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NOAA TIME Eastern Strait of Juan de Fuca, Washington, Mapping Project: Procedures, Data Sources, and Products

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1. Introduction

This report describes a project conducted by the NOAA Center for Tsunami Inundation Mapping Efforts (TIME) to model potential tsunami inundation along the shores of Bellingham, Anacortes, and northwest Whidbey Island, Washington (Fig. 1). This work provides data for the creation of tsunami hazard maps covering these areas. The maps are prepared through National Tsunami Hazard Mitigation Program funds to assist local governments in the development of evacuation plans in areas at risk of potentially dangerous tsunamis. The source of the tsunami scenario is a major (magnitude 9.1) earthquake along the Cascadia Subduction Zone. Previous tsunami mapping studies for sites along open coasts of the Pacific Northwest used the same source scenario that is discussed in detail by Priest *et al.* (1997) and Myers *et al.* (1999). A high-resolution inundation model is applied to estimate wave propagation and runup on land within the region of interest.

2. Background

The Cascadia Subduction Zone (CSZ) is a significant seismic and tsunami hazard for the Pacific Northwest. Geologic evidence from stratigraphic studies suggest that great earthquakes (magnitude > 8) have occurred along the CSZ (Atwater *et al.*, 1995). Estimates of the recurrence interval for a large event on the CSZ are between 500–540 years (Atwater and Hemphill-Haley, 1997). Numerous geological studies of the CSZ have found evidence of tsunami deposits at 60 sites in the Pacific Northwest region, including one within the region of interest at Swantown Marsh on Whidbey Island (Peters *et al.*, 2003). Native American oral tradition suggests a significant earthquake and subsequent tsunami from the CSZ at the entrance to the Strait of Juan de Fuca (Swan, 1868).

Inundation studies for the Cascadia-generated tsunami have been done for several sites at the open coast of Oregon and Washington, where high-resolution modeling of tsunami inundation has been completed (Priest *et al.*, 1997; Myers *et al.*, 1999). The studies also included a low-resolution tsunami propagation model for a larger area of the coast and some internal waterways. This modeling has shown that simulated tsunami waves propagated through the Strait of Juan de Fuca (SJDF) without much attenuation and generated

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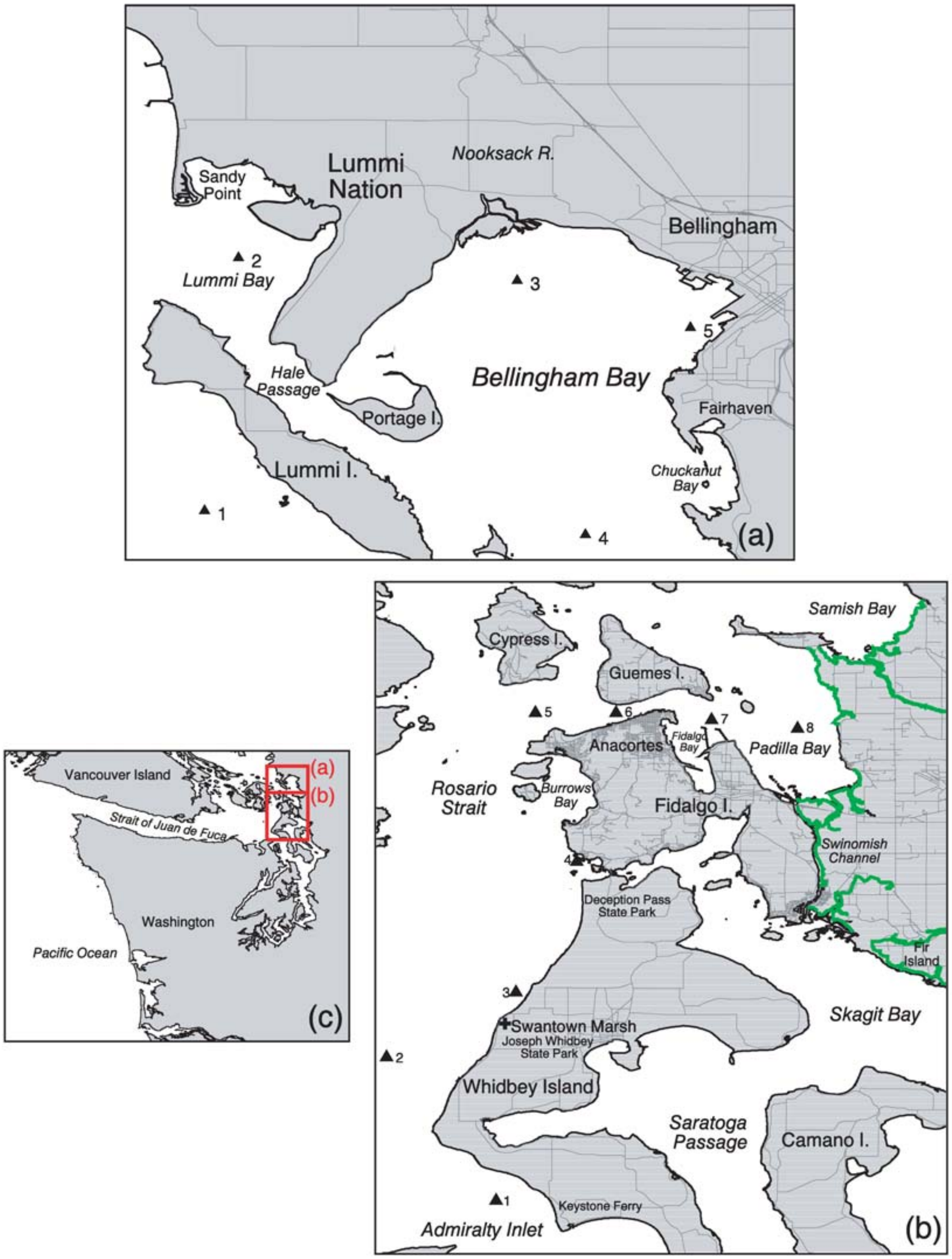

Figure 1: Study areas of the Eastern Strait of Juan de Fuca Tsunami Mapping Project. (a) The high-resolution modeling area of Bellingham and Lummi Nation. (b) The high-resolution modeling area of Anacortes and northwest Whidbey Island. (c) The study area with respect to Washington State. Triangles represent locations of wave height time series. Green lines represent the location of levees (Skagit County GIS, personal communication).

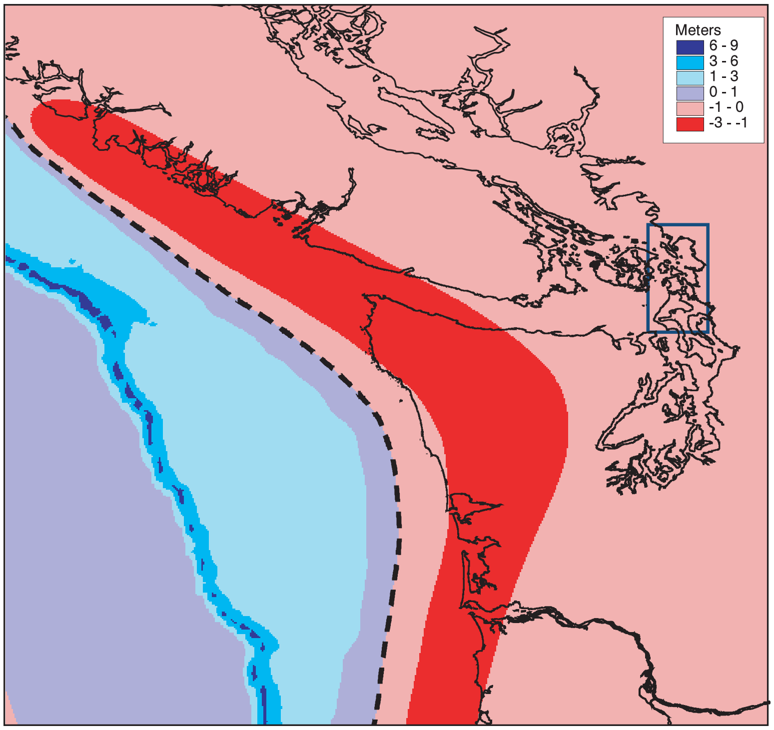

Figure 2: Distribution of computed vertical deformation used as a tsunami source for the inundation study. The dashed line represents the axis of the Cascadia Subduction Zone. The blue rectangle outlines the area of high resolution tsunami inundation modeling.

significant amplitudes at the coasts of eastern SJDF. These preliminary results prompted focused study of the potential impact of a tsunami within the eastern SJDF and the local waters surrounding Bellingham, Anacortes, and Whidbey Island (Fig. 1) presented here.

3. Tsunami Source

The geometry of the CSZ (Fig. 2) suggests that the megathrust earthquake would generate vast areas of coastal subsidence and offshore uplift that will displace tremendous amounts of water. The displaced water will result in a tsunami propagating along the outer Washington coast and into the SJDF. The impact of the tsunami within the eastern SJDF and the local waters surrounding Bellingham, Anacortes, and Whidbey Island (Fig. 1) is estimated here using high-resolution numerical modeling.

The tsunami source for this study assumes wave generation by a rupture along the CSZ. Six scenarios, defined by Priest *et al.* (1997) and Myers *et al.* (1999), were obtained from the Oregon Department of Geology and Mineral Industries. We chose Scenario 1A as the maximum credible event for this study. Scenario 1A consists of a magnitude (M_w) 9.1 CSZ earthquake with a rupture length of approximately 1,050 km, average rupture width of 70 km, and average slip of 17.5 m (Fig. 2). See Priest *et al.* (1997) for a complete discussion.

4. Tsunami Model

Tsunami propagation within the northern straits of Washington and wave inundation on dry land were simulated with the MOST numerical model (Titov and González, 1997; Titov, 1997; Titov and Synolakis, 1995, 1997). The MOST model has been extensively tested against various laboratory experiments (Titov and Synolakis, 1995, 1998) and verified by successfully reproducing field data for many historical tsunamis (Yeh *et al.*, 1995; Titov and Synolakis, 1997, 1998; Titov and González, 2001; Titov *et al.*, 2004). Titov *et al.* (2003) described the details of the MOST model application for a tsunami inundation mapping project. The following briefly describes the use of the MOST model for modeling the Cascadia tsunami in the SJDF.

The MOST model is designed to use several nested computational grids to telescope into the high-resolution inundation area. Three levels of computational grids were used for this project to properly simulate the tsunami generation in deeper ocean, wave propagation through the relatively narrow SJDF, and inundation at impact areas. To reproduce the correct wave dynamic during the inundation computations, high-resolution grids were used for areas around Bellingham, Anacortes, and Whidbey Island. These high-resolution computations require high-quality bathymetry and topography data merged into one computational grid.

The tsunami simulations did not include tidal dynamics in the modeled area. The tides were assumed to interact linearly with a propagating tsunami wave, and Mean High Water level was assumed for all computational areas to simulate credible worst case scenario of tsunami inundation during high tide. Appendix A describes the tidal datum distribution.

As in previous tsunami inundation studies, the topography used for the simulation does not include buildings, trees, and smaller vegetation—i.e., a so-called "bald earth" digital elevation model (DEM). These obstacles may change and decrease inundation estimates, especially for large flat areas. One way of accounting for that increased dissipation in the long-wave model is the use of a greater bottom friction parameter (Fujima, 2001). However, there are not enough data and scientific studies to choose the proper friction coefficients to account for large structures. In the absence of proven scientific estimates, we have chosen to use a standard engineering value for the Manning parameter corresponding to mildly rough surfaces ($n = 0.025$).

Appendix A describes details of the grid development procedure and lists the bathymetric and topographic sources used to create the computational grids.

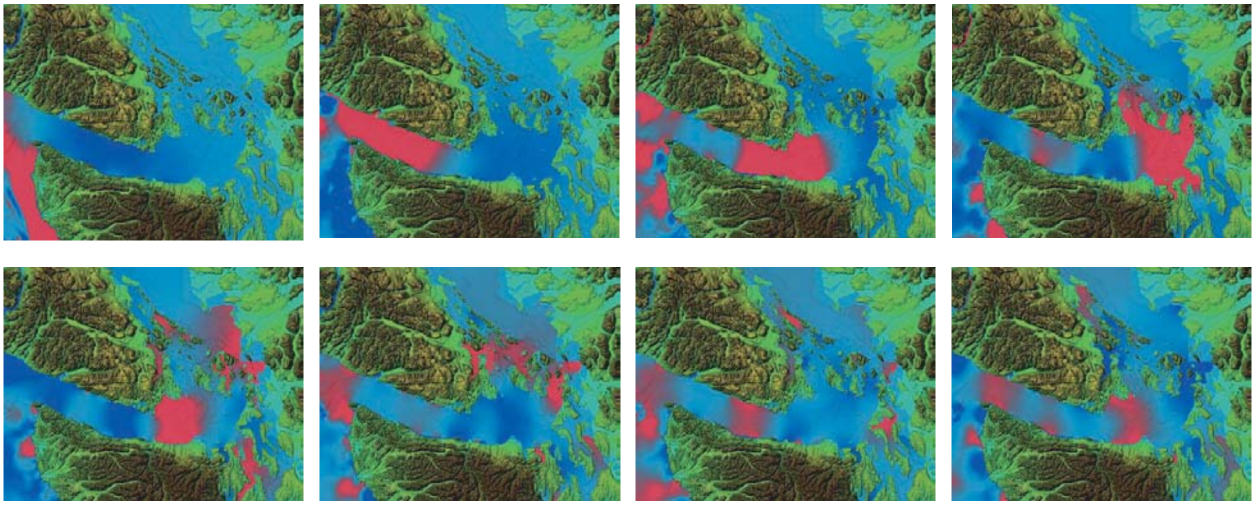

Figure 3: Snapshots of model offshore tsunami propagation in the Strait of Juan de Fuca, Rosario Strait, and Admiralty Inlet. Frames are shown from left-to-right, top-to-bottom at 30-minute intervals from 30 minutes to 4 hours after generation. Red color indicates positive wave amplitudes in meters above Mean High Water (MHW), blue is negative (below MHW). Wave amplitudes range from −1 to 2 meters.

5. Discussion of Modeling Results

5.1 Offshore dynamics

The Cascadia tsunami source (Scenario 1A) creates significant subsidence near the coast with the area of larger uplift further offshore (Fig. 2), causing the waters to initially recede and form a leading-depression wave propagating into the SJDF (Walsh *et al.*, 2002). This leading depression wave is followed by a positive wave of about 2 m amplitude. The tsunami propagates through the SJDF for more than 2 hours before reaching the eastern shores of the Strait (Fig. 3). The maximum amplitude of the propagating wave stays virtually constant inside the SJDF at around 2 m, since the Strait forms a near perfect one-dimensional channel where wave energy is not dissipating.

Upon reaching the western shore of Whidbey Island, the tsunami wave splits north into Rosario Strait and south into Admiralty Inlet. The wave crest reaches Anacortes with amplitudes above 1.4 m 2:09 (2 hours, 9 min) after generation. The amplitudes increase above 2.8 m before reaching the Bellingham shores 2:43 after generation (Fig. 4). Figures 5 and 6 show time series of amplitudes within the high-resolution computational area.

The considered model source (Fig. 2) is associated with a Cascadia event that is believed to have occurred at 0500 UTC, on 27 January 1700 (Satake *et al.*, 1996). Our high-resolution model provides travel time and amplitude estimates for this event. Tidal hindcasts were calculated around the Cascadia event using established techniques (Mofjeld *et al.*, 1997) at specific locations of the inundation modeling study (Fig. 7). Assuming modeled propagation times, the tsunami reached all of these sites at the low water phase of the predicted tides. The model results are obtained for the Mean High Water level, suggesting smaller amplitudes if an event occurred at a lower tide.

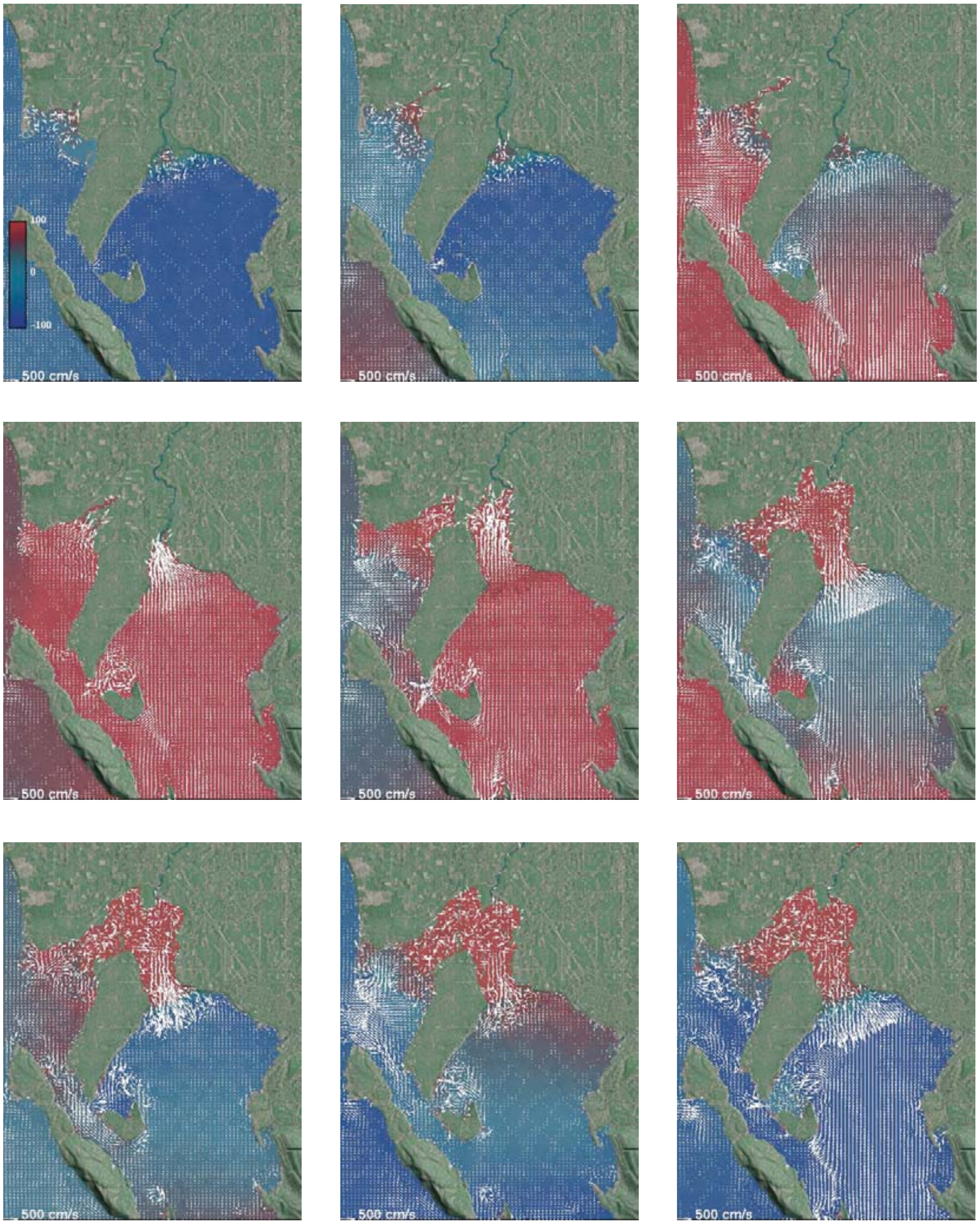

Figure 4: Snapshots of local tsunami propagation in Bellingham and Lummi Bays. Frames are shown from left-to-right, top-to-bottom at 15-minute intervals from 2 hours to 4 hours after generation. Red color indicates positive wave amplitudes in centimeters above Mean High Water (MHW), blue is negative (below MHW). Vectors represent current speeds in centimeters per second.

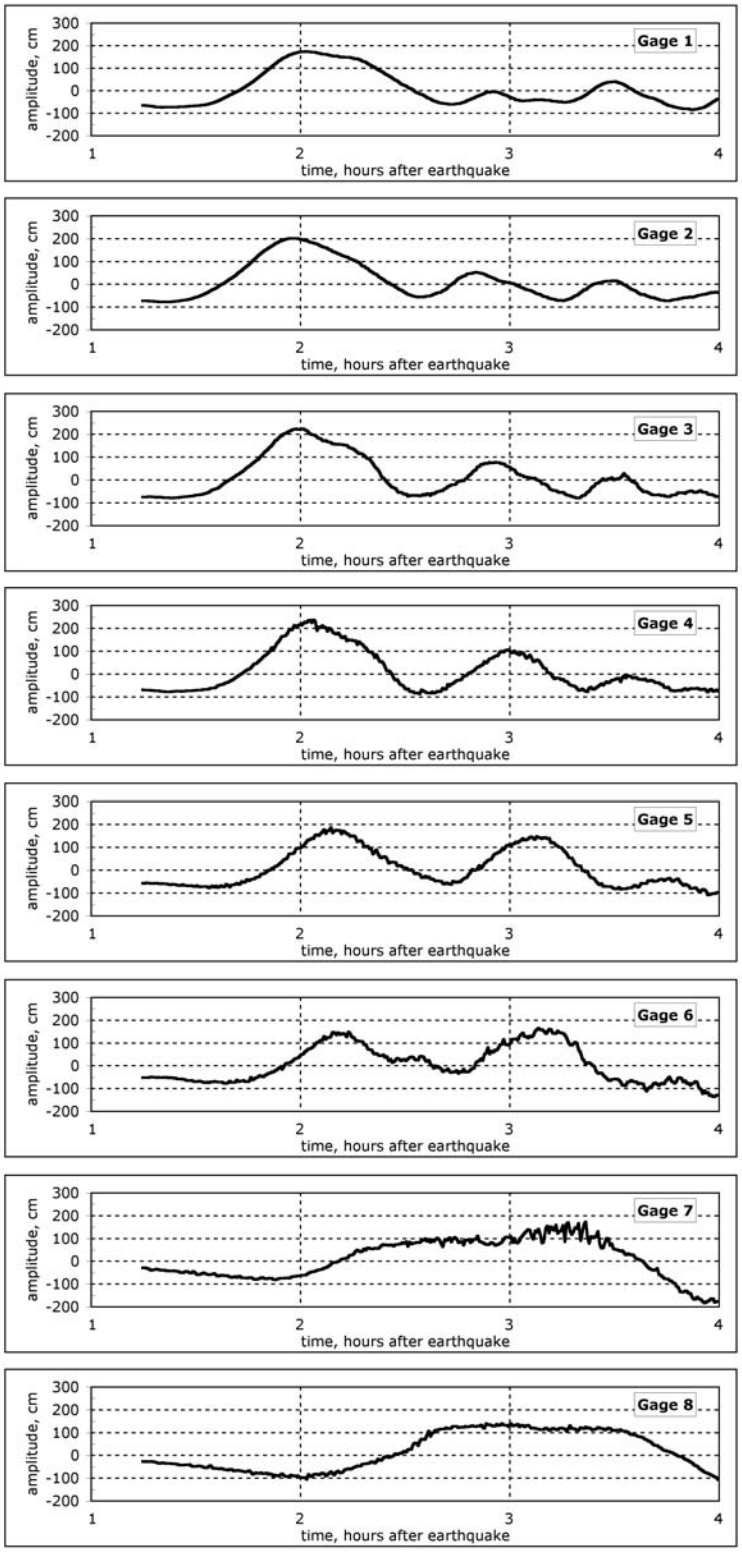

Figure 5: Time series of Anacortes and northwest Whidbey Island tsunami wave propagation. Figure 1b shows the location of each gage.

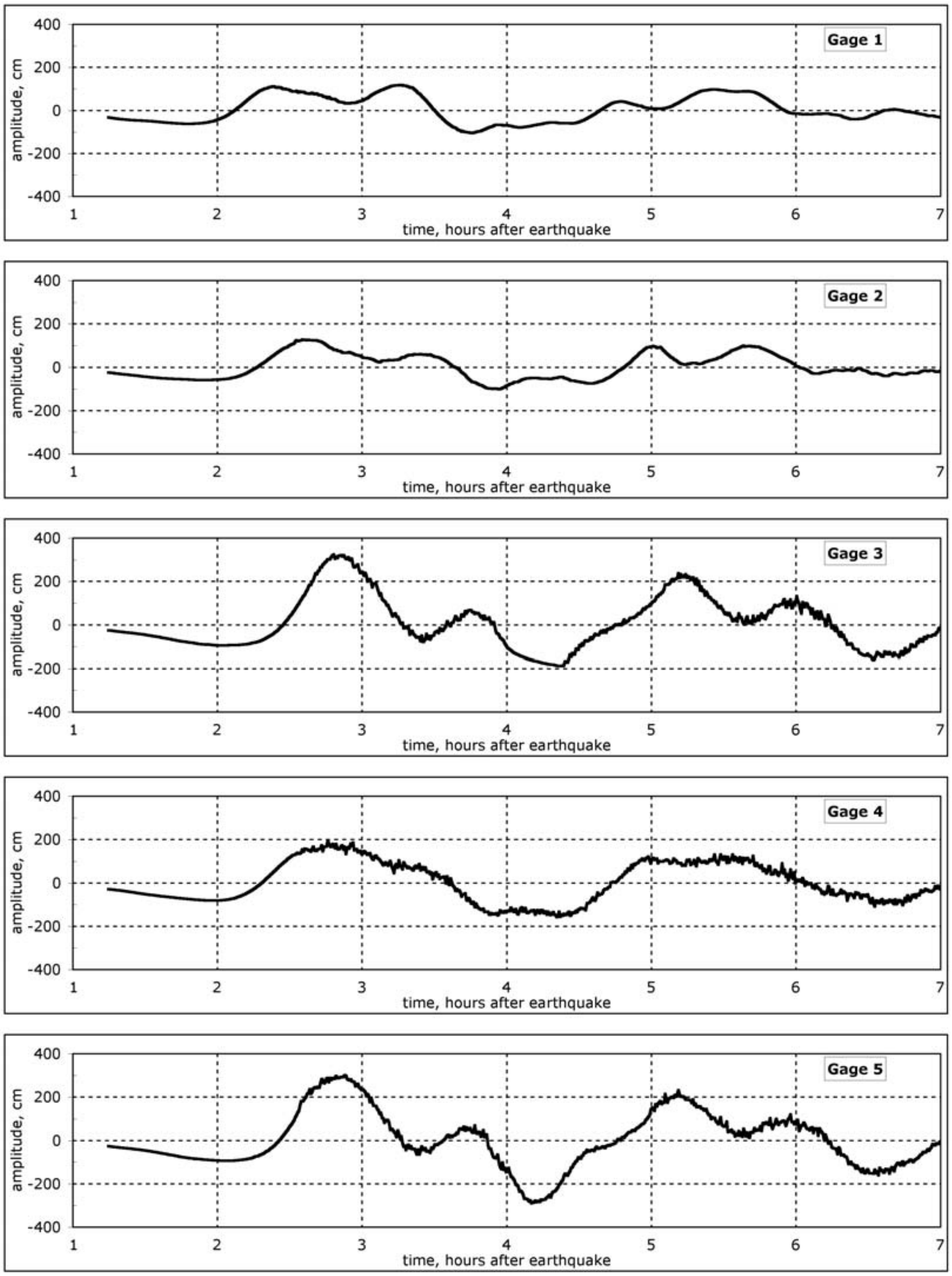

Figure 6: Time series of Bellingham tsunami wave propagation. Figure 1a shows the location of each gage.

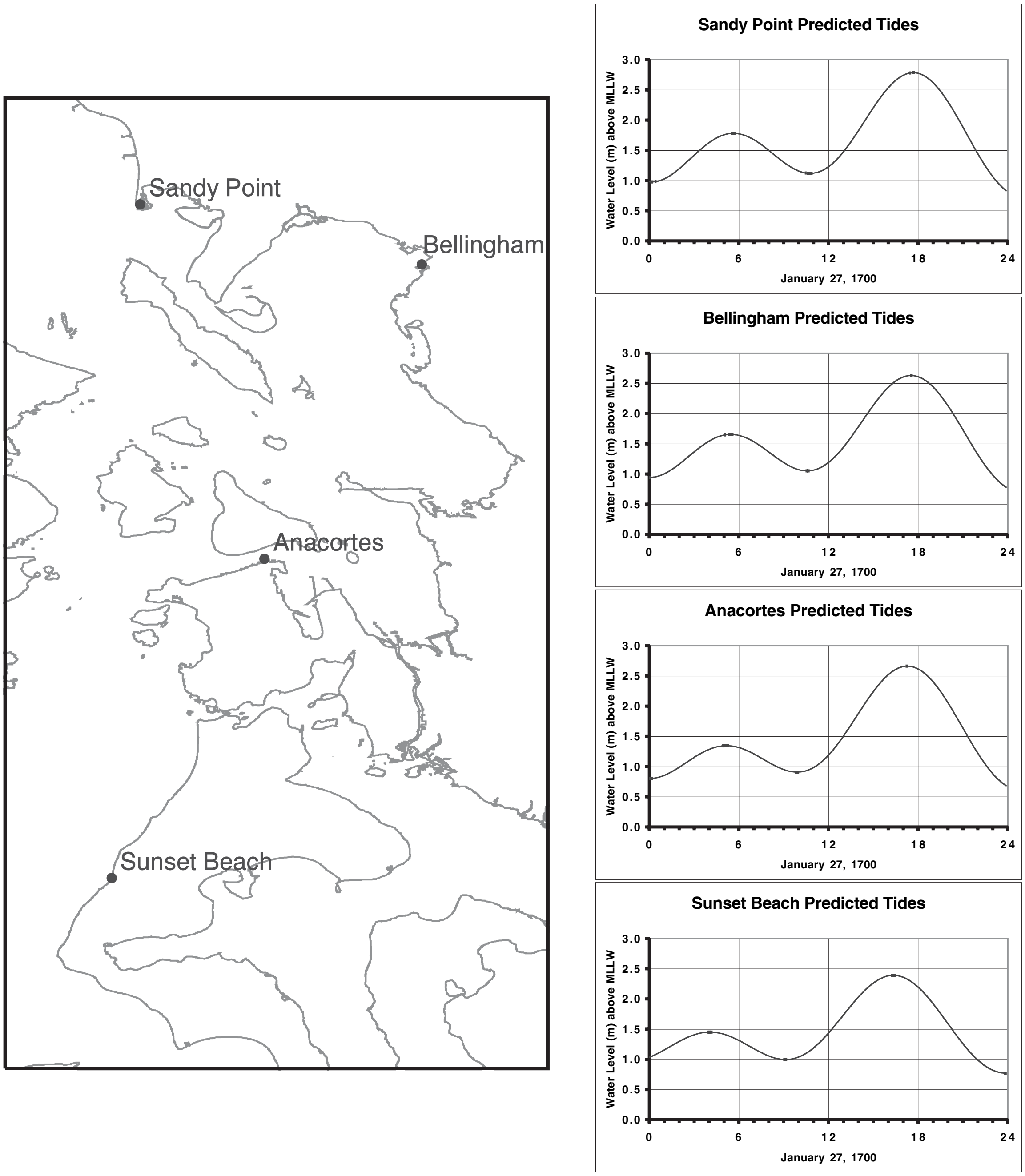

Figure 7: Water-level sites with associated tides hindcast around the time of 1700 Cascadia Subduction Zone Earthquake (0500 UTC 27 January 1700). The period is 0000-2354 UTC 27 January 1700 with sampling every 6 minutes. The observed tidal harmonic constants (O1, K1, N2, M2, S2) were obtained from Parker (1977); the remaining 37 harmonic constants are inferred based on amplitude ratios and phase differences from the reference water-level station for the eastern Strait of Juan de Fuca and Strait of Georgia (Port Townsend).

5.2 Inundation details

The model predicts extensive inundation along the low-lying shores of Lummi Bay, Bellingham Bay, Samish Bay, Padilla Bay, Swinomish Channel, and northwestern Whidbey Island. Though not part of the study area, inundation is also predicted along the Skagit River delta, also known as Fir Island (Fig. 1). The results are explained below.

5.3 Bellingham Area

The simulation shows that most of the tsunami flooding in the Bellingham vicinity occurs on and near river deltas, where large areas are not more than 3 m above Mean High Water.

The tsunami arrives in the vicinity of Bellingham Bay after about 2 hours of propagation from the source at the Cascadia margin. The wave approaches Lummi Bay earlier but with smaller offshore amplitudes (1 to 2 m) than at Bellingham Bay (2 to 4 m). Nevertheless, these relatively small amplitudes are enough to inundate the low-lying area of Lummi river delta and propagate deep inland along the river valley. The waves start to inundate the delta of Lummi river at around 2:15 after generation. By 2:30 the crest of the wave arrives and completely overtops the Sandy Point spit at the mouth of Lummi Bay.

The modeled tsunami starts to inundate the shores of Bellingham Bay at around 2:30 after generation. The crest of the wave reaches the shores near the delta of Nooksack River about 15 minutes later and water starts inundating the river valley. The tsunami flooding propagates simultaneously along Lummi and Nooksack River deltas, and about 3:15 after tsunami generation the two floods meet and completely surround the Lummi Peninsula, transforming it into an island for some period of time.

Again, simulations of tsunami inundation dynamics, especially for such extensive on-land penetrations, depend on the choice of bottom friction model and the bottom roughness coefficient. Our low bottom roughness with Manning formulation gives conservative estimates of the tsunami penetration distances (Fig. 8) and flow speeds (Fig. 9). Without site-specific data, our generic formulation and the roughness coefficients have not been fine-tuned for the details of the area (vegetation type, buildings, etc.). Different bottom roughness may produce different inundation area. Our choice of roughness coefficient leads to conservative estimates of potential hazard zones.

Figure 8 shows maximum computed inundation for this area. It illustrates the large inundation distances along river deltas with highest vertical runup above 3.4 m in the Nooksack River delta. The highest vertical runup in the Bellingham area (above 5 m) is computed on the northern tip of Portage Island. The model does not show significant inundation at the port of Bellingham. However, tsunami amplitudes near the port facilities are virtually the same as the seawall height, which makes the port a potentially hazardous zone during the tsunami.

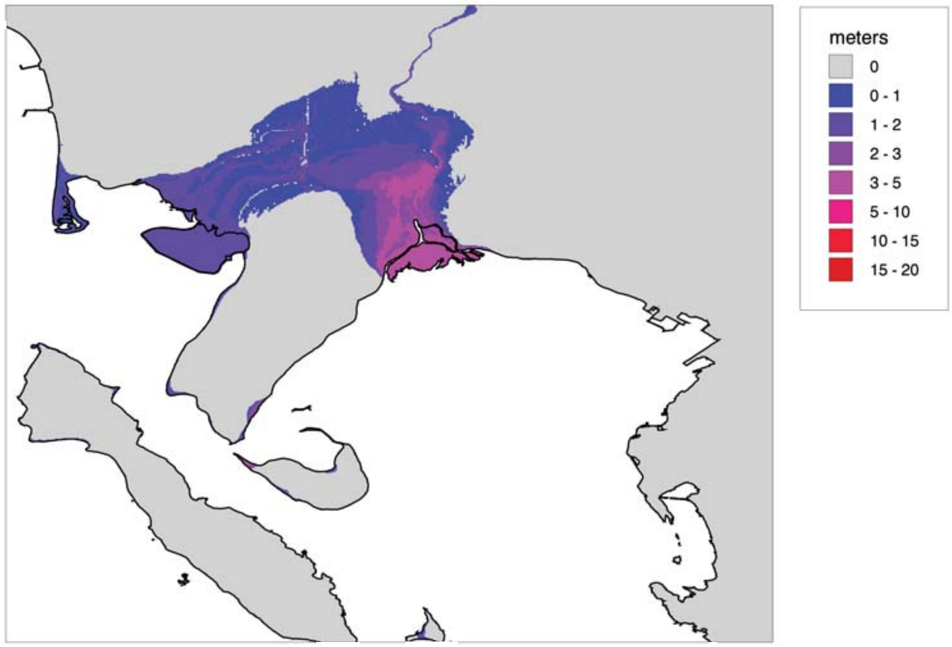

Figure 8: Maximum computed inundation depths (depth of water over land) for the Bellingham area at a resolution of 1 arc-second.

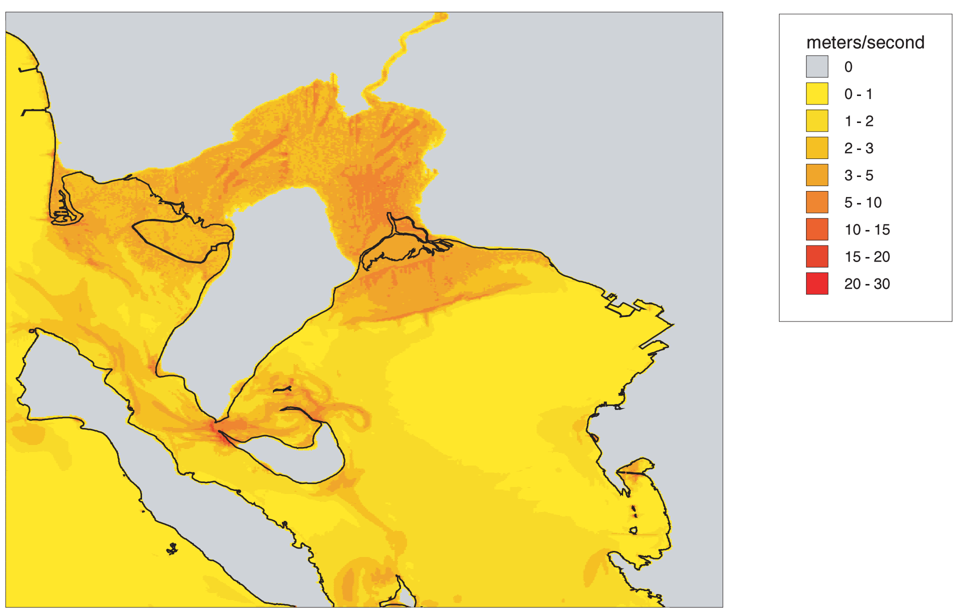

Figure 9: Maximum computed flow speed (m/s) for the Bellingham area at a resolution of 1 arc-second.

5.4 Anacortes Area

The maximum amplitudes of the first and second waves approaching Anacortes and western Fidalgo Island are similar, ranging from 1.5 to 1.8 m. Fidalgo Bay and Padilla Bay experience an initial water withdrawal, as the leading depression wave comes in, followed by the tsunami elevation wave with amplitudes from 1 to 1.6 m (Fig. 5). Little to no inundation occurs in downtown Anacortes (Fig. 10).

The Skyline Marina at the north end of Burrows Bay experiences higher levels of inundation (above 2 m) and high flow speed magnitudes (>1.5 m/s). High currents also occur around the Anacortes Ferry terminal, Guemes Channel, and Fidalgo Bay (Fig. 11).

Large areas of inundation occur in areas of low topography surrounding Samish Bay, Padilla Bay, and the Swinomish Channel. Though not part of the modeling study, inundation also occurs within the vicinity of Fir Island. The coastal areas of Samish Bay, Padilla Bay, Swinomish Channel, and Fir Island all lie within the historic Skagit River delta region (U.S. Army Corps of Engineers, 2002). This region contains a network of levees and coastal dikes to protect farmland from tidal inundation and river flooding (Fig. 1). These features are not resolved in the model; however, an analysis of coastal dike heights along the shores of Samish Bay, Padilla Bay, Swinomish Channel, and Fir Island suggest that tsunami waves will overtop the dikes and cause inundation as suggested by the model.

The average heights of the dikes along the shores of Padilla Bay, Swinomish Channel, and Fir Island range from 1.1 to 1.2 m above Mean High Water (Riggs, personal communication; National Geodetic Survey, 2004). Photos of the Samish Bay coastal dikes suggest a similar height (U.S. Army Corps of Engineers, 2002; Bloch *et al.*, 2002). Maximum wave heights along the coastal dikes range from 1.5 to 1.8 m for Samish Bay, 2.0 to 2.5 m for Padilla Bay, 1.0 to 2.5 m for Swinomish Channel, and 1.0 to 1.5 m for Fir Island.

High flow speeds (>1.5 m/s) may also breach many of these coastal dikes and levees. Levees along the Swinomish Channel have not been maintained (U.S. Army Corps of Engineers, 2002), and some of the coastal dikes along Samish Bay are in poor condition (Bloch *et al.*, 2002). Damage of dikes and levees within the Fir Island region have occurred due to flooding in 1990 and 2003 (U.S. Army Corps of Engineers, online source; Washington Military Department Emergency Management Division, 2004).

5.5 Whidbey Island

The initial wave approaching Whidbey Island has the largest maximum amplitude, ranging from 1.5 to 2.5 m (Fig. 5). The second and third waves approach 1.1 m. The simulated tsunami wave floods areas of low topography on Whidbey Island at Deception Pass State Park, Joseph Whidbey State Park, and the Keystone Ferry terminal (Fig. 10).

Deception Pass State Park has areas of inundation in low topographic elevations, with inundation values above 1.5 m overtopping the West Beach

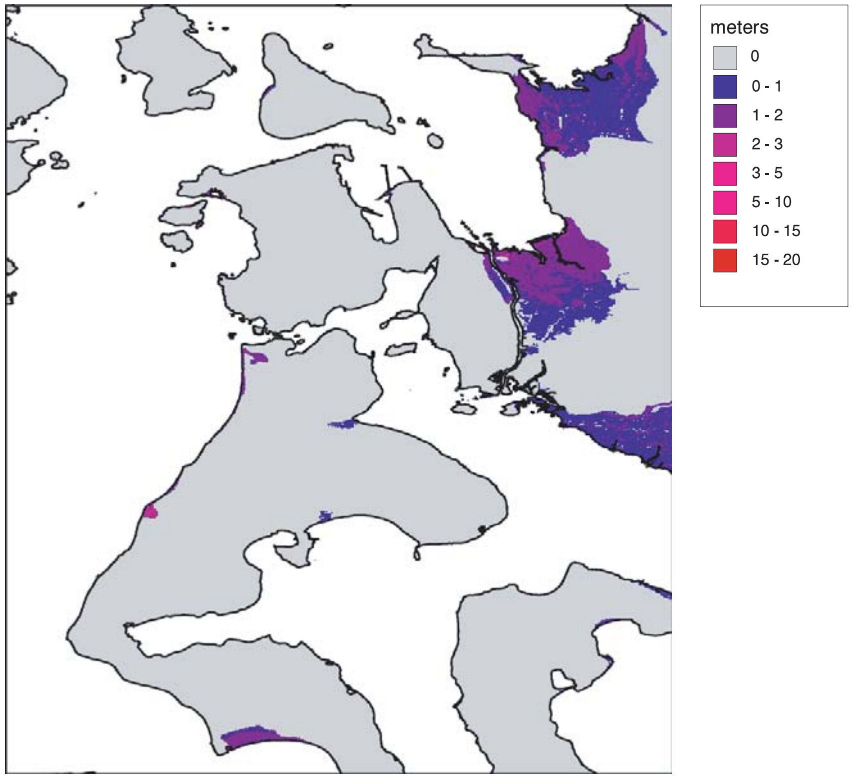

Figure 10: Maximum computed inundation depths (depth of water over land) for the Anacortes and Whidbey Island area at a resolution of 1 arc-second.

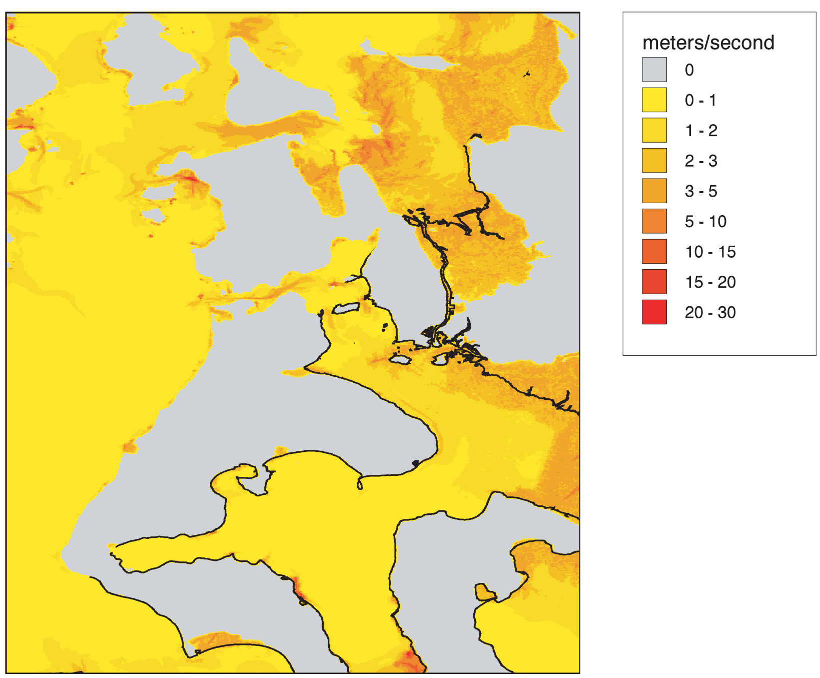

Figure 11: Maximum computed flow speed (m/s) for the Anacortes and Whidbey Island area at a resolution of 1 arc-second.

barrier of Cranberry Marsh. Flow speeds above 2 m/s occur within the shallow depths around West Point and into Deception Pass.

High inundation amplitudes (>2 m) with a landward extent ranging from 150 m to 850 m are also found at Swantown Marsh in Joseph Whidbey State Park, where flow speed above 4 m/s occur along the narrow beach barrier. Inundation covers the entire marsh area, which is approximately 0.4 sq km in size (Island County Public Works, 2002). Evidence of prehistoric tsunami, presumably from a Cascadia earthquake, has been found at these marshes by Williams and Hutchinson (2000). The locations of the discovered tsunami-transported sediments are within the area of the computed tsunami inundation. The sediments from the presumed Cascadia tsunami were found in several cores within 100 m from the shoreline. The landward extent of the modeled inundation is larger; this discrepancy may be attributed to several factors, including topographic data resolution and quality, and tidal level during the event. Also, lack of sediments in a limited amount of cores does not necessarily exclude the inundation of this area. In general, the model results for this location support the hypothesis of a Cascadia tsunami as the source of the Swantown Marsh sediments.

The same study at Swantown Marsh found no evidence of tsunami deposits corresponding to the 1700 Cascadia event (Williams and Hutchinson, 2000), which should have been comparable in size with the modeled event. Estimates from tide models for the time of the 1700 event at the Sunset Beach water-level station (a location just north of Swantown Marsh) show tides about 1 m below Mean High Water at the time of tsunami arrival (assuming the modeled 2-hour propagation time before the tsunami hits this area, Fig. 7). Hence, the computed amplitudes become only 1 m at this location, which make it too small to overcome the beach ridge.

The modeled tsunami also floods areas within the Keystone Harbor. Inundation amplitudes there reach 1.4 m above Mean High Water. High flow speeds (>3 m/s) occur in the immediate vicinity of the Keystone Ferry terminal (Fig. 11).

6. Summary

The described tsunami modeling project studied local inundation and propagation effects at the eastern Strait of Juan de Fuca for a tsunami originated on the Cascadia margin. The results of the study were used for the development of tsunami inundation maps for the area.

The main surprising result of the study is the extensive tsunami flooding at some areas of the eastern SJDF for a tsunami originated at the open ocean. A relatively narrow and long straight with numerous islands across its main body seemingly protect the inner shores of Washington from a tsunami wave propagating from the open ocean. Yet, the simulation results show that the tsunami wave not only preserved the amplitude during its propagation but also was additionally amplified at some east coast locations, especially at Bellingham Bay.

Given the surprisingly high amplitudes of the approaching waves, the inundation pattern of tsunamis with such amplitudes is expected. Long waves like tsunamis tend to flood the entire area below its shoreline amplitude. Over flat topography, such waves lose their energy via bottom friction and the inundation depths then slowly decrease over long penetration distances.

Many historical tsunamis demonstrated similar inundation patterns. The recent example of the 2001 Peru tsunami demonstrated up to 1 mile inland flooding over flat agricultural fields near Camána (Okal *et al.*, 2002). Similar settings at the deltas of the Nooksack and Lummi Rivers resulted in comparable model predictions of extensive tsunami flooding. Figures 8 and 9 show maximum computed inundation depths that illustrate those inundation patterns. It demonstrates the decrease of flow depths away from a shoreline for inundation at large flat areas such as the Nooksack and Lummi River deltas. Coastal dikes within the historic Skagit River delta region may slow inundation along the coastal areas of Samish Bay, Padilla Bay, and the Swinomish Channel; however, a height analysis of these manmade structures suggest that tsunami waves will overtop and/or breach many of the coastal dikes.

These modeling results are intended for development of the tsunami inundation maps and associated products for the regions of Bellingham, Anacortes, and northwest Whidbey Island. The numerical data provided to the Washington State officials were used in the creation of official inundation maps (Walsh *et al.*, 2004a,b). Appendix B lists all modeling products prepared as a result of this study.

7. Acknowledgments

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Appendix A: Bathymetry Data and Computational Grids

Procedure

The TIME Center has developed data grids for the Eastern Strait of Juan de Fuca inundation mapping project using the following five-step process:

1. Data Collection
2. Data Assessment
3. Grid Computation
4. Grid Assessment
5. Product Delivery

The best available bathymetric and topographic data were obtained from government agencies. These sources are listed in the next section. The data were reformatted and then analyzed for quality using ESRI© ArcGIS software. Datasets were converted to geographic coordinates and the North American Datum of 1927 at the modeler's request. Bathymetric data were then corrected from a vertical datum of Mean Lower Low Water (MLLW) to Mean High Water (MHW) using an averaged value of tidal data from National Ocean Service tertiary and secondary water level stations located within the region of interest (Fig. A1). These data are controlled by the Friday Harbor, San Juan Channel National Ocean Service primary water level station (station number 944-9880). The mean values were calculated by the National Ocean Service using the 1960–1978 tidal epoch throughout the grid region. This approximation is accurate to within ± 0.057 m along the region's shoreline (Table A1). Since the grids were built, the National Ocean Service has updated values to the 1983–2001 tidal epoch. The difference of mean values from the 1960–1978 epoch to the 1983–2001 epoch for this region is $+0.022$ m.

A coastline file was generated based on governmental data sources. The coastline represents the Mean High Water line as defined by the U.S. Geological Survey. Piers with open pile foundations were eliminated from the coastline data for inundation modeling purposes. Tsunami waves can freely propagate under open pile piers; therefore, the inundation is better modeled without those piers than as part of the reflective shoreline.

A combined bathymetric and topographic data grid was then generated using ArcGIS. Various datasets were combined using Triangulated Irregular

Table A1: Vertical control for grid development.

Datum	Value (meters)	Error (meters)
MHW	2.202	±0.057
NGVD29	0.810	±0.010
MLLW	0.000	

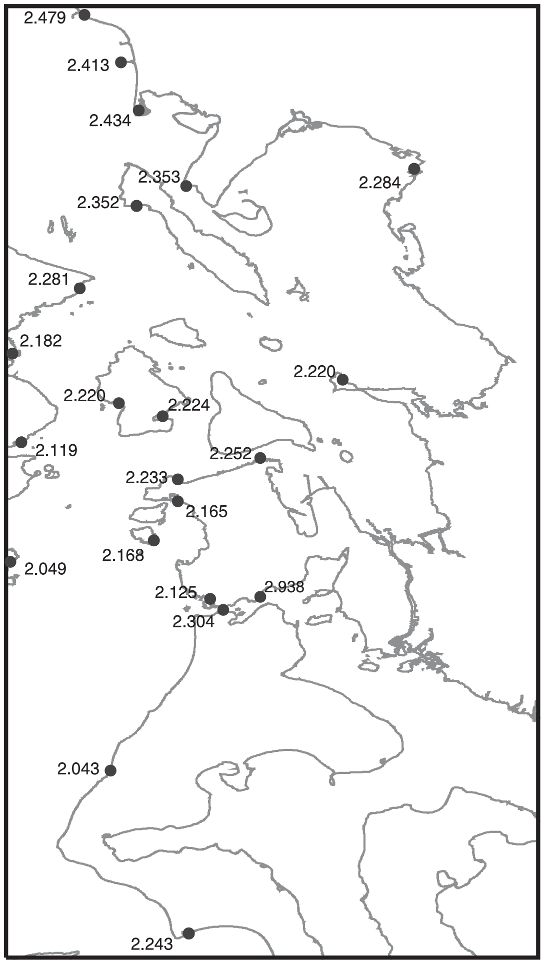

Figure A1: Tidal datum distribution of Bellingham, Anacortes, and Whidbey Island areas.

Network modeling. The results were converted into rectangular grids of 1-, 6-, and 36-arcsecond resolution (Table A2, Fig. A2).

The computed grids were analyzed for quality. Comparisons were made between the original datasets and the grids. Datums were verified, point errors were removed, and the grids were checked for logical consistency.

Data Sources

The data sources for the grids are described in Table A3. The resolution of each data source varied; data sources for the highest resolution grid ranged from approximately 1–30 m. Many sources were in different formats, which may lead to a small conversion error. The vertical accuracy of the data is based on the root mean square error, approximately 5% of depth for bathymetry and one-half of the contour interval for topography. Grid accuracy is

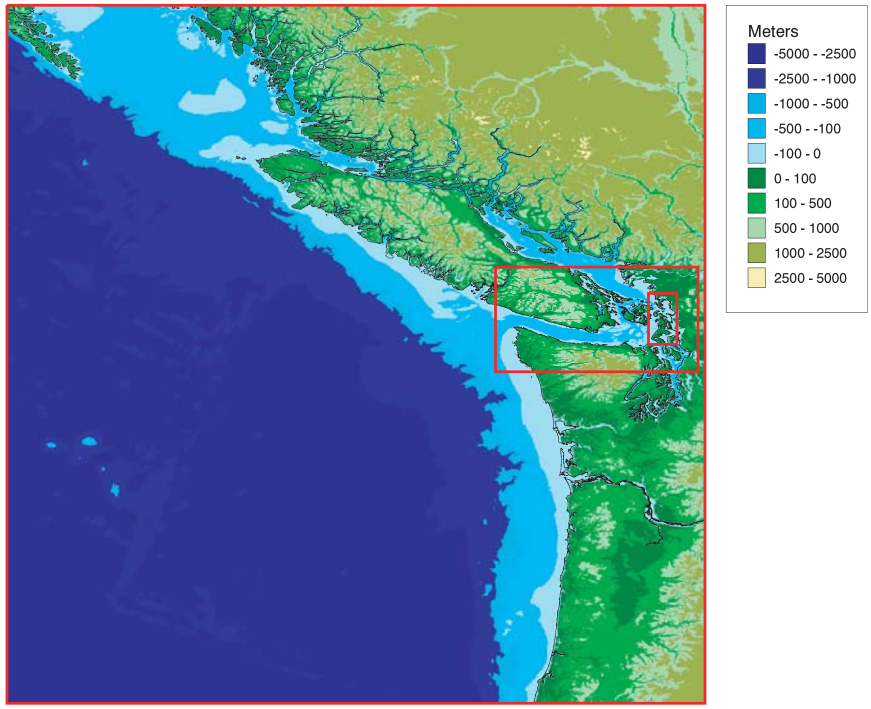

Figure A2: Digital Elevation Models for modeling propagation in the Strait of Juan de Fuca and inundation in the Bellingham, Anacortes, and Whidbey Island areas.

Table A2: Grid summary.

Region	Name	Resolution	Extents (SW and NE corners)
Cascadia Subduction Zone	sjdf36	36 arc-seconds	SW: −132.00, 43.00 NE: −122.00, 53.00
Eastern Strait of Juan de Fuca	sjdf6	6 arc-seconds	SW: −125.00, 47.75 NE: −122.10, 49.25
Bellingham, Anacortes, and Whidbey Island	sjdf1	1 arc-second	SW: −122.81, 48.14 NE: −122.40, 48.87

based on the level of detail of the source and the grid interval used to sample the source.

The data sources used for the grids are credited to the following groups:

- National Oceanic and Atmospheric Administration, National Geodetic Database Centers. Hydrographic Surveys, GEODAS Version 4.1 Software. Boulder, Colorado. Website reference: `http://www.ngdc.noaa.gov/mgg/bathymetry/relief.html`

- National Oceanic and Atmospheric Administration, National Ocean Service. NOS Estuarine Bathymetry. Silver Spring, Maryland. Website reference: `http://mapfinder.nos.noaa.gov/`

Table A3: Data sources used for grid development.

Media Source	Media	Data	Description
National Ocean Service (NOS)	Digital Elevation Model	30-meter NOS bathymetric digital elevation model	Quality-controlled bathymetric data grid based on 1934–1982 NOS hydrographic surveys
National Geophysical Data Center (NGDC)	CD-ROM (GEODAS Version 4.1)	NOS Hydrographic Surveys	Bathymetric data from 1982–1998 NOS hydrographic survey
Canadian Hydrographic Service	Point Data	Hydrographic Surveys	Bathymetric data from 1999 hydrographic surveys
USGS Open File Report OF99-369	ArcInfo Grid	250K digital elevation model	Bathymetric and topographic data from various sources
University of Washington PRISM Project	ArcInfo Grid	10-meter topographic digital elevation model	Topographic data obtained from the U.S. Geological Survey
City of Bellingham	ArcView shapefiles	5-foot topographic contours of Bellingham	Topographic data obtained from aerial photography collected in 1988
City of Anacortes	CAD drawing	10-foot topographic contours of Anacortes	Topographic data obtained from aerial photography collected in 2001

- U.S. Geological Society, Western Region Geology. Open File Report OF99-369 Cascadia DEM. Seattle, Washington. Website reference: `http://geopubs.wr.usgs.gov/open-file/of99-369/`

- Washington State Geospatial Data Archive, University of Washington. U.S. Geological Survey 10-meter Digital Elevation Model. Seattle, Washington. Website reference: `http://duff.geology.washington.edu/data/raster/tenmeter/`

- City of Bellingham, Planning Department. City of Bellingham Topographic Contours. Anacortes, Washington. Website reference: `http://www.cob.org/planning/`

- City of Anacortes, Public Works. City of Anacortes Topographic Contours. Anacortes, Washington. Website reference: `http://www.cityofanacortes.org/`

- National Oceanic and Atmospheric Administration, Center for Operational Oceanographic Products and Services, Water Level Station Information for Seattle, Washington. Silver Spring, Maryland. Website reference: `http://www.co-ops.nos.noaa.gov/`

- Information about ESRI ArcGIS software can be found on the Internet at `http://www.esri.com/`

Appendix B: Modeling Products

Animations, screenshots, time series, GIS files, metadata, and user documentation were developed for distribution to the Washington State Division of Geology and Earth Resources and the Washington State Military Department Emergency Management Division. The Washington State Military Department Emergency Management Division is responsible for redistribution of these products.

An overview of products are listed in Table B1. All vector files and raster grids are in the ESRI ArcGIS 3.2 format and have the following parameters:

- Horizontal Datum: North American Datum of 1983
- Vertical Datum: Mean High Water
- Projection: State Plane Coordinate System, Zone 5626
- XY Units: feet
- Z Units: meters (meters/second for current speeds)

The vector files and raster grids have an associated jpeg image and are displayed in an ArcGIS 3.2a project for easy access and distribution. The animations are in QuickTime format.

Table B1: Product summary.

Item	Name	Filename	Type	Image
1	Time Series	bell_timeseries wdb_timeseries	ASCII	bell_timeseries.jpg wdb_timeseries.jpg
2	Animations	bell_qt1, bell_qt2, whidb_qt	QT	bell_screenshots sjdf_screenshots
3	User Documentation	Bellingham presentation, Product Report, Grid Report		
4	Grid Limits	limits	vector	sjdfgrids.jpg
5	Shoreline	shoreline	vector	sjdfgrids.jpg
6	Elevation Grids (36-, 6-, 1-arcsecond)	sjdf1, sjdf6, sjdf36	raster	sjdfgrids.jpg
7	Source Deformation (Scenario 1A)	src1a	raster	sjdfdef.jpg
8	Water Level Stations for Tidal Datums	tides	vector	sjdfvdatum.jpg
9	Maximum Inundation Lines	ainun, binun	vector	ainun.jpg, binun.jpg
10	Maximum Inundation Depths and Zones	amaxd, bmaxd	raster	amaxd.jpg, amaxdz.jpg bmaxd.jpg, bmaxdz.jpg
11	Maximum Current Speeds and Zones	amaxu, bmaxu	raster	amaxu.jpg, amaxuz.jpg bmaxu.jpg, bmaxuz.jpg
12	Maximum Wave Heights	amaxh, bmaxh	raster	amaxh.jpg, bmaxh.jpg
13	Time Series Gages	agages, bgages	vector	agages.jpg, bgages.jpg