DEVELOPMENT OF A TSUNAMI FORECAST MODEL FOR SEWARD, ALASKA

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DRAFT

Contents

Abstract 6
1.0 Background and Objectives 6
2.0 Forecast Methodology 7
2.1 Study Area – context 7
2.2 Historical Events 8
2.3 Tide gauges/Water level data 8
2.3 Bathymetry and Topography 9
2.4 Model Setup 9
3.0 Results 11
3.1 Model Validation 11
3.2 Results of tested event 11
3.2.3 1964 Great Alaska Tsunami 12
3.2.3 1996 Andreanov Tsunami 14
3.3 Model stability and reliability 15
3.3.1 Artificial 9.5 Mw Tsunami 15
4.0 Summary 18
5.0 References 18
6.0 Appendix A – Bathymetry and topography 20
7.0 Appendix B 22
7.1 SIM .in files for Seward, AK 22
8.0 Appendix B 23

List of Tables

Table 1 Seward, Alaska grid bathymetry/topography characteristics 10

Table 2 SIM and RIM parameters for Seward, Alaska.....10

Table 3 Historical events simulated to validate the Seward, AK SIM and RIM. 11

Table 4 Events used to test the Seward SIM using SIFT 3.0.....25

List of Figures

Figure 1 Seward, Alaska context map 8

Figure 2 Maximum elevations in cms of Reference SIM at Seward for the 1964 Alaska tsunami. 12

Figure 3 Maximum elevations in cms Optimized SIM at Seward for the 1964 Alaska tsunami. 13

Figure 4 Maximum elevation in cms of the Optimized SIM at Seward for the Andreanov tsunami. 14

Figure 5 Maximum elevations in cms of Reference SIM for Seward for an artificial 9.5 Mw tsunami event originating in the Alaska Subduction zone.....16

Figure 6 Maximum elevations in cms of Optimized SIM for Seward for an artificial 9.5 Mw tsunami event originating in the Alaska Subduction zone.....17

Figure 7 Bathymetric differences for the Reference SIMS at Seward, Alaska. 20

Figure 8 Bathymetric differences for the Optimized SIMs at Seward, Alaska.....21

Figure 9 Propagation forecast for the 1946 Alaska tsunami used to test the Seward, AK SIM in SIFT 3.0. 24

Figure 10 Water level times series for the 1946 Alaska tsunami at the Seward, AK warning point. 25

Figure 11 Inundation Forecast for Seward, AK SIM A Grid for the 1946 Alaska tsunami. 26

Figure 12 Inundation Forecast for Seward, AK SIM B Grid for the 1946 Alaska tsunami. 27

Figure 13 Inundation Forecast for Seward, AK SIM C Grid for the 1946 Alaska tsunami. 28

Figure 14 Propagation forecast for a synthetic 8.1 Mw from an Indonesia source to test the Seward, AK SIM in SIFT 3.0. 29

Figure 15 Water level times series for a synthetic 8.1 Mw Indonesian event at the Seward, AK warning point. 30

Figure 16 Inundation Forecast for Seward, AK SIM A Grid for the synthetic 8.1 Mw Indonesian event. 31

Figure 17 Inundation Forecast for Seward, AK SIM B Grid for the synthetic 8.1 Mw Indonesian event. 32

Figure 18 Inundation Forecast for Seward, AK SIM C Grid for the synthetic 8.1 Mw Indonesian event. 33

Figure 19 Propagation forecast for a synthetic 9.3 Mw from an Alaska near field event to test the Seward, AK SIM in SIFT 3.0.....34

Figure 20 Water level times series for a synthetic 9.3 Mw from an Alaska near field event at the Seward, AK warning point. 35

Figure 21 Inundation Forecast for Seward, AK SIM A Grid for the synthetic 9.3 Mw Alaska near field event. 36

Figure 22 Inundation Forecast for Seward, AK SIM B Grid for the synthetic 9.3 Mw Alaska near field event. 37

Figure 23 Inundation Forecast for Seward, AK SIM C Grid for the synthetic 9.3 Mw Alaska near field event. 38

Development of a Tsunami Forecast Model for Seward, Alaska

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Abstract

This study addresses the development, validation and stability tests of the tsunami forecast model for Seward, Alaska. Based on the Method of Splitting Tsunamis (MOST), the model is constructed at a resolution of 40 m to enable a 4.0 hour simulation of wave inundation onto dry land. A reference model was developed in parallel using higher resolution grids (40 m) to provide modeling references for the forecast model. With the lack of historical tide gauge data for the Seward area, SIMs and RIMs were developed using synthetic data to simulate the run up values noted during the 1964 and 1996 tsunamis. A larger magnitude megatsunami event (Mw 9.5) was simulated to test the stability and sensitivity of the Seward SIM and remained stable during the simulation. Additional testing of the Seward SIM was completed with Desktop SIFT and found that a near field source (Alaska-Cascade) would greatly impact the Seward region and additionally, earthquake sources from near Indonesia have a lesser impact on the SIM.

1.0 Background and Objectives

An efficient tsunami forecast system provides timely basin-wide warning of in-progress tsunami waves accurately and quickly (Titov et al., 2005). NOAA's Short-term Inundation Forecast of Tsunami (SIFT) is an advanced tsunami forecasting system that combines real-time tsunami event data with numerical models to produce estimates of tsunami wave arrival times and amplitudes. The SIFT system integrates several key components: the tsunameters for real-time monitoring of tsunami signals in the deep ocean, a basin-wide pre-computed propagation database of water level and flow velocities based on potential seismic unit sources, an inversion algorithm to derive the tsunami source based on the tsunameter observations during a tsunami event, and the Stand-by Inundation Models (SIMs) to provide accurate and speedy numerical modeling of tsunami impact for coastal communities. A SIM is used to create the forecast model to provide an estimate of wave arrival time, wave height, and inundation immediately after a tsunami event. Tsunami forecast models are run in real time while a tsunami is propagating in the open ocean, consequently they are designed to perform under very stringent time limitations. The Stand-by Inundation Model (SIM), based on the Method of Splitting Tsunami (MOST), emerges as the solution in SIFT by forecasting real-time tsunami in minutes while employing high resolution grids. Each SIM consists of three telescoped grids with increasing spatial resolution, and temporal resolution for simulation of wave inundation onto dry land.

The SIM utilizes the most recent bathymetry and topography available to reproduce the correct wave dynamics during the inundation computation. SIMs are constructed for populous coastal communities at risk for tsunamis in the Pacific, Atlantic and Caribbean. Previous and present development of SIM in the Pacific (Titov et al., 2005; Titov, 2009; Tang et al., 2008; Wei et al., 2008) has shown the accuracy and efficiency of the up-to-date SIMs implemented in SIFT in the real-time tsunami forecast, as well as in hindcast research.

This report describes the development and testing of a reference and forecast inundation model for Yakutat, Alaska. The forecast model will be incorporated into the U.S. tsunami warning system for use at the Pacific and West Coast-Alaska Tsunami Warning Center. Synolakis et al. (2007) and Tang et al. (2008) describe the technical aspects of SIM development, stability testing and robustness.

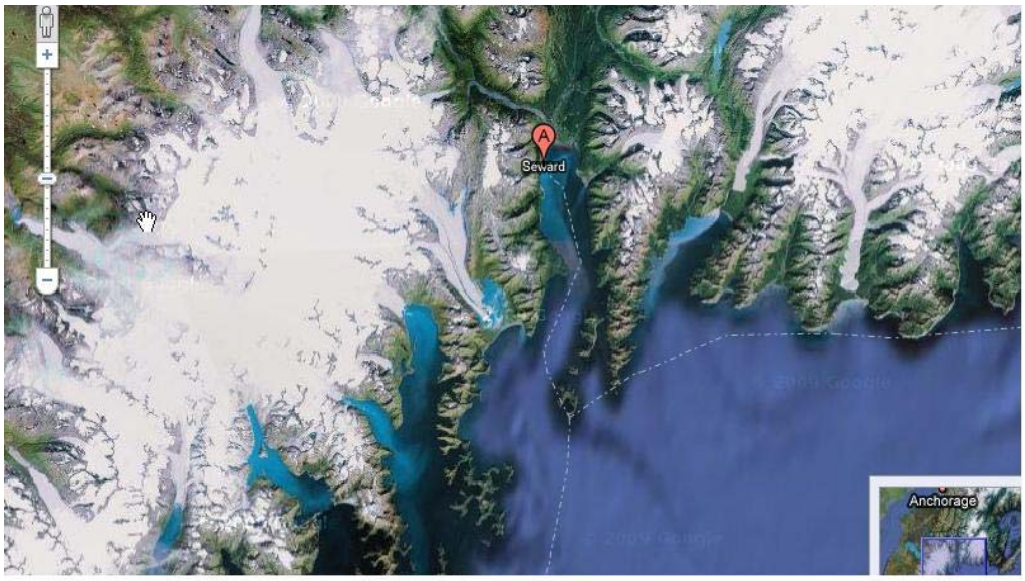
2.0 Forecast Methodology

The methodology for modeling these coastal areas is to develop a set of three nested grids (A, B, C), each of which is successively finer in resolution, until the near-shore details can be resolved to the point that tide gauge data from historical tsunamis in the area match reasonably with the modeled results. The procedure is to start with high resolution large spatial extent grids referred to as the reference SIM and then after a reasonable data fit is achieved to optimize the grids by coarsening the resolution and shrinking the domain until the model runs in under 10 minutes of wall clock time. At this time, the significant portion of the modeled tsunami waves typically 4 to 10 hr of modeled tsunami time has passed through the model domain without too much signal degradation. This final model is referred to as the "optimized SIM" or forecast model.

2.1 Study Area – context

Seward is located on Resurrection Bay on the Kenai Peninsula of Alaska. It is approximately 125 miles to the south of Anchorage. According the 2000 US census, the population of Seward is approximately 3016. The city itself is approximately 21.5 square miles. The population density of Seward is 196 persons per square mile. Seward is home to a busy fishing port as well as serving seasonal Alaska cruise ship visitors. Unlike many coastal communities in Alaska, Seward is accessible by many means –including boat, seaplane, railroad, bus and automobile. Its location and proximity to the railroad make it the terminus of many leisure cruises and the tourist population increases during the summer months. The Seward harbor remains ice free all year round, making it a critical supply center for the interior of Alaska.

Figure 1 Seward, Alaska context map



2.2 Historical Events

There are no existing historical tide gauge records for Seward. The NGDC tsunami runup database noted several instances of minor tsunami runup events in the 20th century. The most significant events include the 1946 Unimak earthquake and a 8.3m max water height noted for the 1964 Alaska earthquake (http://www.ngdc.noaa.gov/hazard/tsu_db.shtmllast accessed April 14, 2009).

2.3 Tide gauges/Water level data

A tide gauge was established at Seward in 1925. The current tide gauge was installed in 1989. The GPS verified location of the tide gauge is 60.12 N and 149.42666 W. The recorded mean range at Seward is 8.33 feet and the diurnal range is 10.62 feet. Mean sea level is 11.70 feet.

2.3 Bathymetry and Topography

Accurate bathymetry and topography are crucial inputs to developing the reference and stand by models, especially in for the inundation of the near shore environment. To develop each grid, we attempt to gather and use the best available data for the area studied. Grids may be updated if newer more accurate data is available. Grids are made available in the ESRI ArcGIS raster format. Additionally, all data were converted to the WGS 84 vertical datum.

Eight, three, one and one third arc second merged bathymetry and topography data built by NCTR were used to create the grids used for building the RIMs and SIMs for Seward. Plots of the modified bathymetry files for the reference and the optimized grids are located in Appendix A (Figures 7 and 8). The SIM C grid shows little difference between the original the modified bathymetry values.

2.4 Model Setup

The model used to estimate tsunami amplitude is the MOST model (Titov and Gonzalez 1997, Tang et. al 2006) which is a finite difference method of characteristic model which takes input from a propagation run data base and then, via a series of nested grids, resolves the near shore bathymetry and topography to estimate the water level at coastal sites. Adjustable parameters include: time step, number of time steps, near shore wet/dry boundary depth, coarse grid wet/dry boundary depth, run down or not in coarse grids friction coefficient, output time, grid size, grid resolution and grid position.

Once tested these parameters remain fixed from run to run, under the assumption that the parameters may be location dependent with features such as sharp bathymetric changes, high resolution needed for channels, sand bars, but should not depend on the flow field of the particular tsunami being modeled.

For Seward, the grid resolution and extents for the reference and optimized grids are given in Table 1. Figures of the model extents for reference and optimized grids are found in the attached Appendix A (Figures 7 and 8). These grid parameters are not unique to the stand by inundation model and could be modified considerably as the results indicate. They are sufficient to show that the model reproduces historical tsunami, and that the model is stable enough with these grids to handle a large tsunami simulation.

Grid	Ref Res (“)	RIM bathy/topo extent Lat [°N] Long [°W]	Resolution (“)	SIM bathy/topo extent Lat [°N] Long [°W]
A	48	62.00-55.00 156.00-146.00	120	60.5-55.5 155.00-147.00
B	6	60.25-59.85 149.5-149.25	9	60.25-59.75 149.5-149.25
C	1	60.16-60.04 149.5-149.3	3	60.16-60.04 149.46-149.3

Table 1 Seward, Alaska grid bathymetry/topography characteristics

Grid	Region	Reference Inundation Model (RIM)				Stand-by Inundation Model (SIM)		
		Coverage	Cell	Time		Coverage	Cell	Time
		Lat. [°N]	Size	Step		Lat. [°N]	Size	Step
		Lon. [°W]	["]	[sec]		Lon. [°W]	["]	[sec]
A	Blying Sound	62.00-55.00 156.00-146.00	48	0.8		155-147 60.5-55.5	120	1.1
B	Resurrection Bay	60.25-59.85 149.5-149.25	6	1.6		60.25-59.75 149.5-149.25	9	2.2
C	Seward	60.16-60.04 149.5-149.3	1	4		60.16-60.04 149.46-149.3	**3**	8.8
Minimum offshore depth [m]			1			1		
Water depth for dry land [m]			0.1			0.1		
Manning coefficient			0.0009			0.0009		
CPU time for a 4-hour simulation			103 minutes			3.55 minutes		

Table 2 SIM and RIM parameters for Seward, Alaska

3.0 Results

3.1 Model Validation

Since no historical gauge records exist for Seward, the model was validated using data simulating the 1964 tsunami event records of tsunami run up estimated to be approximately 8.3 meters as referenced in the National Geophysical Data Center tsunami run up database.

Table 3 lists the events that were simulated for model validation testing for Seward, Alaska.

Event	Time (UTC)	Zone	M_w	Lat	Lon	Source
Andreanof	1996.06.10 04:03:35.4	AASZ	7.8	51.478N	176.847E	2.4×a15+0.8×b16
Kuril	1994.10.04 13:22:58.3	KISZ	8.1	43.706N	147.328E	9.0×a20
Alaska	1964.03.28 03:36:14	AASZ	9.0	61.04N	147.73W	Tang et al.

Table 3 Historical events simulated to validate the Seward, AK SIM and RIM.

3.2 Results of tested event

3.2.1 1964 Alaska simulation

Figure 2 shows that run-up to almost 10m in both the optimized and reference runs for the 1964 event, which is higher than the recorded tsunami estimates as noted in the NGDC database.

3.2.3 1964 Great Alaska Tsunami

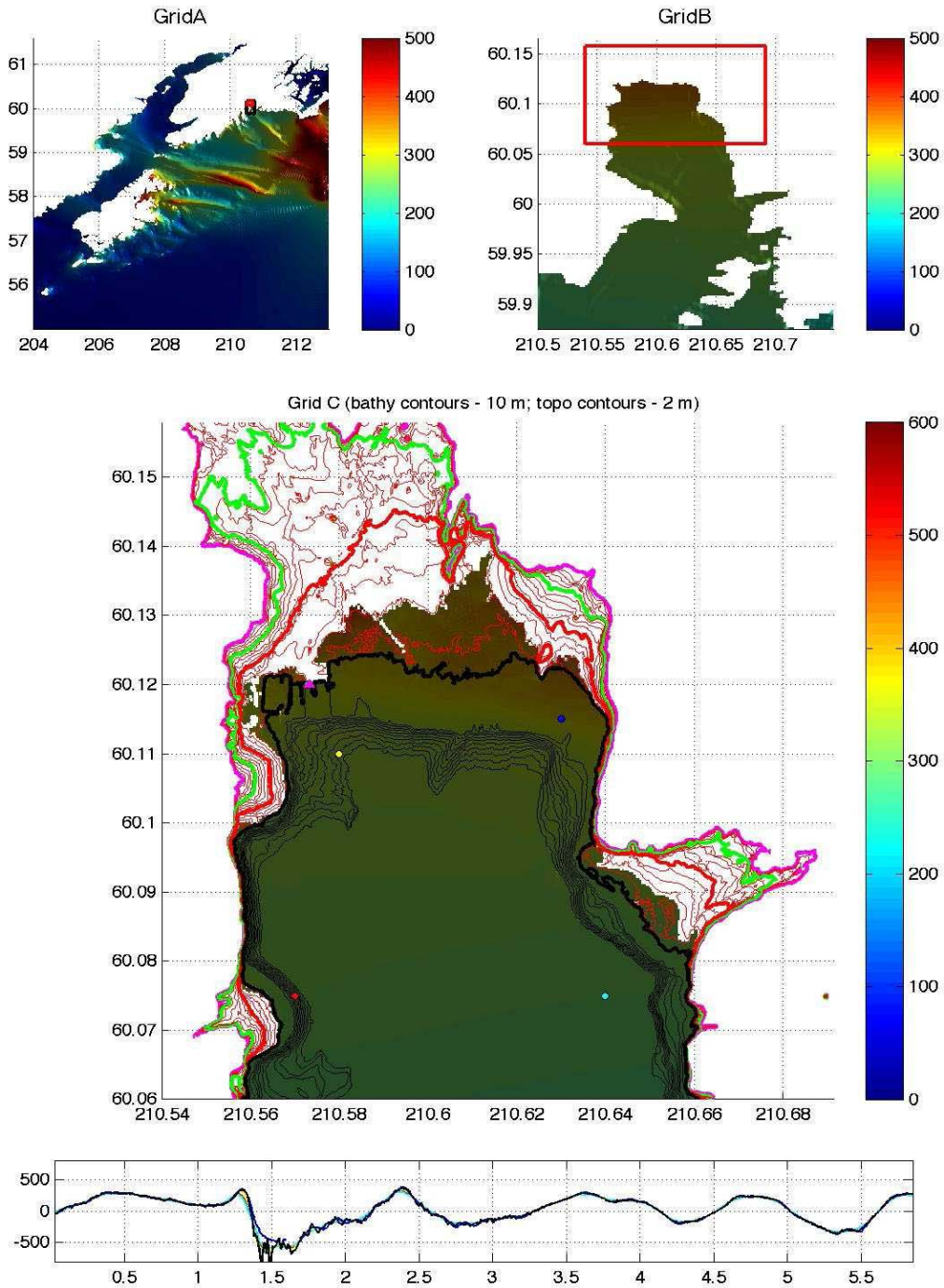


Figure 2 Maximum elevations in cms of Reference SIM at Seward for the 1964 Alaska tsunami. Maximum elevation (in cms) at the 3 grids for the Optimized runs and time series (bottom graph) at specific locations in grid C (black line in the time series corresponds to the physical gauge location denoted by the magenta triangle in the grid C plot). Time is in hours and elevation in cms. In the grid C plot bathymetric contours are denoted by thin black lines and topographic contours by thin red lines. The 0, 10 m, 20 m and 30 m contours are denoted by the thick black, red, green and magenta lines respectively

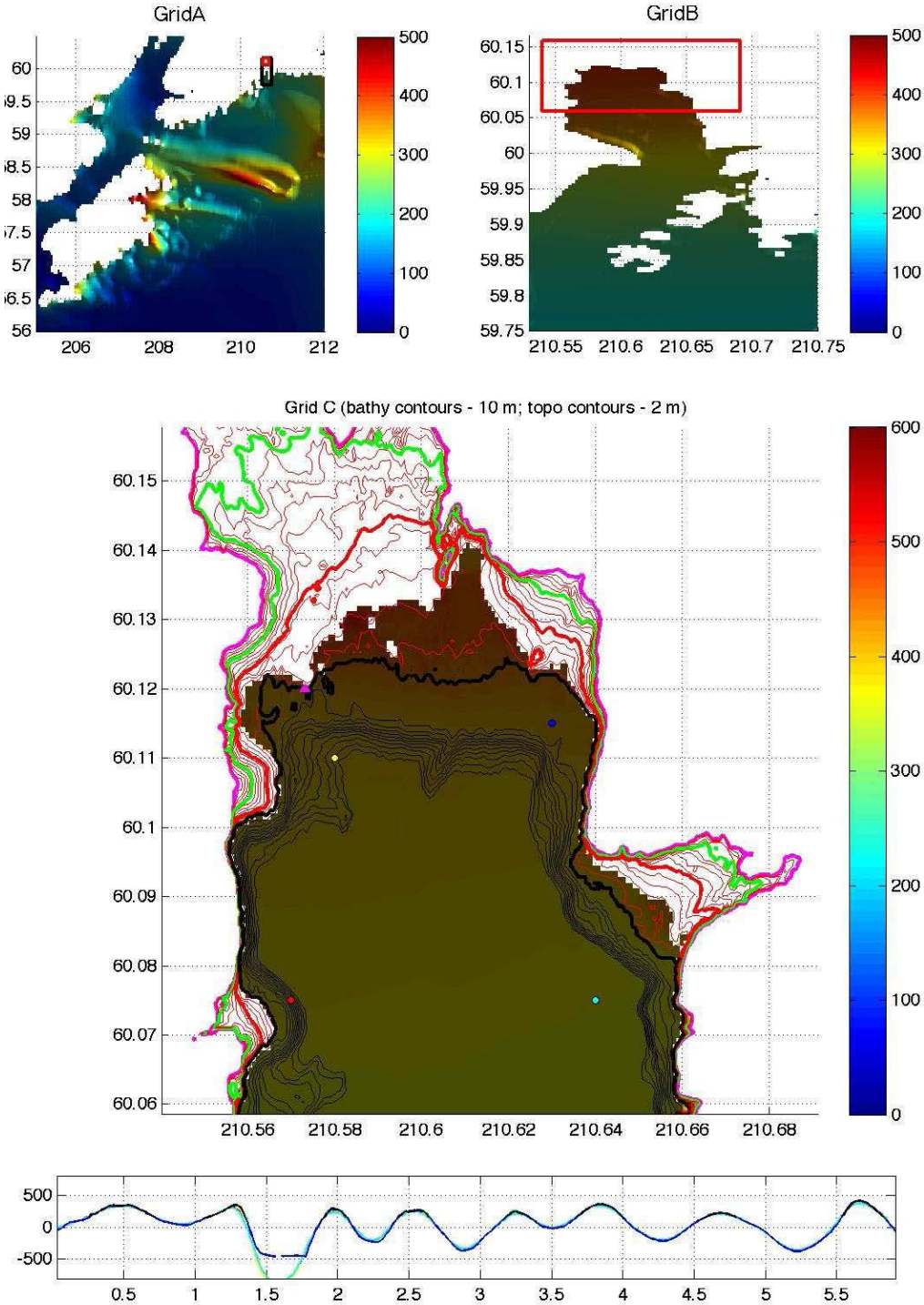


Figure 3 Maximum elevations in cms Optimized SIM at Seward for the 1964 Alaska tsunami. Maximum elevation (in cms) at the 3 grids for the Optimized runs and time series (bottom graph) at specific locations in grid C (black line in the time series corresponds to the physical gauge location denoted by the magenta triangle in the grid C plot). Time is in hours and elevation in cms. In the grid C plot bathymetric contours are denoted by thin black lines and topographic contours by thin red lines. The 0, 10 m, 20 m and 30 m contours are denoted by the thick black, red, green and magenta lines respectively

3.2.3 1996 Andreanov Tsunami

The 1996 Andreanov event was simulated to test the Optimized SIMs for Seward. (Figure 4) The plots show that there was no signal at Seward, which is consistent with the event at those locations.

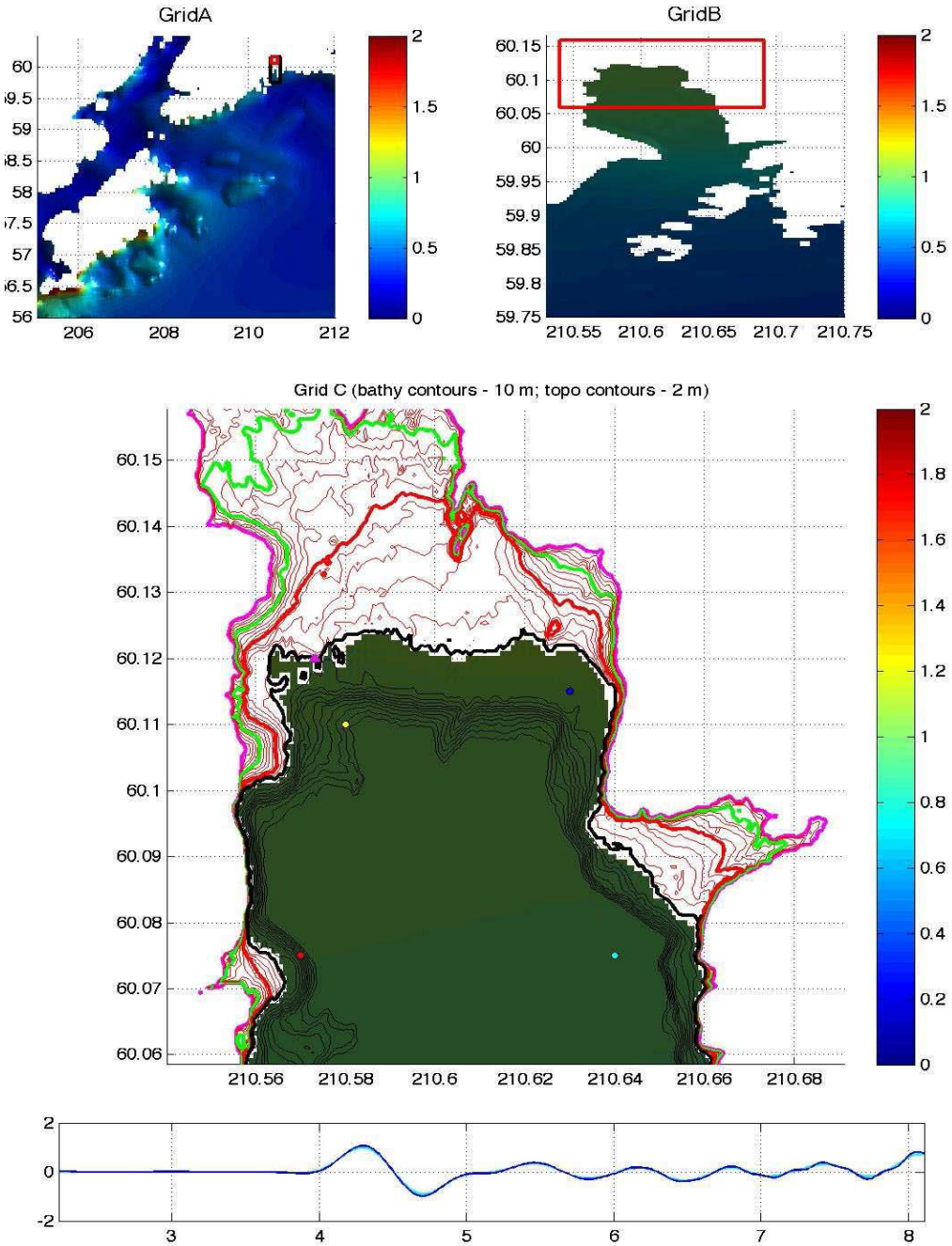


Figure 4 Maximum elevation in cms of the Optimized SIM at Seward for the Andreanov tsunami. Maximum elevation (in cms) at the 3 grids for the Optimized runs and time series (bottom graph) at specific locations in grid C (black line in the time series corresponds to the physical gauge location denoted by the magenta triangle in the grid C plot). Time is in hours and elevation in cms. In the grid C plot bathymetric contours are denoted by thin black lines and topographic contours by thin red lines. The 0, 10 m, 20 m and 30 m contours are denoted by the thick black, red, green and magenta lines respectively

3.3 Model stability and reliability

3.3.1 Artificial 9.5 Mw Tsunami

A large artificial tsunami equivalent to a 9.5 Mw earthquake originating in the Alaska subduction zone was simulated outside the B grid region to examine the pattern of run up in the Seward area as well as to indicate the stability of the model for potential large events. In general; each simulated earthquake tested uses 20 unit sources a propagation database developed by NCTR (Gica et al. 2008). The testing of the hypothetical events uses 20 sources in 10 pairs matched pairs with an uniform slip of 29 m. (Tang et. al 2008)

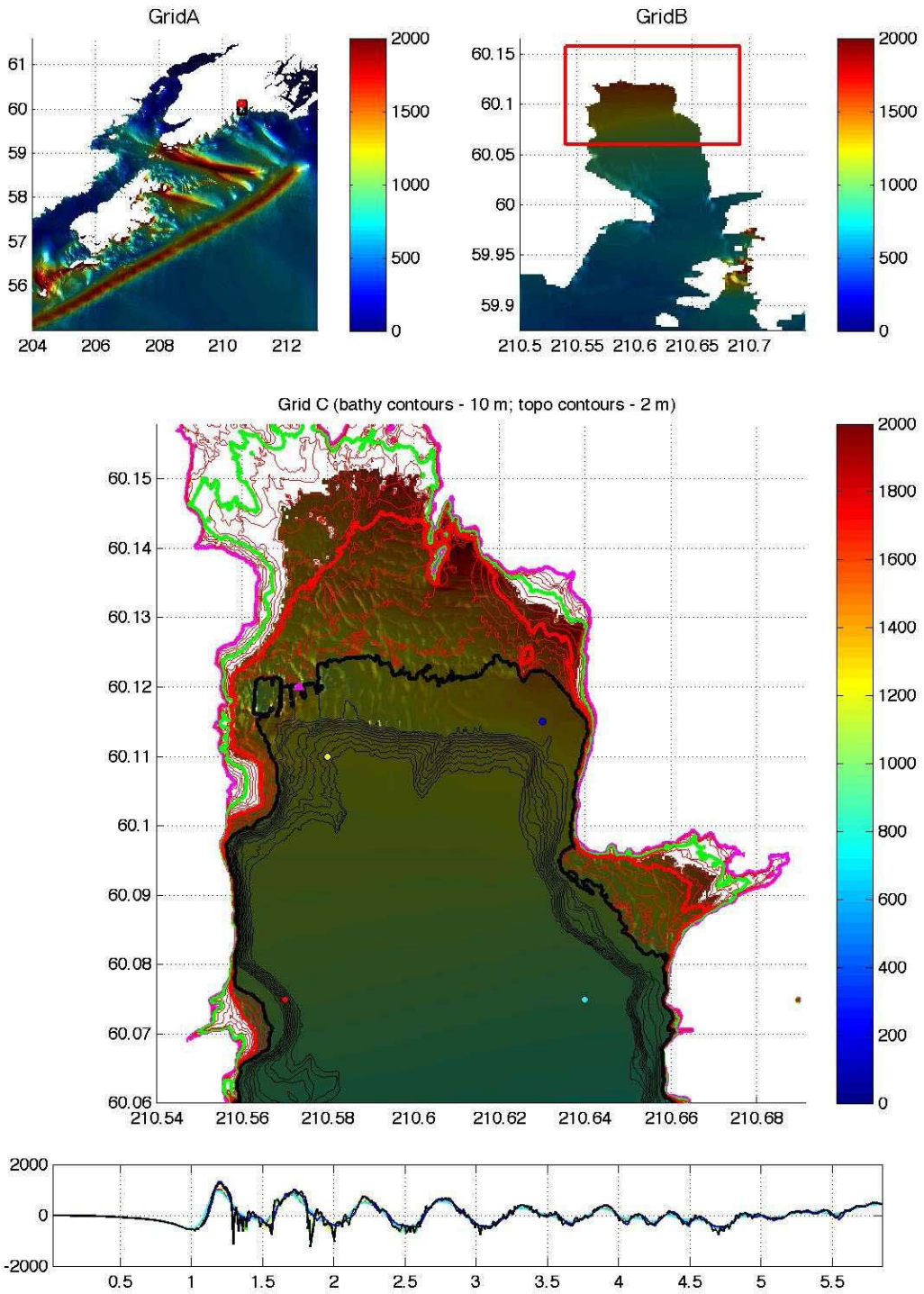


Figure 5 Maximum elevations in cms of Reference SIM for Seward for an artificial 9.5 Mw tsunami event originating in the Alaska Subduction zone. Maximum elevation (in cms) at the 3 grids for the Optimized runs and time series (bottom graph) at specific locations in grid C (black line in the time series corresponds to the physical gauge location denoted by the magenta triangle in the grid C plot). Time is in hours and elevation in cms. In the grid C plot bathymetric contours are denoted by thin black lines and topographic contours by thin red lines. The 0, 10 m, 20 m and 30 m contours are denoted by the thick black, red, green and magenta lines respectively

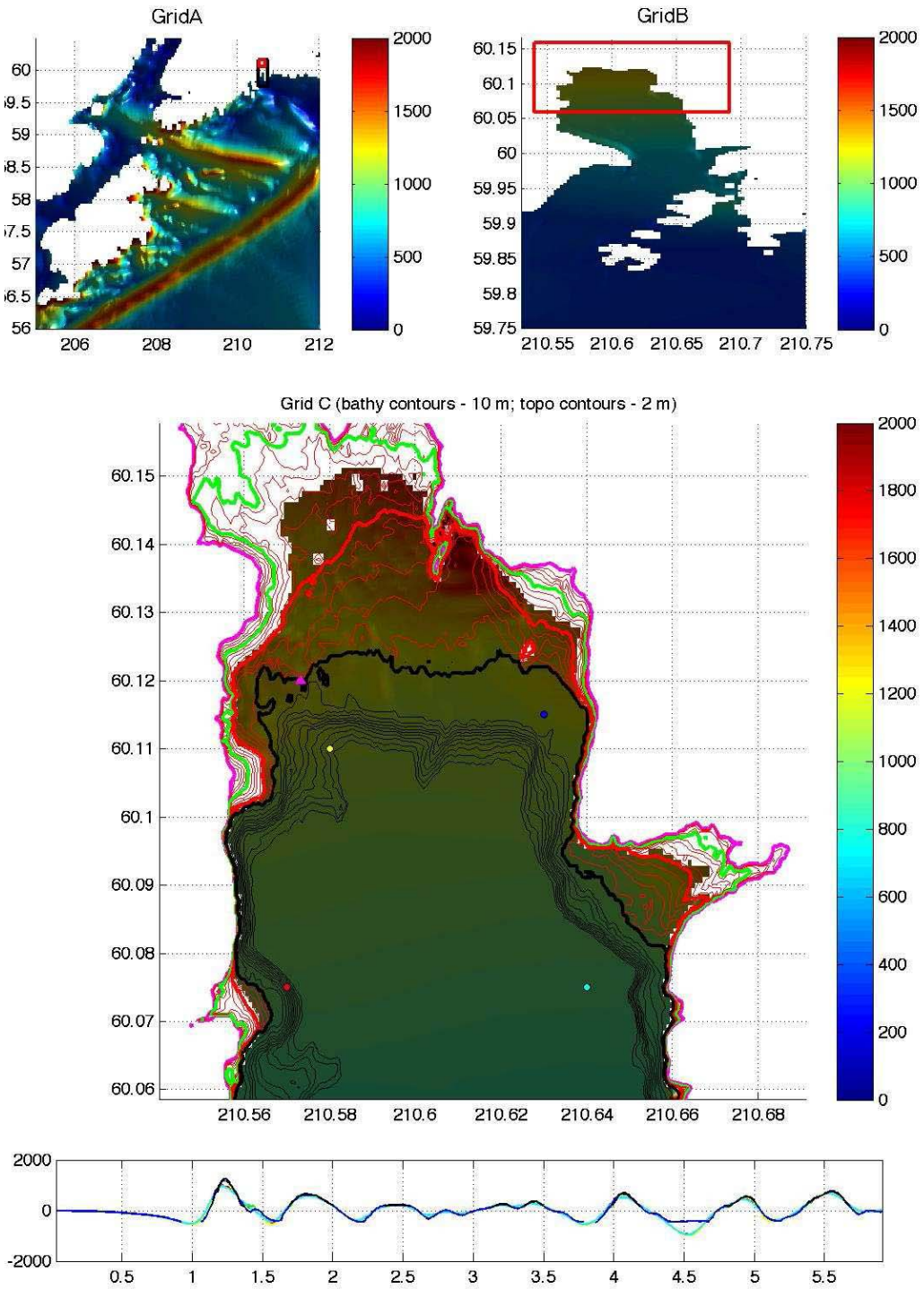


Figure 6 Maximum elevations in cms of Optimized SIM for Seward for an artificial 9.5 Mw tsunami event originating in the Alaska Subduction zone. Maximum elevation (in cms) at the 3 grids for the Optimized runs and time series (bottom graph) at specific locations in grid C (black line in the time series corresponds to the physical gauge location denoted by the magenta triangle in the grid C plot). Time is in hours and elevation in cms. In the grid C plot bathymetric contours are denoted by thin black lines and topographic contours by thin red lines. The 0, 10 m, 20 m and 30 m contours are denoted by the thick black, red, green and magenta lines respectively

4.0 Summary

A SIM and RIM developed and tested for Seward, Alaska demonstrated a good level of fit with simulated data for two historical events – the 1964 Alaska tsunami and the 1996 Andreanov events. In the case of the 1964 tsunami, wave heights matched closely with what was recorded. Synthetic events tested using the Alaska Subduction Zone sources demonstrated that wave heights in excess of 15 m would inundate the C grid. Results Desktop SIFT testing with one historical event -1946 Alaska tsunami showed that very little inundation occurs in the C grid. Far field tsunami sources also yielded very little impact on the Seward area, however a near field tsunami from near Kodiak Island would greatly impact the Seward area.

5.0 References

http://www.ngdc.noaa.gov/hazard/tsu_db.shtml (last accessed April 14, 2009)

http://explorenorth.com/alaska/history/seward-history.html (last accessed April 14, 2009)

http://en.wikipedia.org/wiki/Seward,Alaska(last accessed April 14,2009)

Gica, E., M. Spillane, V.V. Titov, C. Chamberlin, and J.C. Newman (2008): Development of the forecast propagation database for NOAA's Short-term Inundation Forecast for Tsunamis (SIFT). NOAA Tech. Memo. OAR PMEL-139, 89 pp

Synolakis, C.E., E.N. Bernard, V.V. Titov, U. Kânoğlu, and F.I. González (2007): Standards, criteria, and procedures for NOAA evaluation of tsunami numerical models. NOAA Tech. Memo. OAR PMEL-135, NOAA/Pacific Marine Environmental Laboratory, Seattle, WA, 55 pp

Tang, L., C. Chamberlin, and V.V. Titov (2008): Developing tsunami forecast inundation models for Hawaii: Procedures and testing. NOAA Tech. Memo. OAR PMEL-141, 46 pp

Tang, L., C. Chamberlin, E. Tolkova, M. Spillane, V.V. Titov, E.N. Bernard, and H.O. Mofjeld (2006): Assessment of potential tsunami impact for Pearl Harbor, Hawaii. NOAA Tech. Memo. OAR PMEL.

Titov, V., and F.I. González (1997): Implementation and testing of the Method of Splitting Tsunami (MOST) model. NOAA Tech. Memo. ERL PMEL-112 (PB98-122773), NOAA/Pacific Marine Environmental Laboratory, Seattle, WA, 11 pp.

6.0 Appendix A – Bathymetry and topography

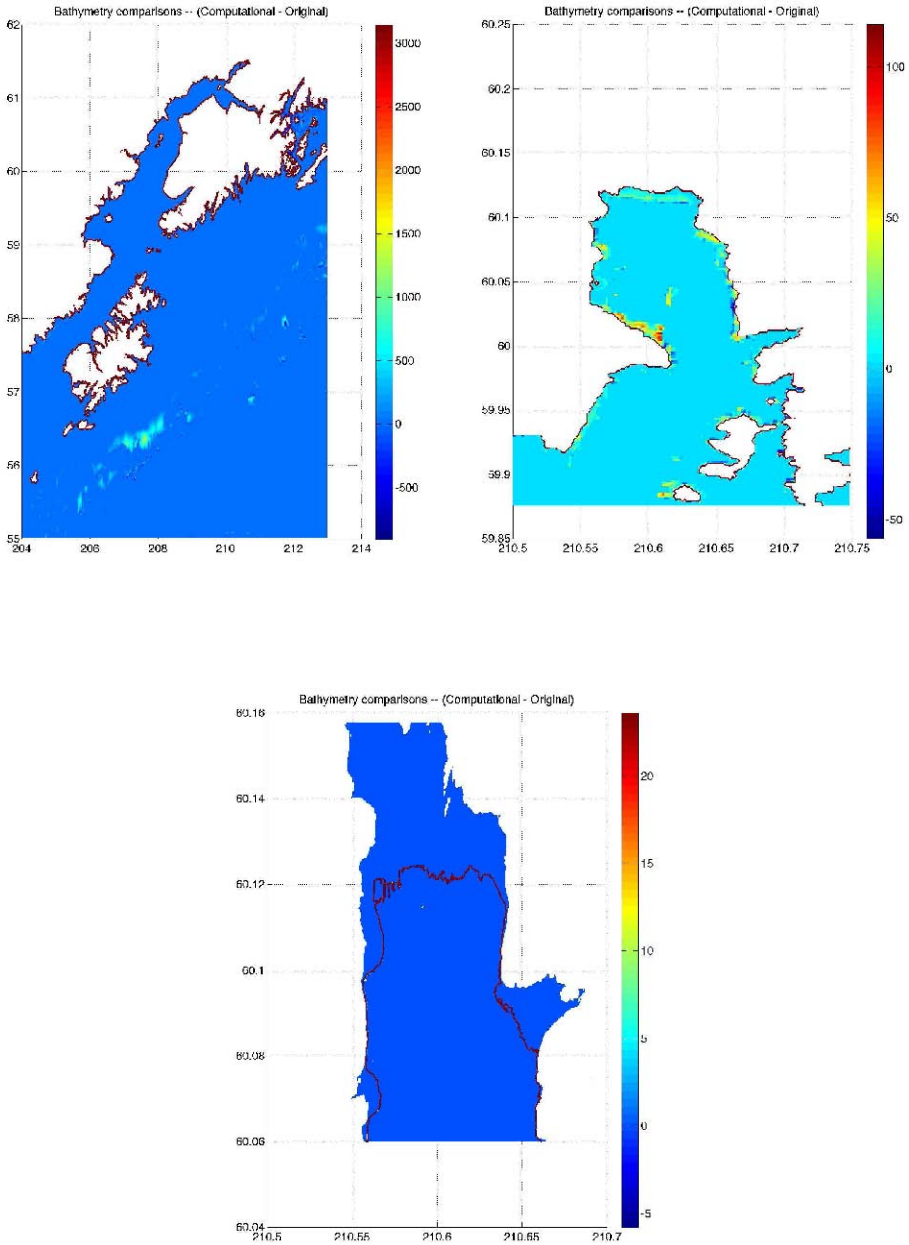


Figure 7 Bathymetric differences for the Reference SIMS at Seward, Alaska (positive values refer to greater depths in the computational grid in comparison to the original bathymetry). The solid contour line refers to the MSL position

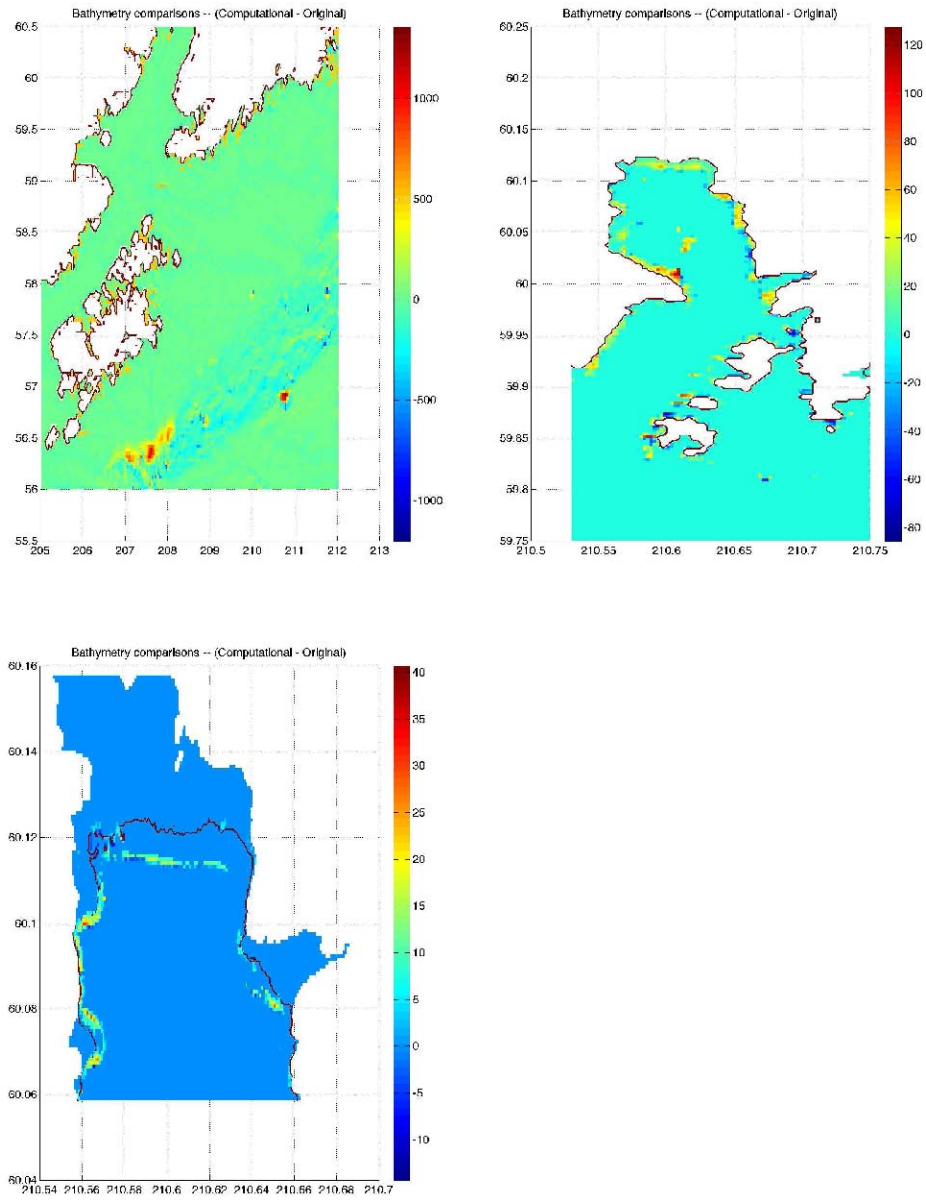


Figure 8 Bathymetric differences for the Optimized SIMs at Seward, Alaska (positive values refer to the greater depths in the computational grid in comparison to the original bathymetry). The solid contour line refers to the MSL position).

7.0 Appendix B

7.1 SIM .in files for Seward, AK

```
0.0001 Minimum amplitude of input offshore wave (m):
1      Input minimum depth for offshore (m)
0.10   Input "dry land" depth for inundation (m)
0.0009 Input friction coefficient (n**2)
1      runup flag for grids A and B (1=yes,0=no)
300.0  blow up limit
0.85   Input time step (sec)
42353  Input amount of steps
10     Compute "A" arrays every n-th time step, n=
3      Compute "B" arrays every n-th time step, n=
30     Input number of steps between snapshots
1      ...Starting from
1      ...Saving grid every n-th node, n=
seward_run2d/gridA
seward_run2d/gridB
seward_run2d/gridC
./
./
```

8.0 Appendix B

The Seward SIM was revisited in 2009 using the SIFT 3.0 software. Two megatsunami events were used for stability testing and two events and the 1946 Alaska tsunami was used to validate the model in SIFT 3.0. The results are presented in the following set of view graphs and tables.

Event	Time (UTC)	Zone	Mw	Lon	Lat	Source
Alaska	1946.04.01 12:28	AASZ	9.0	147.73W	61.04N	Tang et al. 2008
Indonesia		MOSZ	8.1			
Alaska		AASZ	9.3			

Table 4 Events used to test the Seward SIM using SIFT 3.0.

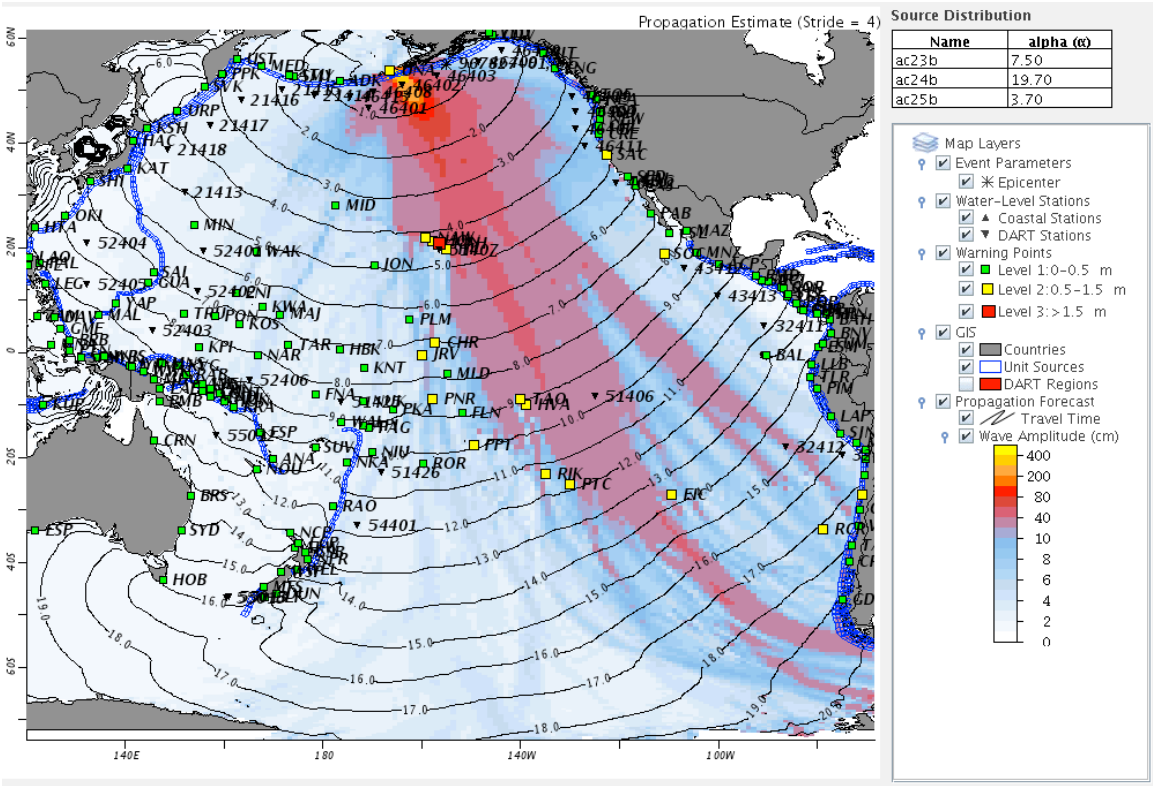


Figure 9 Propagation forecast for the 1946 Alaska tsunami used to test the Seward, AK SIM in SIFT 3.0.

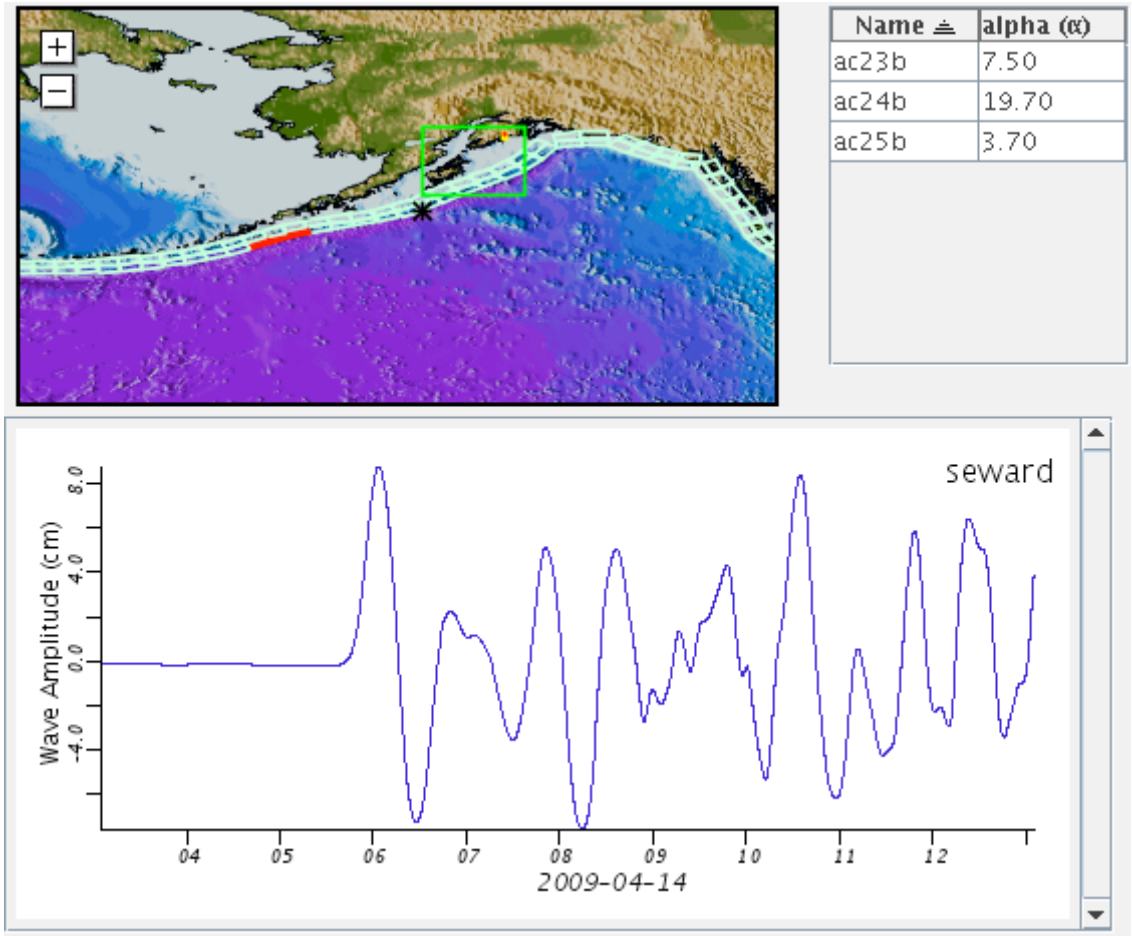


Figure 10 Water level times series for the 1946 Alaska tsunami at the Seward, AK warning point.

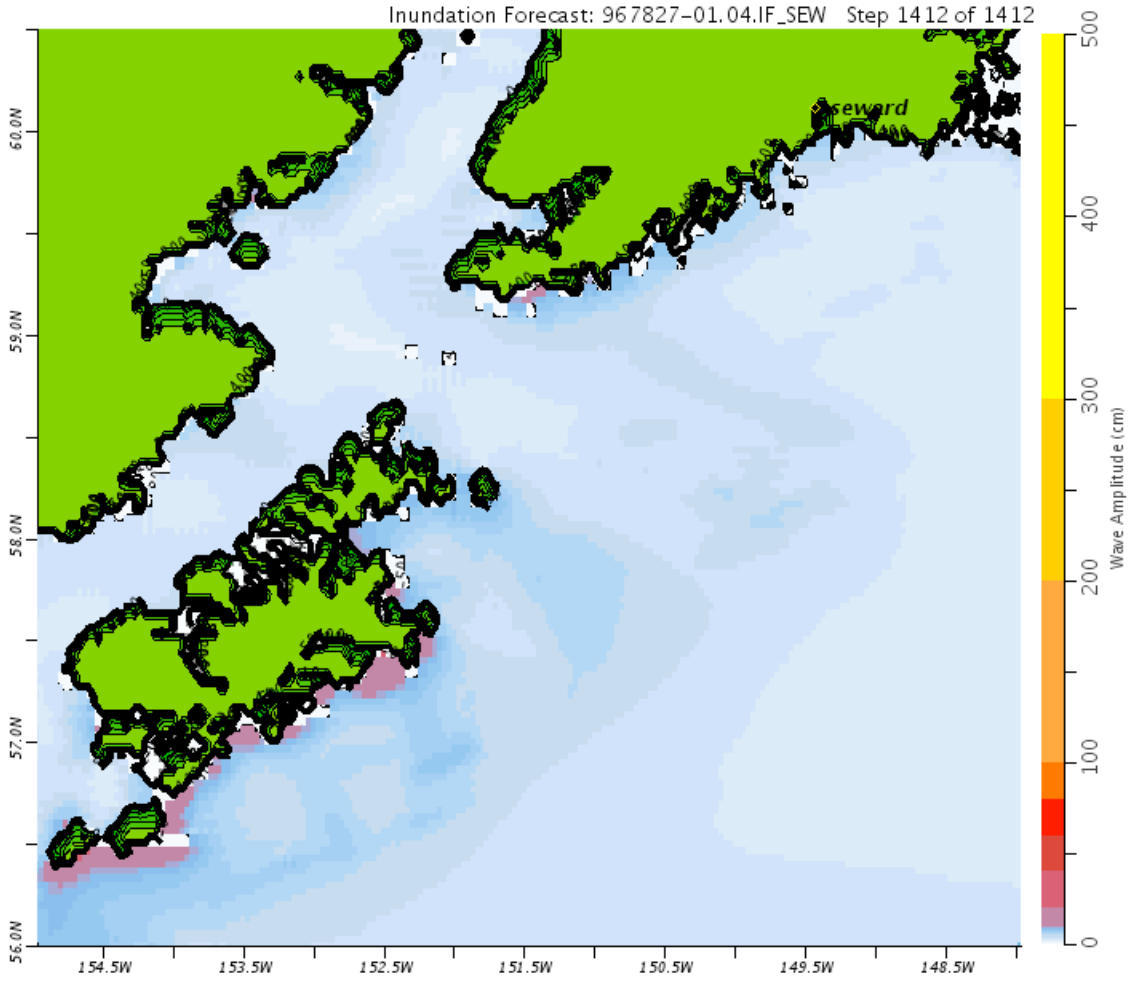


Figure 11 Inundation Forecast for Seward, AK SIM A Grid for the 1946 Alaska tsunami.

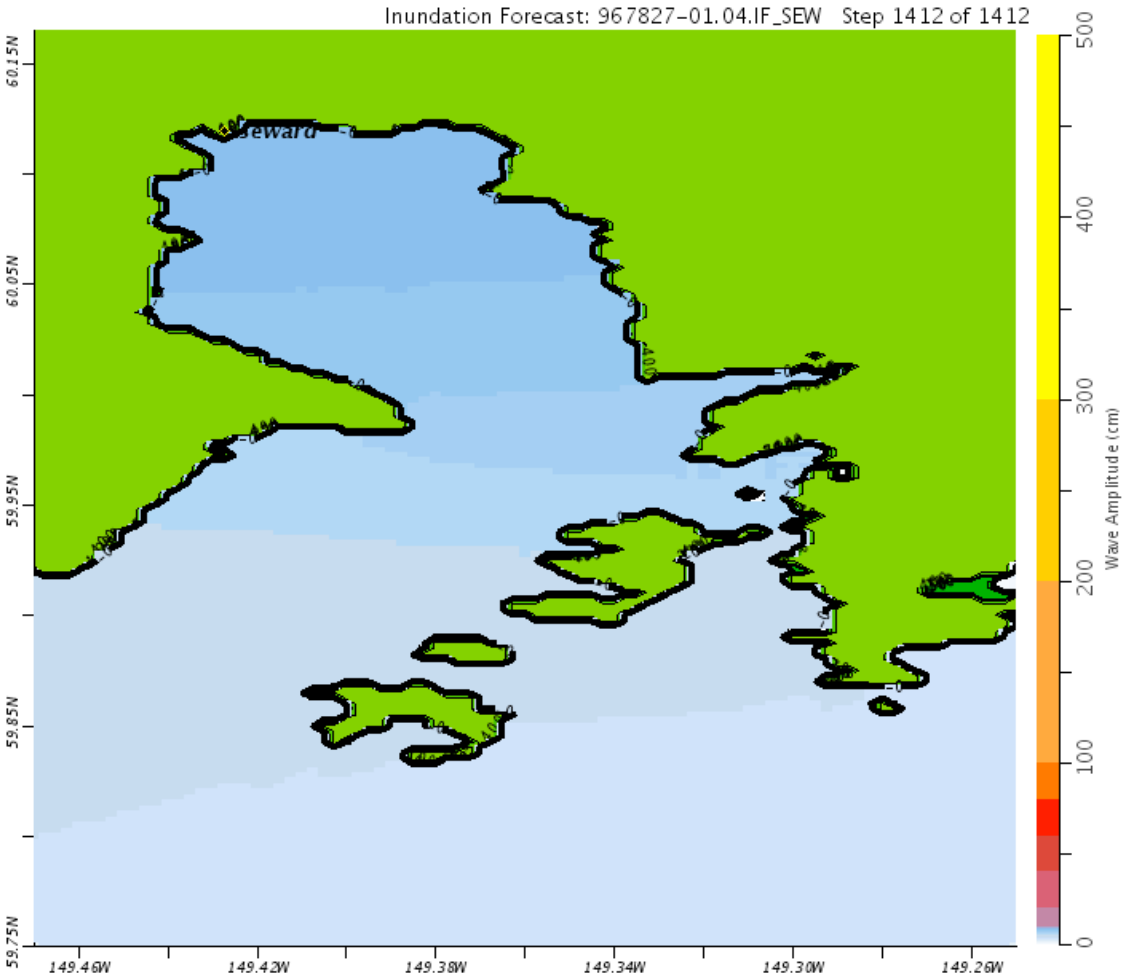


Figure 12 Inundation Forecast for Seward, AK SIM B Grid for the 1946 Alaska tsunami.

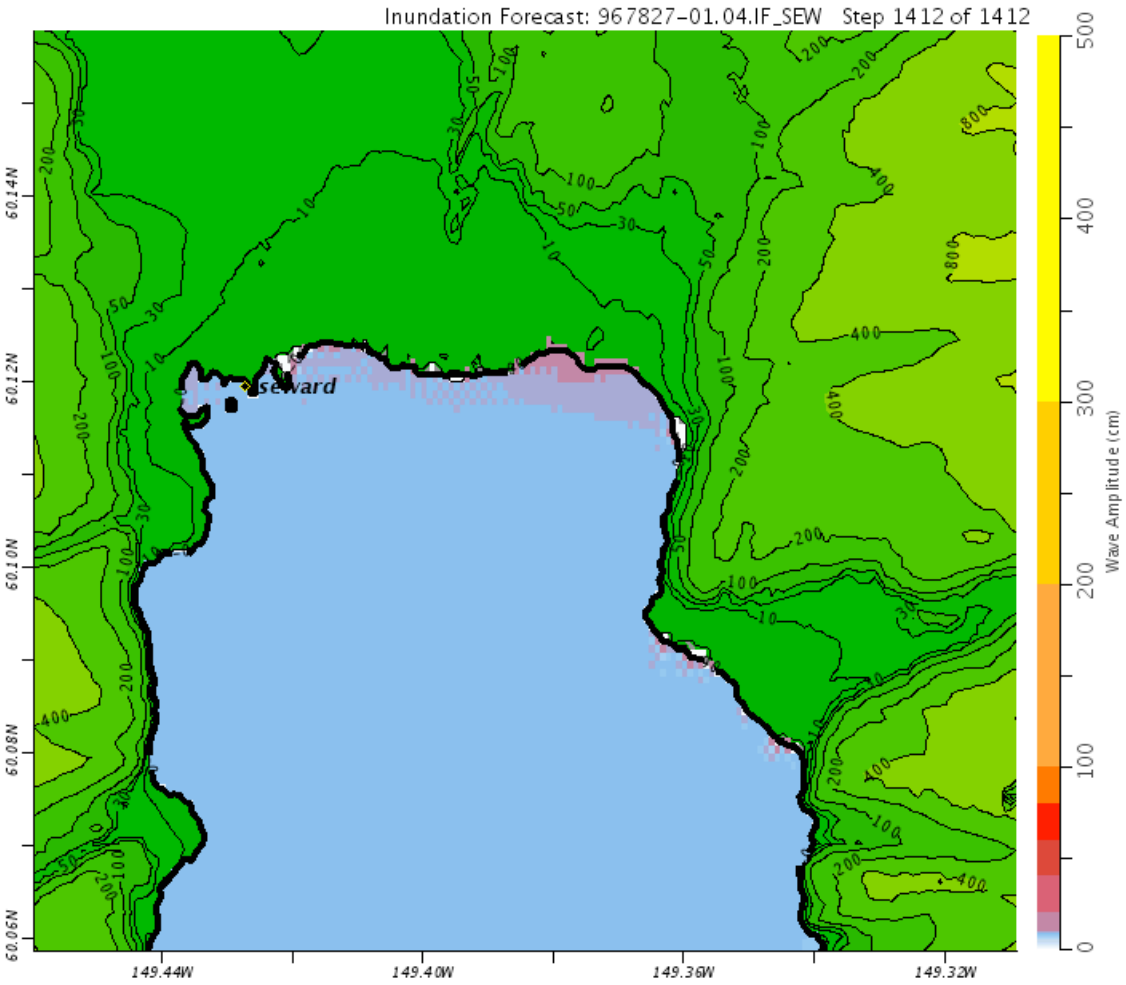


Figure 13 Inundation Forecast for Seward, AK SIM C Grid for the 1946 Alaska tsunami.

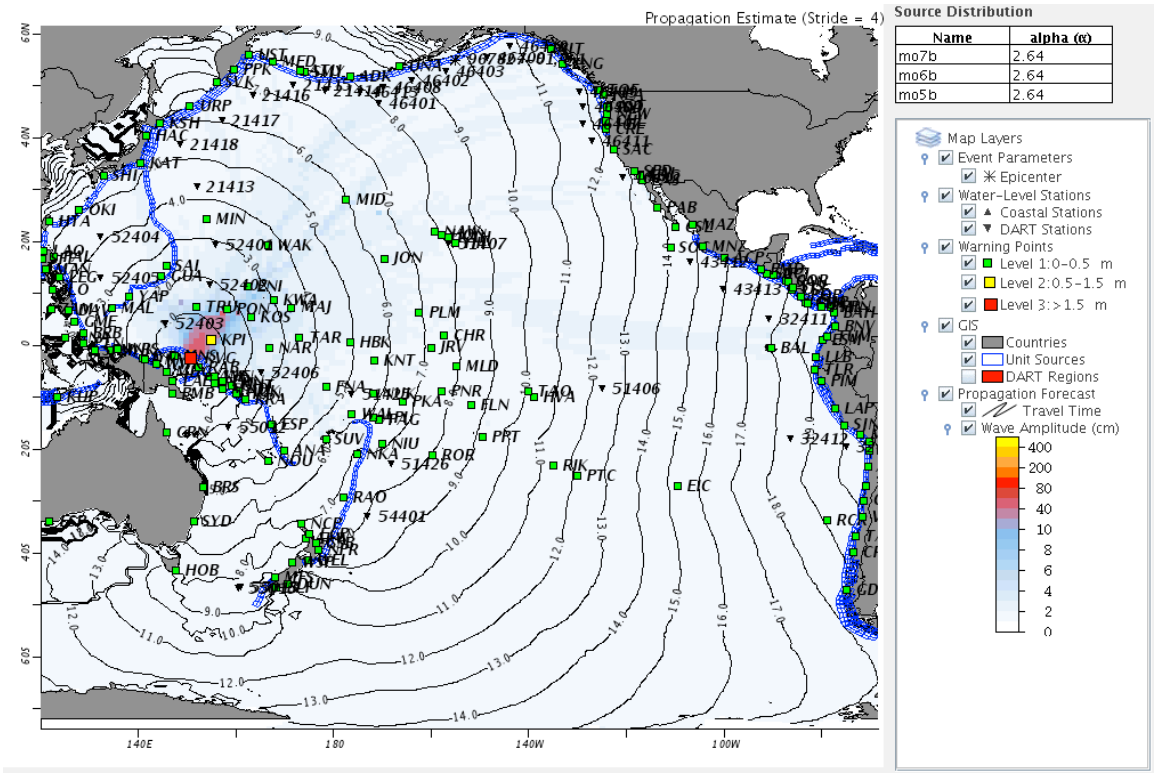


Figure 14 Propagation forecast for a synthetic 8.1 Mw from an Indonesia source to test the Seward, AK SIM in SIFT 3.0.

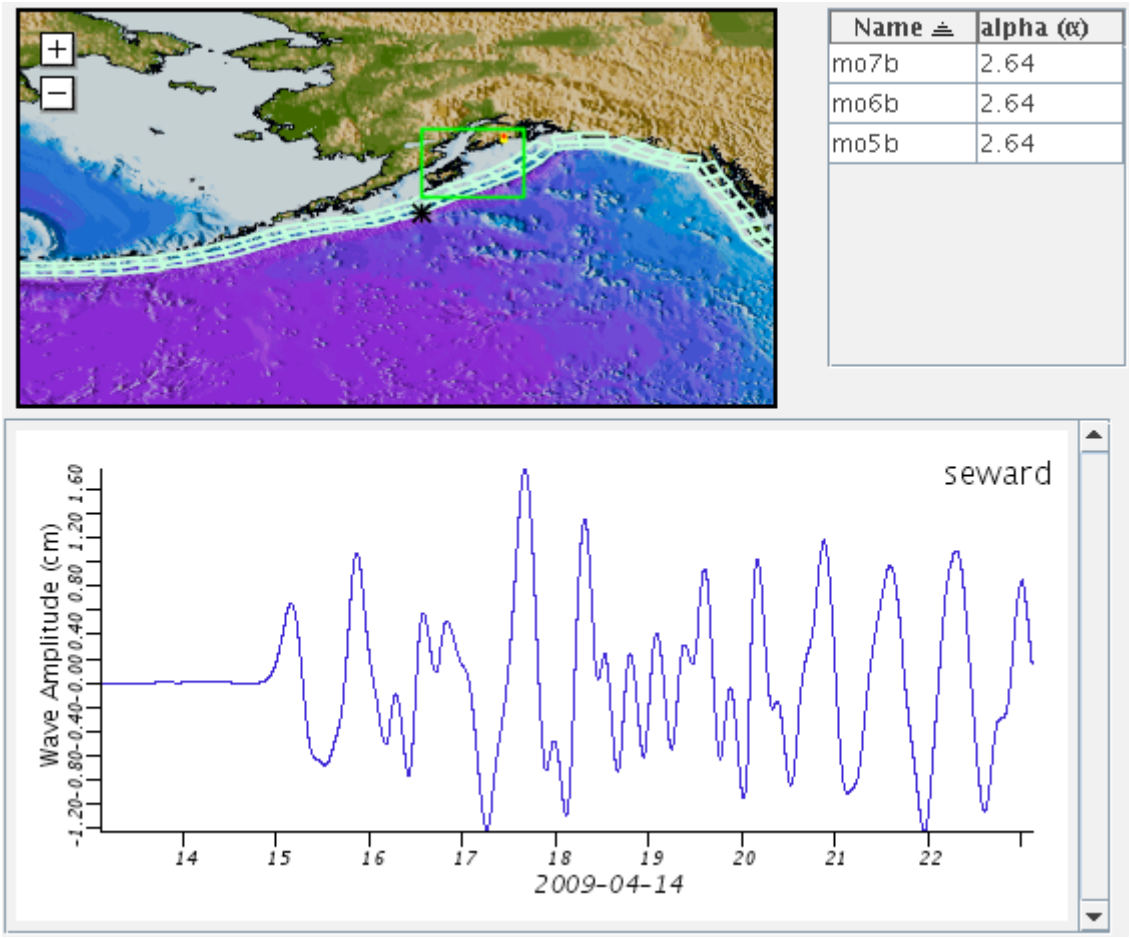


Figure 15 Water level times series for a synthetic 8.1 Mw Indonesian event at the Seward, AK warning point.

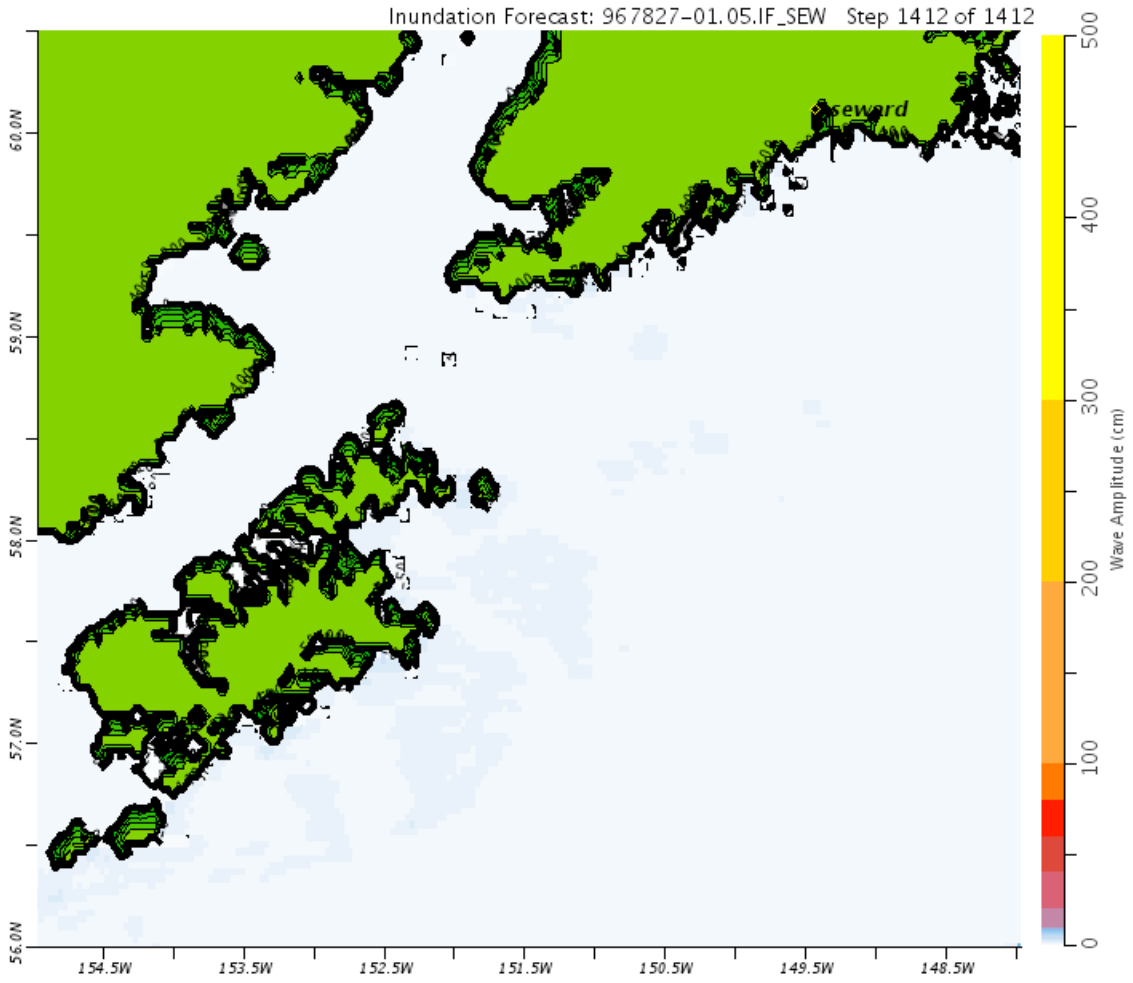


Figure 16 Inundation Forecast for Seward, AK SIM A Grid for the synthetic 8.1 Mw Indonesian event.

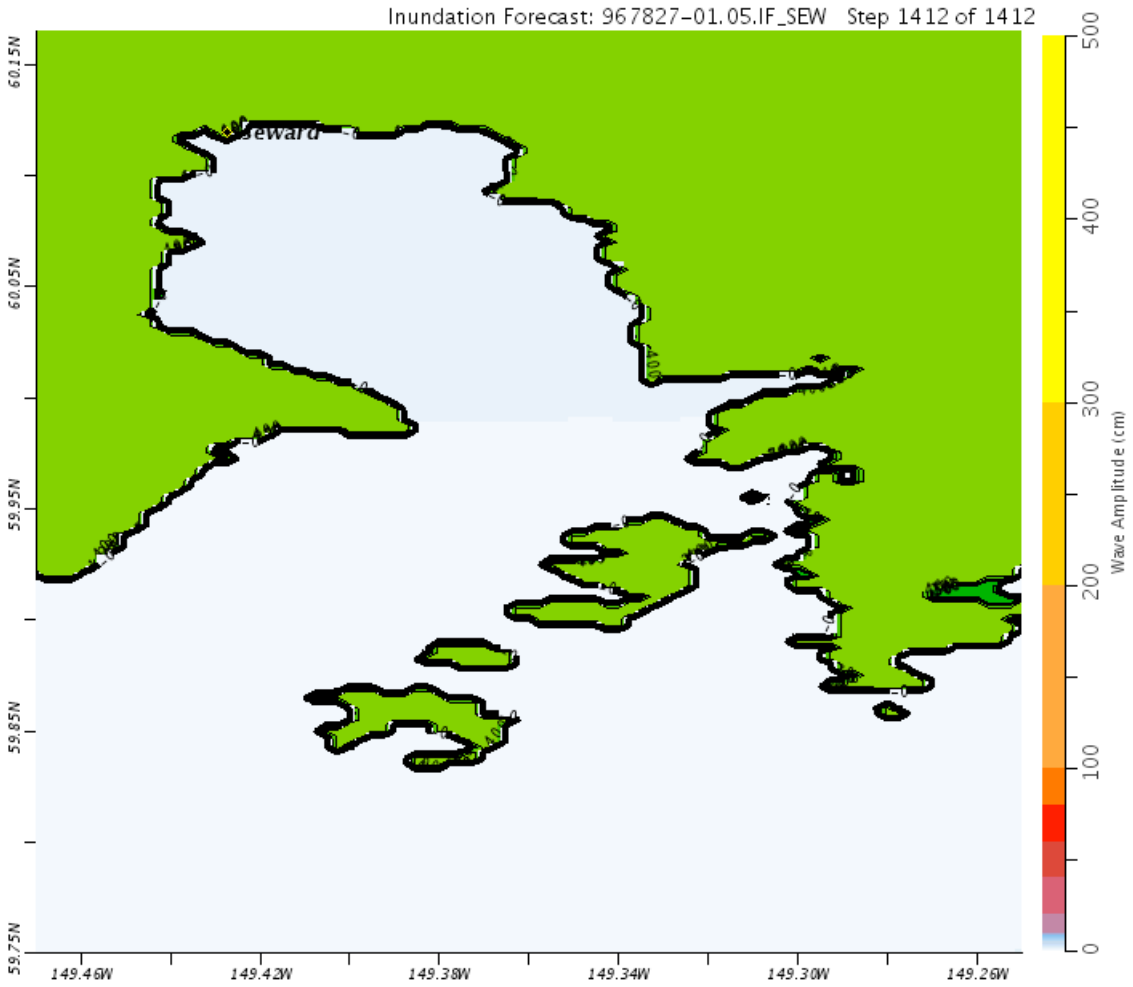


Figure 17 Inundation Forecast for Seward, AK SIM B Grid for the synthetic 8.1 Mw Indonesian event.

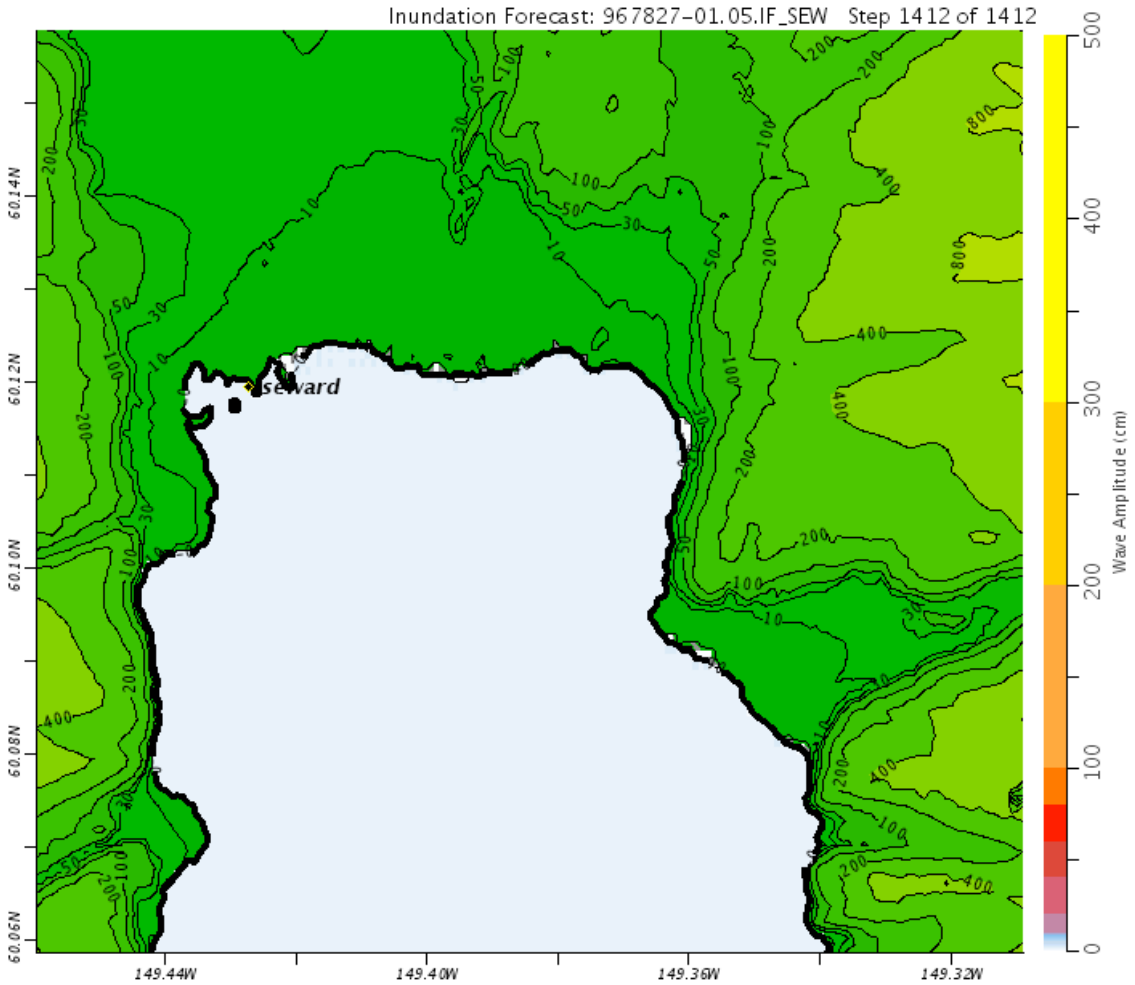


Figure 18 Inundation Forecast for Seward, AK SIM C Grid for the synthetic 8.1 Mw Indonesian event.

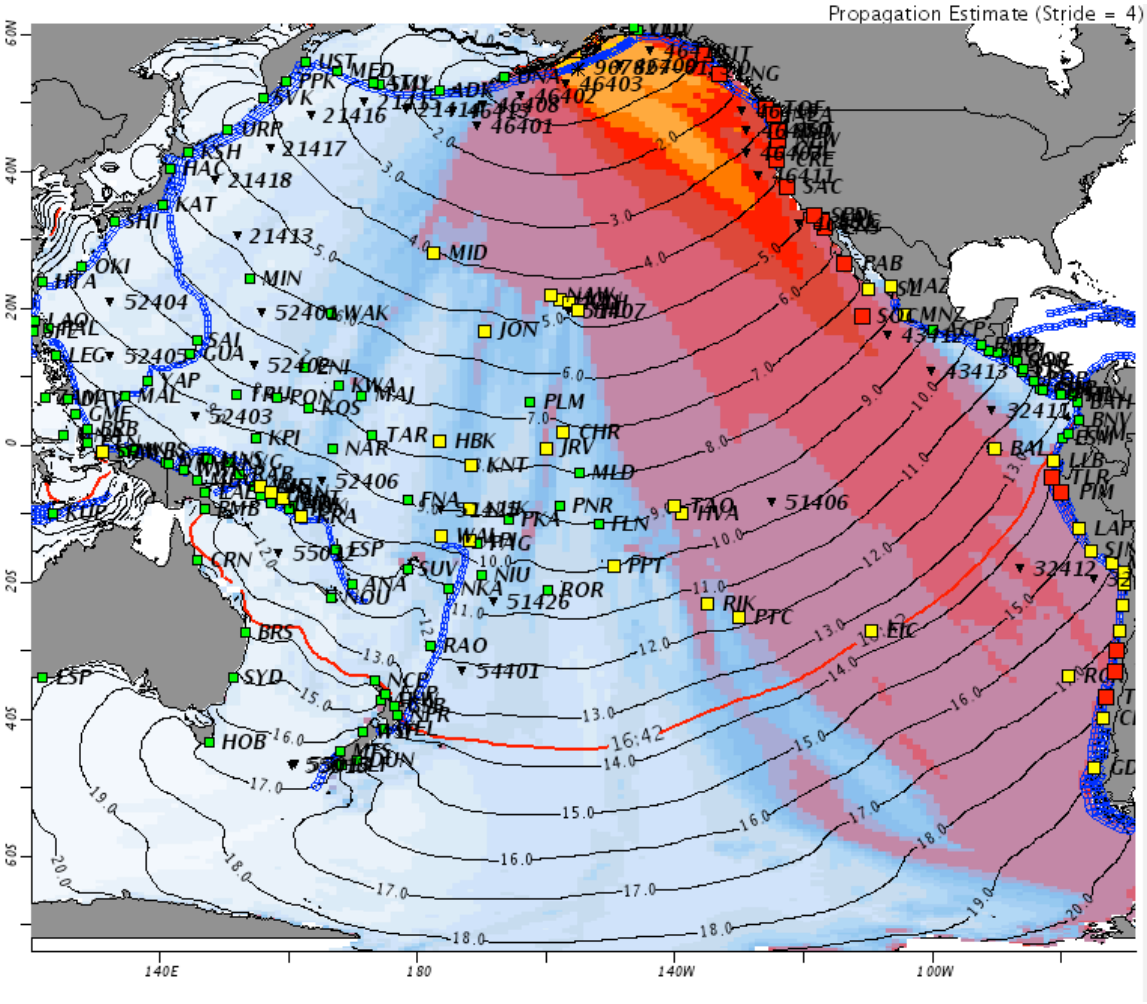


Figure 19 Propagation forecast for a synthetic 9.3 Mw from an Alaska near field event to test the Seward, AK SIM in SIFT 3.0.

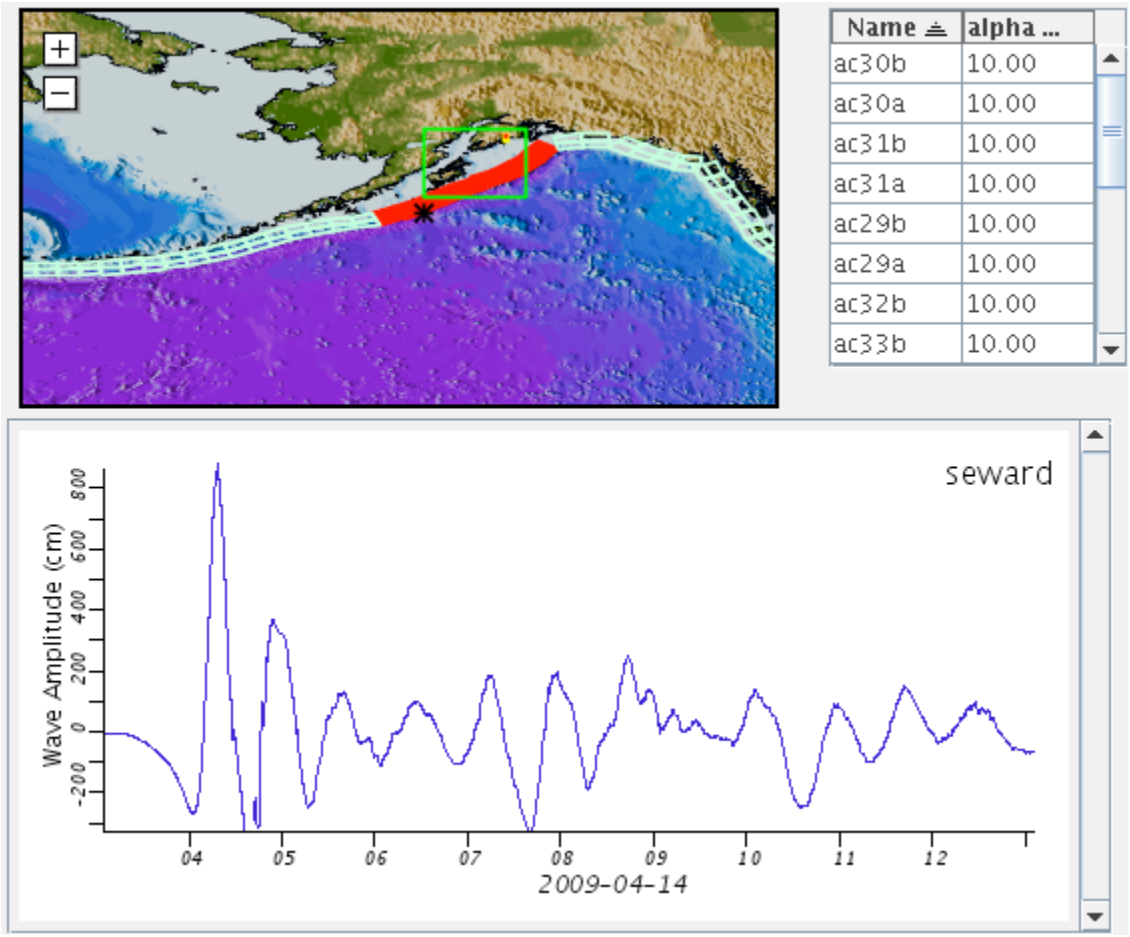


Figure 20 Water level times series for a synthetic 9.3 Mw from an Alaska near field event at the Seward, AK warning point.

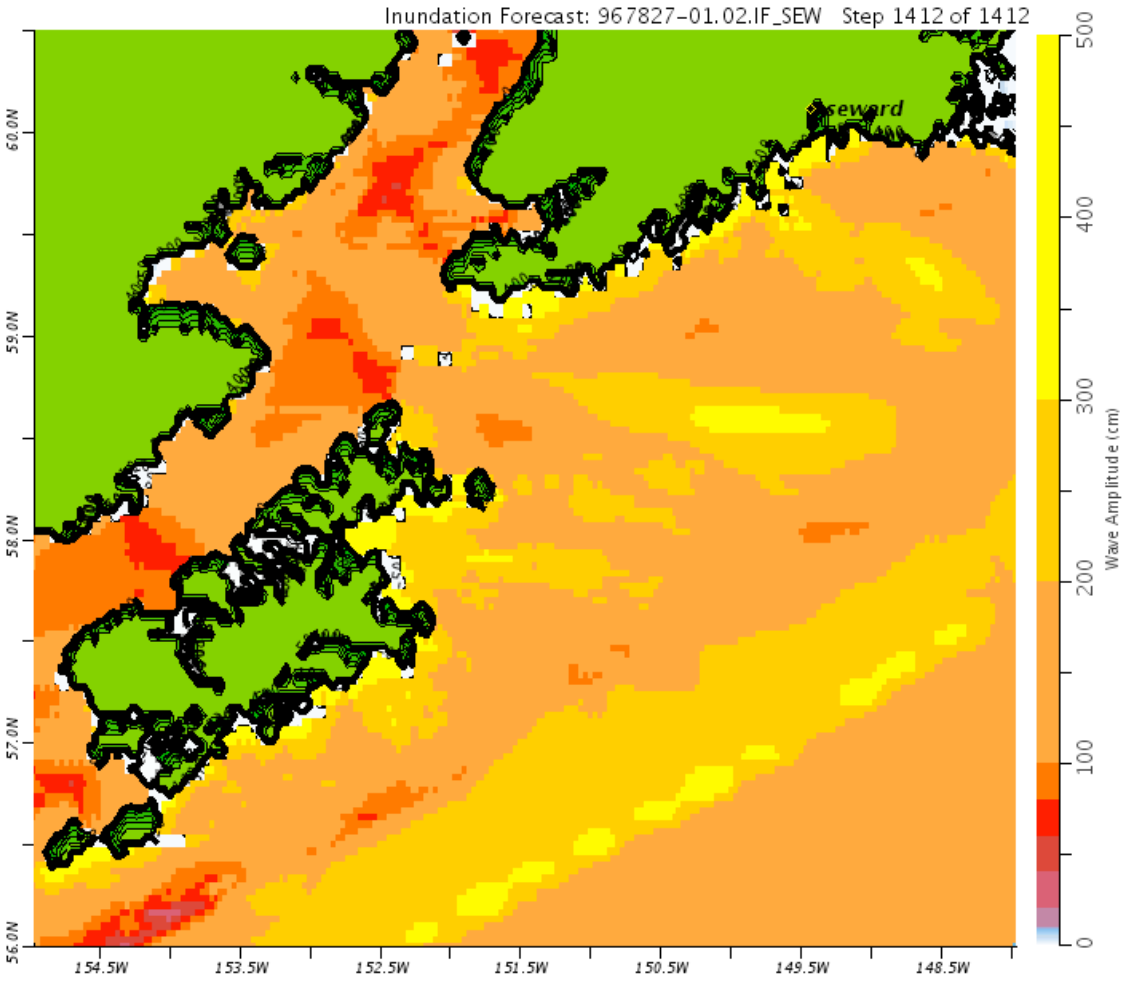


Figure 21 Inundation Forecast for Seward, AK SIM A Grid for the synthetic 9.3 Mw Alaska near field event.

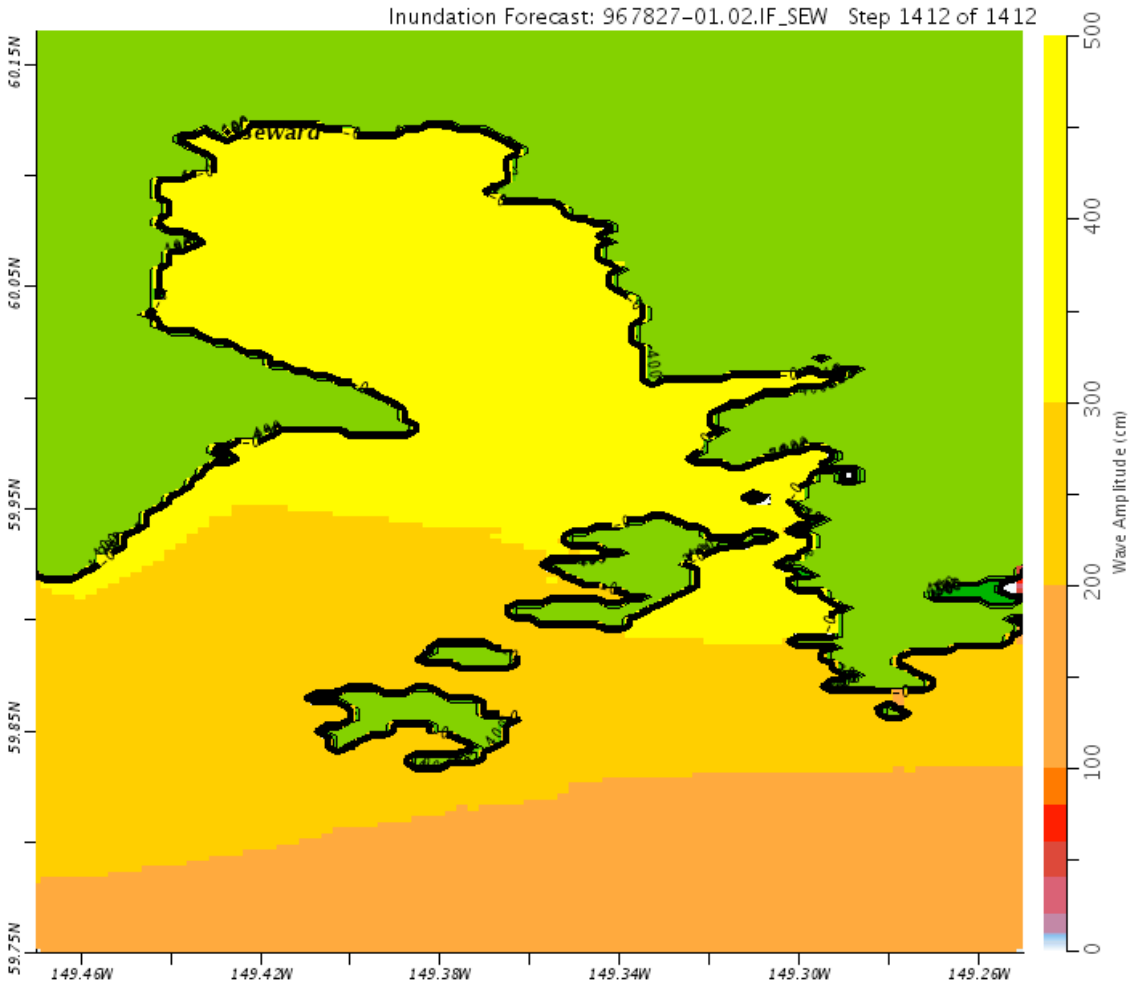


Figure 22 Inundation Forecast for Seward, AK SIM B Grid for the synthetic 9.3 Mw Alaska near field event.

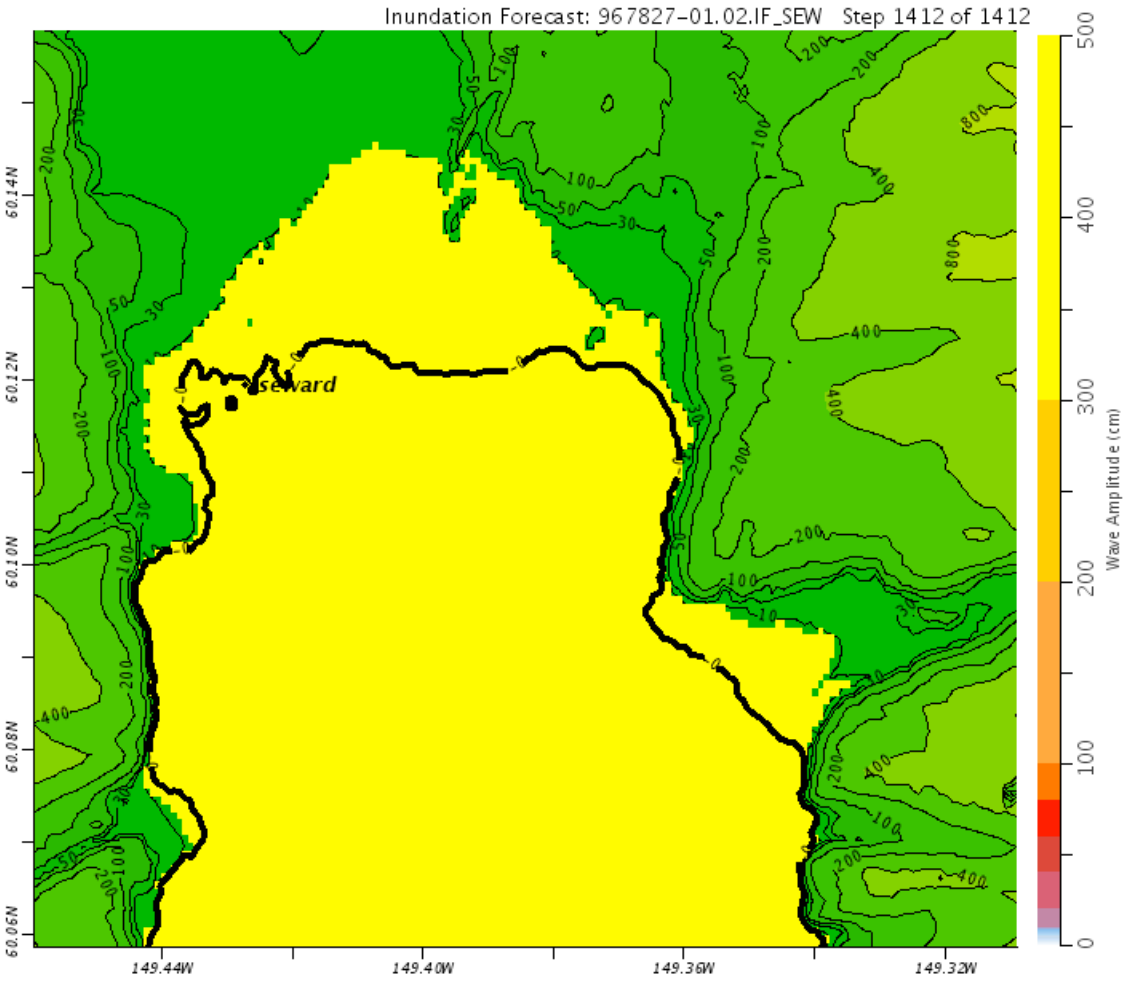


Figure 23 Inundation Forecast for Seward, AK SIM C Grid for the synthetic 9.3 Mw Alaska near field event.