4). Amplification of up to 2 m takes place along Anchor Point-Homer shoreline and along the Iliamna Volcano shoreline on the west side of Cook Inlet. This amplification is especially important for the coastal communities along the eastern shore of Lower Cook Inlet as tsunami travels to the Seldovia and English Bay areas in 50 min and to the Anchor Point and Homer areas in about 75 min, so that warning time for these communities is quite short.

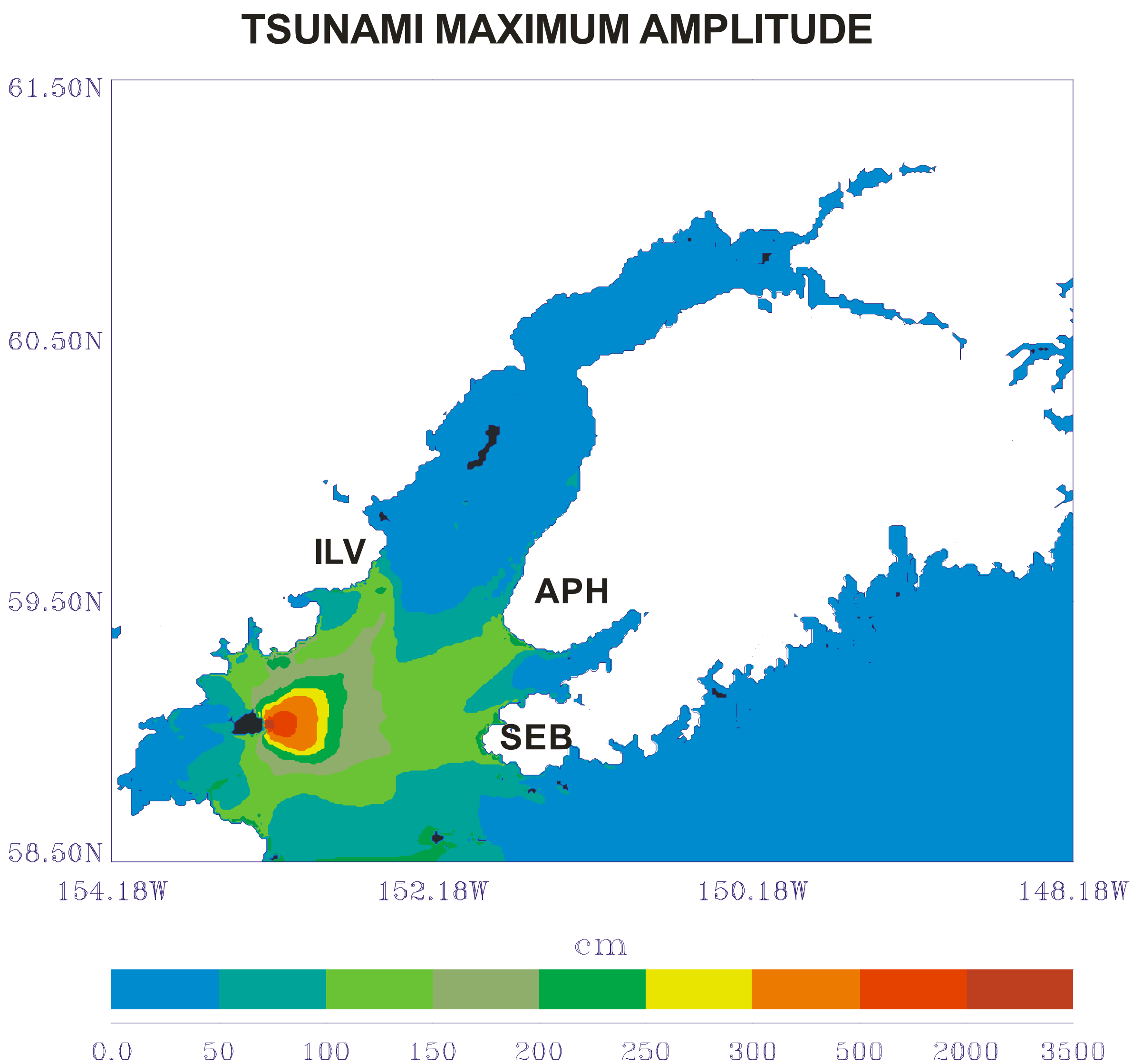

Figure 4. Maximum tsunami amplitudes in centimeters. Abbreviations: APH, Anchor Point –Homer; SEB Seldovia-English Bay; ILV, Iliamna Volcano.

3. COMPARISON OF NUMERICAL MODELING AND GEOLOGIC FIELD DATA

The 1883 avalanche from Augustine Volcano buried the former shoreline of Augustine Island, and displaced the new shoreline 2 km seaward at Burr Point. Bathymetry indicates the 1883 debris avalanche traveled an additional 3 kilometers farther northward beneath the sea (Waitt and Beget, 1996; Beget and Kienle, 1992). The horseshoe shaped crater left by the 1883 sector collapse had a volume of ca. 0.5 km3, and is probably a good approximation of the the volume of the debris avalanche itself.

In several locations near the current coastline paleotsunami deposits ranging from 10-230 cm in thickness and consisting mainly of mud and mollusc shells, but also including packages of beach sand and rounded pumice occur on top of hummocks of the 1883 debris avalanche at elevations ranging from 12-15 m above the high tide line. The presence of rounded pumice and incorporated marine fossils are similar to the sedimentological characteristics of tsunami deposits from the Krakatoa eruption (Carey et al., 2000). The 1883 Augustine tsunami deposits are overlain by 1883 tephra from Augustine volcano and by1912 Katmai tephra, confirming that they record the 1883 tsunami. Because the tsunami occurred at low tide, the original wave height near the source at Augustine Island must have been greater than 20 m. This agrees well with the numerical modeling of the proximal tsunami wave (fig. 4).

Distal 1883 tsunami deposits have been difficult to locate, because the wave height is similar to the ca. 8 m tidal range and the tsunami occurred at low tide. However, recent work has identified paleotsunami deposits at several localities around Cook Inlet. At English Bay (now called Nanwelak) the 1883 tsunami deposits occur at elevations virtually identical to the wave heights reported in the eyewitness account from this area. These deposits can be dated because the 1883 volcanic ash from Augustine Volcano directly overlies the layer of marine sands and cobbles found in low-lying coastal area, which in turn is overlain by the 1912 Katmai tephra (fig. 5).

Distal 1883 tsunami deposits are also found near Cannery Creek, along the Iliamna Volcano shoreline, where they occur more than a m above the high tide line (Anders and Beget, 1999). Other distal 1883 tsunami deposits are found in cores from tidal lagoons near Homer. The localities where the 1883 deposits have been found correspond with sites where numerical modeling shows that wave amplification occurs.

Waythomas (2000) discounted historic accounts of the 1883 Augustine tsunami after finding no paleotsunami deposits during a regional survey. However, the local amplification of tsunamis indicated by the numerical modeling suggests that the major impacts of some Augustine tsunamis may occur only in restricted areas of higher runup.

The tsunami generated by the 1964 Good Friday 9.2 M earthquake in Alaska affected much of lower Cook Inlet, and provides an interesting comparison to the 1883 Augustine event, as the 1964 tsunami was also about 6 m high in the lower Cook Inlet area, similar to the reported height of the Augustine tsunami, and also occurred near low tide. The 1964 tsunami caused significant damage to waterfront docks and buildings in Seldovia. Local residents in Seldovia and English Bay who had lived there during the 1964 tsunami can point out the high water lines they observed. Paleotsunami deposits of sand, rounded beach gravel and drift wood from the 1964 event occur in these areas. The sedimentology of the 1964 tsunami deposits in the English Bay and Seldovia areas are identical to those of the 1883 tsunami deposits we report on here.

Fig. 5. Paleotsunami deposits near Nanwelak (English Bay), Alaska. Beach cobbles and sand occur in a 1-5 cm thick discontinuous layer overlying poorly developed paleosols, and underlying Augustine 1883 and Katmai 1912 volcanic ash deposits.

4. Summary and Conclusions:

The pattern of dispersal and the magnitudes of tsunami waves which might be potentially generated by a debris avalanche into Cook Inlet from Augustine Volcano indicated by numerical modeling are consistent with geologic evidence of the height and extent of the 1883 Augustine tsunami. An important finding of this work is that, because of the irregular bathymetry around Augustine Island and the geomorphology of surrounding coastlines, significant local amplification of tsunami waves from Augustine Volcano occurs in several areas around lower Cook Inlet. These include the Iliamna coastline on the west side of Cook Inlet, and coastal areas near the small town of English Bay and more developed coastal areas near the towns of Homer and Anchor Point.

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Augustine Volcano - John Seach. Alaska. 58.77 N, 153.68 W summit elevation 2104 m Stratovolcano. Augustine Volcano is located in southwestern Cook Inlet about 280 kilometers southwest of Anchorage, Alaska. It is the most active of the eastern Aleutian volcanoes of Alaska.Â The volcano contains summit lava domes and debris-avalanche and pyroclastic-flow deposits. At least 11 large debris avalanches have reached the sea during the past 2000 years.Â From 27-31 March 1986 large explosions sent eruption clouds into the stratosphere and produced pyroclastic flows that reached the sea. Flights were diverted from the area. On 29th March, a DC-10 airline experienced windscreen and turbine abrasion from volcanic ash while descending to Anchorage airport.