

NOAA OAR Special Report

PMEL Tsunami Forecast Series: Vol. NNNN
**Development of a Tsunami Forecast Model for Elfin
Cove, Alaska**

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North and South Inian Passes. Observed maxima (and water depths) are based on NOAA EcoFOCI current meter data from 2010 and 2011.

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Foreword

Tsunamis have been recognized as a potential hazard to United States coastal communities since the mid-twentieth century, when multiple destructive tsunamis caused damage to the states of Hawaii, Alaska, California, Oregon, and Washington. In response to these events, the United States, under the auspices of the National Oceanic and Atmospheric Administration (NOAA), established the Pacific and Alaska Tsunami Warning Centers, dedicated to protecting United States interests from the threat posed by tsunamis. NOAA also created a tsunami research program at the Pacific Marine Environmental Laboratory (PMEL) to develop improved warning products.

The scale of destruction and unprecedented loss of life following the December 2004 Sumatra tsunami served as the catalyst to refocus efforts in the United States on reducing tsunami vulnerability of coastal communities, and on 20 December 2006, the United States Congress passed the “Tsunami Warning and Education Act” under which education and warning activities were thereafter specified and mandated. A “tsunami forecasting capability based on models and measurements, including tsunami inundation models and maps.” is a central component for the protection of United States coastlines from the threat posed by tsunamis. The forecasting capability for each community described in the PMEL Tsunami Forecast Series is the result of collaboration between the National Oceanic and Atmospheric Administration office of Oceanic and Atmospheric Research, National Weather Service, National Ocean Service, National Environmental Satellite Data and Information Service, the University of Washington’s Joint Institute for the Study of the Atmosphere and Ocean, National Science Foundation, and United States Geological Survey.

Abstract. Operational tsunami forecasting by NOAA’s Tsunami Warning Centers relies on the detection of tsunami wave trains in the open ocean, inversion of these data (transmitted via satellite) to quantify their source characteristics, and real-time modeling of the impact on threatened coastal communities. The latter phase of the process involves, for each such community, a pre-tested Forecast Model capable of predicting the impact, in terms of inundation and dangerous inshore currents, with sufficient resolution and within the time constraints appropriate to an emergency response.

In order to achieve this goal, considerable advance effort is required to tune each forecast model to the specific bathymetry and topography, both natural and manmade, of the impact area, and to validate its performance with a broad set of tsunami sources. Where possible the validation runs should replicate observed responses to historical events, but the sparse instrumental record of these rare but occasionally devastating occurrences

dictates that comprehensive testing should include a suite of scenarios that represent extreme events.

During the forecast model design phase, and in research mode outside the pressures of an emergency situation, more detailed and slower-running models can be investigated. Such a model, referred to as a Reference Model, represents the most credible numerical representation of tsunami response for the study region, using the most detailed bathymetry available and without the run-time constraint of operational use. Once a reference model has been developed, the process of forecast model design is to determine where efficiencies can be gained, through reducing the grid resolution and increasing the model time step, while still adequately representing the salient features of the full solution.

This report documents the reference and forecast model development for Elfin Cove and vicinity, comprising much of the Alexander Archipelago. Elfin Cove is a small inlet on the north coast of Chichagof Island, and is exposed to the Pacific Ocean via Cross Sound. Icy Strait provides a connection eastward to Glacier Bay, which extends deep into the Alaska Panhandle mainland, and Chatham Strait. The latter forms the eastern boundary of Chichagof and Baranof Islands and is another deep-water connection to the Pacific. Chatham Strait continues northward as Lynn Canal, leading to Skagway; other branches connect to Juneau and other communities. The vicinity of Elfin Cove is sparsely populated but has important marine resources, commercial and recreational fishing, and is traversed by several segments of the Alaska Marine Highway. Glacier Bay is a popular venue for cruise ships and other tourist activity. This report addresses the tsunami aspects of the natural hazard spectrum.

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1.0 Background and Objectives

1.1. The Setting

The “Panhandle” of Southeast Alaska (see Figures 1-3) extends from Yakutat to the U.S./Canada border and is a region incised with deep channels and complex topography. The mainland is exposed to the open ocean north of Cross Sound while to the south the islands of the Alexander Archipelago provide a screen. The deep waters of Chatham Strait provide a passage for tsunami waves deep into the interior: to Skagway and Haines via Lynn Canal, to the state capital Juneau, and to several of the larger communities. Cross Sound is linked to Chatham Strait via Icy Strait along which Glacier Bay and its associated National Park is a major tourist destination.

Tsunami models are being developed for several communities of southeastern Alaska in recognition of the threat they face from both local and remote sources. Tide gages are in place that can serve to validate these models permitting their use to provide real-time warning capability to emergency managers. One such tide gage is located in Elfin Cove, approximately midway between Sitka and Yakutat and the subject of this report and tsunami modeling effort. The small community (2000 population 30 and accessible only by water or seaplane) is a census-designated place on the Inian Peninsula of Chichagof Island. Although the fifth largest island in the U.S. its entire population in 2000 was only 1,342. The Inian Peninsula, and a cluster of islands of the same name, partially block Icy Strait while to the west several islands screen Elfin Cove from the open Pacific Ocean. The Alaska Marine Highway passes between Elfin Cove and the Inian Islands with ferry service to Hoonah (2000 population 560) at the mouth of Port Frederic inlet, Pelican (2000 population 163) on Lisianski Inlet and northward to Yakutat and Anchorage. During the summer months there is a significant though transient population increase. Commercial fishing vessels transiting to the Bering Sea or engaged in local recreational fishing swell the population of Elfin Cove to 170 or so and the community is occasionally visited by tour vessels with up to 100 passengers that can tax its limited infrastructure. Power is generated locally, potable water comes from a spring and there are no regularly scheduled modes of transportation. Elfin Cove has no roads but is served by a network of boardwalks. Medical services are volunteer-provided; all in all the community is self-sustaining but at risk if an emergency were to arise.

As the most northerly access to the Inland Passage, Cross Sound and Icy Strait are heavily traversed year-round by ferry, cargo, and cruise ship traffic. In summer cruise ship traffic is particularly intense with two vessels, each carrying up to 3,000 passengers and crew, visiting Glacier Bay each day. Tidal currents through the narrow North and South Inian Passes and other navigational channels are very strong and it is important that the tsunami model being designed here should address the impact of tsunami-driven currents in addition to the potential for inundation. While the forecast model is named for Elfin Cove, its choice is largely dictated by the presence of a tide gage for use in model validation and in operations; the scope of the model must be more regional than is usual. By contrast, models created for the closest communities to the north and south (Yakutat

and Sitka respectively with greater population and infrastructure) have a more local focus.

Lisianski Strait separates Chichagof Island from the smaller Yakobi Island to the west. Further south Peril Strait provides another, albeit far more constricted, connection between the Pacific and Chatham Strait, allowing ferry service to Sitka (2000 population 8,881) on Baranof Island. At the south end of Baranof Island, just inside the entrance to Chatham Strait, is Port Alexander (2000 population 81) whose selection for as a forecast model site also reflects its strategically located tide gage.

Though far from the open ocean, Skagway and Juneau have reported substantial tsunami waves, particularly from the major Alaskan earthquake of 1964 but also from more remote events such as Chile 1960 and Honshu 2011. The domain of the Elfin Cove model, which must allow for the possibility of waves arriving from the east via Chatham and Icy Straits, will be large enough to permit estimates for Juneau, Skagway and other communities in its vicinity.

1.2. Natural Hazards

Lander (1996), in an extensive compilation of tsunami knowledge for Alaska since the earliest records in the 1700s, distinguishes between the several categories of tsunami to which the region is prone. Together with the National Geophysical Data Center's (NGDC) online hazard database (Dunbar, 2007; see www.ngdc.noaa.gov/hazard/), a wide set of historical cases are available with which to exercise a forecast model. Observations suited to model validation are however quite limited. Tide gage records from Elfin Cove itself are only available after August 2005, and reports and observations from other sites in the vicinity (primarily Sitka) will be employed to validate the model for earlier events.

The instrumental record is too short, in the geologic context, to provide samples of the range of tsunami events that may occur at future times within the Pacific basin. Thus, once developed and validated, the model will be exercised with a comprehensive suite of synthetic scenarios. The benefits of this are twofold: to check that the model is robust, unlikely to fail in an operational setting and, as a byproduct, identify tsunami source regions to which southeast Alaska is particularly susceptible. It should be noted that the model currently is applicable only to tsunamis generated by direct seismic forcing. Lander (1996) discusses other mechanisms: related to volcanic activity, or landslides perhaps triggered by seismic action, that are manifested in the observational record. Notorious among the latter is the 1958 event in Lituya Bay, just north of Cross Sound, where the collapse of a steep mountainside caused a surge of over 500 meters at the other side of the bay. Though dramatic, such events are generally quite localized, but it should be stressed that in its current form the tsunami model employed in the forecast system does not cover landslide-generated tsunamis.

Earthquake, landslide, and flooding damage can result even without the medium of tsunami waves. Nonetheless history has shown that death, injury, and property damage associated with tsunamis both local and remote have been significant so that the

modeling effort and operational forecast capability provides important benefits to the State of Alaska. Equally, since tsunamis generated off southeast Alaska can potentially impact the entire Pacific basin, the degree of success of the Elfin Cove model in a local event can lend credence to the forecast systems projections for more remote and larger communities, of the United States and other nations.

An inset to Figure 6, taken from the USGS seismic hazard analysis for Alaska (Wesson et al., 2007), shows the major fault ruptures that have occurred in the region since the 1930s. Several are local to the Alaska Panhandle region, though none have caused major tsunami impacts since 1964. The main panel of Figure 6 shows (in green) several of the faults, together with the unit source rectangles employed to represent them in the NCTR propagation database. The Fairweather Fault, extending northward from Haida Gwaii generated the Queen Charlotte event of 1949, the 1958 earthquake associated with the Lituya Bay tsunami and one near Sitka in 1972 (Doser and Lomas, 2000). It is primarily a strike slip fault, as is the Transition Zone Fault which angles off to the northwest. The junction near Cross Sound was the site of a series of a cluster of small earthquakes in 1973. Between these faults is the Yakutat Terrane (Worthington, 2012) or Yakutat Block (whose submarine portion is cross-hatched in Figure 6).

The rectangular outlines of the 100x50km unit sources of the NCTR propagation database are shown in Figure 6. Those drawn in black are combined for the ACSZ 40-49 mega-tsunami source described later in this report. Representing an Mw 9.3 event this synthetic source is likely far in excess of any probable occurrence but should serve as an extreme test of model stability. At the northern end of the Yakutat Block the potential for a larger event becomes more realistic as it subducts beneath the North American Plate in the vicinity of the Chugach-St Elias Mountains. Major earthquakes occurred near Yakutat in 1899 for which the 1979 event shown in Figure 6 is considered an aftershock. The rupture zone of the 1964 Alaska earthquake did not extend into the region (Shennan et al., 2009). Often referred to as the “Yakataga Gap” this is a potential site for future large earthquakes in Alaska seismic hazard mapping (Wesson et al., 2007), and Alaska Earthquake Information Center (AEIC) charts (www.aeic.alaska.edu).

1.3. Tsunami Warning and Risk Assessment

The forecast model development, described here, will permit Elfin Cove, AK, to be incorporated into the tsunami forecasting system SIFT, developed at NCTR (NOAA Center for Tsunami Research) and now in use at the U.S. Tsunami Warning Centers (TWC’s). The system has had considerable success in accurately forecasting the impact of both moderate and severe tsunami events in recent years and in the following section the methodology that permits such forecasts is discussed as prelude to a description of development of the forecast model for Elfin Cove. With the model in hand, validated with historical events and with its stability verified by extensive testing against extreme scenarios, real-time forecasts will be available to inform local emergency response. Additionally, the synthetic scenarios investigated during model development, and reported here, provide an initial tsunami risk assessment as described in the Results and Discussion section.

2.0 Forecast Methodology

2.1 The Tsunami Model

A tsunami forecast model is used to extend a pre-computed deep-water solution into the shallows, and onshore as inundation if appropriate. The model consists of a set of three nested grids, of increasingly fine resolution that, in a real-time application of the MOST model (Method of Splitting Tsunami: Titov and Synolakis, 1998; Titov and González, 1997), permits forecasts at spatial scales (as little a few tens of meters) relevant to local emergency management. The validity of the MOST model applied in this manner, and the operational effectiveness of the forecast system built around it, has been demonstrated during unplanned tests triggered by several mild to moderate tsunami events in the years since the 2004 Indian Ocean disaster (Wei et al., 2008). Successful hindcasting of observed historic events, even mild ones, during forecast model development lends credence to the ability to accurately forecasting the impact of future events. Such validation of tsunami modeling procedures is documented in other volumes of the series of which this report is but one. Before proceeding to a description of the forecast model development for Elfin Cove, it is useful to describe the steps in the overall forecast process.

2.2 The SIFT Forecast System

Tsunami forecasts are generated at Tsunami Warning Centers, staffed 24/7 in Alaska and Hawaii, using the SIFT (Short-term Inundation Forecasting for Tsunamis) tool, developed at NCTR. The semi-automated process facilitates the steps by which TWC operators assimilate data from an appropriate subset of the DART[®] tsunami sensors, “invert” the data to determine the linear combination of pre-computed propagation solutions that best match the observations, then initiate a set of forecast model runs if coastal communities are threatened or, if warranted, cancel the warning.

Steps in the process are as follows:

- When a submarine earthquake occurs the global network of seismometers registers it. Based on the epicenter, the unit sources in the Propagation Database (Gica et al., 2008) that are most likely to be involved in the event, and the DART[®] array elements (Spillane et al., 2008) best placed to detect the waves passage are identified. TWC watch-standers can trigger DART[®]s into rapid sampling mode in the event that this did not occur automatically in response to the seismic signal.
- There is now an unavoidable delay while the tsunami waves are in transit to the DART[®]s; at least a quarter of a cycle of the first wave in the train must be sampled before moving to the “inversion” step.
- When sufficient data have accumulated, at one or more DART[®]s, the observed time series are compared with the model series from the candidate unit sources. Since the latter are pre-computed (using the MOST code), and the dynamics of tsunami waves in deep water is linear, a least squares approach taking very little time can identify the unit sources, (and the appropriate scale factors for each), that

best fit the observations. The “inversion” methodology is described by Percival et. al., (2009).

- Drawing again on the Propagation Database, the scale factors are applied to produce a composite basin-wide solution with which to identify the coastal regions most threatened by the radiating waves.
- It is at this point that one or more forecast models are run. The composite propagation solution is employed as the boundary condition to the outermost (A-grid) domain of a nested set of three real-time MOST grids that telescope with increasingly fine scale to the community of concern. A-grid results provide boundary conditions to the B-grid, which in turn forces the innermost C-grid. Non-linear processes including inundation are modeled so that, relying on the validation procedures during model development, credible forecasts of the current event are available.
- Each forecast model provides quantitative and graphic forecast products with which to inform the emergency response, or to serve as the basis for canceling or reducing the warnings. Unless the tsunami source is local, the forecast is generally available before the waves arrive but, even when lead-time cannot be provided, the several hour duration of a significant event (in which the first wave may not be the most damaging) give added value to the multi-hour forecasts provided.

Because multiple communities may be potentially at risk, it may be necessary to run simultaneously, or in a prioritized manner, multiple forecast models. Each must be optimized to run efficiently in as little time as possible; the current standard is that an operational forecast model should be capable of simulating 4 hours of real time within about 10 minutes of CPU time on a fast workstation computer.

3.0 Model Development

3.1 Digital Elevation Models

Water depth determines local tsunami wave speed and sub-aerial topography determines the extent to which tsunami waves may inundate the land. Thus a prerequisite for credible tsunami modeling is the availability of accurate gridded bathymetric and topographic datasets, termed Digital Elevation Models (DEM). Given their expertise in this area, and the number of coastal communities needing tsunami forecast capability, NCTR relies heavily on the National Geophysical Data Center (NGDC) to provide the DEMs needed. An extract from the South Alaska DEM was used as background in Figure 1 and the outlines of the more finely resolved Southeast Alaska and Elfin Cove DEMs are indicated. In the case of Elfin Cove a customized high resolution DEM, a composite of multiple data sources for the region between Cross Sound and the mouth of Glacier Bay was provided by NGDC. To create this various datasets were merged and converted to a common datum of Mean High Water (MHW). The main features of the Elfin Cove DEM are summarized in Table 1 and documented by Love et al. (2011). Oblique views of these DEMs, produced by NGDC, are reproduced in Figure 3 and assist in visualizing the complexity of the terrain and its multiple waterways. All of the DEMs employed were verified for consistency with charts, satellite imagery, and other datasets during the course of MOST grid development.

Table 1. The main features of the Elfin Cove, Alaska Digital Elevation Model (DEM), whose development is described by Love et al., (2011).

Grid Area	Elfin Cove, Alaska
Coverage Area	137.27° to 135.97° W; 57.53° to 58.67° N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS84)
Vertical Datum	Mean High Water (MHW)
Vertical Units	Meters
Cell Size	1/3 arc-second
Grid Format	ESRI Arc ASCII grid
Version Employed	Update of March 31, 2011

The use of MHW as the “zero level” for forecast results is standard. The MOST model does not include tidal fluctuations and, since a tsunami may arrive at any stage of the tide, it is generally best to employ a “worst-case” approach by assuming high tide when forecasting inundation. For some Forecast Models grounding of vessels and the strong and rapidly varying currents often associated with even mild tsunamis are of concern. Even under normal circumstances the tidal currents in North and South Inian Passes are very strong. NOAA Chart 17302, a portion of which is shown in Figure 4a, alerts mariners to currents of 8 to 10 knots. In light of the importance of cruise ship and ferry traffic, the extent to which these might be accentuated during a tsunami will be assessed. For Elfin Cove itself, there are piers floating docks and refueling facilities associated with seaplane and both commercial and recreational fishing activity as shown in the NOAA

chart reproduced as Figure 4b. Figure 5, a photograph by Rick Sood, shows the character of the inner cove of this small community: in particular the reliance on piers and floating docks that do not substantially impede the circulation.

Two different resolutions are available for the Southeast Alaska DEM: eight thirds of an arc-second, and 8 arc-second. The coverage encompasses the region from Skagway to the north to the Haida Gwaii (Queen Charlotte) Islands in British Columbia, Canada. These DEM datasets, together with the Elfin Cove DEM, are employed in the construction of the three nested grids for the Elfin Cove model. As noted earlier, the scope of the outer Elfin Cove grid was chosen to permit estimates of tsunami signals at Skagway and Juneau but, with the relatively coarse grid spacing needed to attain acceptable operational run times, the estimates are of lower quality than would be possible in dedicated models for these communities.

3.2 Tides and Sea Level Variation

The history of tidal observation at Elfin Cove dates back to 1938 though the earlier records are not readily available. Some marigrams are stored in microfiche format at NGDC and a project to digitize the full collection is underway. The present installation of NOAA's National Ocean Service tide gage (NOS 9452634) at Elfin Cove was in August 2005 with quality controlled 6-minute, and preliminary 1-minute records available online.

Table 2. Characteristics of the Elfin Cove, AK Tide Gage (NOS¹ 9452634).

Elfin Cove, AK Station#9452634 58⁰ 11.6'N, 136⁰ 20.8'W			
Present Installation Aug 11, 2005			
Tidal Datum and Range Values (Epoch 1983-2001)			
MHHW (Mean Higher High)	6.250m	Great Diurnal Range 3.367m	Mean Range 2.648m
MHW (Mean High Water)	5.977m		
MSL (Mean Sea Level)	4.637m		
MLW (Mean Low Water)	3.329m		
MLLW (Mean Lower Low)	2.883m		
Sea Level Trend (1924-2006) and Cycles (from Sitka² AK, NOS 9451600)			
Long Term SL Trend	Decreasing 2.05±0.32mm/year		
Seasonal Cycle Range	Minimum -106mm(Jul); Maximum 131mm(Dec)		
Interannual Variation (from1980)	Minimum -20mm(1989); Maximum +21mm(1998)		
Extremes to date (Jun 2012)			
Maximum	7.435m on 31 Dec, 1985		
Minimum	1.449 on 14 Dec, 2008		

¹NOAA's National Ocean Service, whose CO-OPS Program Office disseminates tide gage information and data.

²At Yakutat AK (NOS 9453220), the long-term trend is -11.54 ± 1.39mm/year.

The bathymetry and topography used in the development of this forecast model was based on the digital elevation model provided by the National Geophysical Data Center and the author considers it to be a good representation of the local topography/bathymetry. As new digital elevation models become available, forecast models will be updated and report updates will be posted at http://nctr.pmel.noaa.gov/forecast_reports/.

The tide gage is located off the seaplane-fueling pier in the outer cove (see Figure 4b). The outer cove is screened by an unnamed nearby island; several other islands to the west (George and Three Hill Islands) and north (the Inian Islands) further limit its exposure. A narrow channel leads to an inner cove in a steep-sided valley where the remainder of the sea level infrastructure of the community is located (see Figure 5). There are no roads; a network of boardwalks links the various structures and facilities.

Station characteristics for NOS 9452634 are provided in Table 2, based on the wealth of online tidal information available at NOAA's CO-OPS (Center for Operational Oceanographic Products and Services) website (tidesandcurrents.noaa.gov). Note the sizeable mean diurnal range of over 2.6 meters and that (based on the records at Sitka and Yakutat) there is a significant long-term sea level trend as expected for this tectonically active area of glacial rebound. Seasonal and inter-annual variability is also substantial as are episodic short-term changes associated with meteorology that are reflected in the extremes listed.

Another feature of the local tidal regime, noted earlier, is the strength of the tidal currents, particularly in the North and South Inian Passes that lie between Chichagof Island and the mainland. There is the potential for tidal power generation in these passes, and in Icy Strait to the east. If it comes to fruition, electricity generation could positively impact the local economy and supply both southeast Alaska and nearby British Columbia (Polagye and Bedard, 2006). From the perspective of tsunami hazard however, the bathymetric features that accentuate tidal currents and their spatial variability may pose a significant risk to commercial and recreational marine traffic in the area, including the large cruise vessels that ply the region during the summer months. An unrelated NOAA project, investigating the Cross Sound and Icy Strait region, includes current meter observations from recent years. These have been made available (Stabeno, personal communication) but do not, unfortunately, cover the recent tsunami events. They do, however, provide a baseline for a discussion of the strength of the additional rapidly varying currents that might arise in a major tsunami event.

3.3 Signal to Noise Considerations for the Elfin Cove Tide Gage

Unlike the U.S. West Coast, where the Kuril event of November 2006 is a useful test case for model validation, run-up reports in the NGDC catalog for the Gulf of Alaska are much weaker (~ 12 cm for Sitka and Yakutat and unreported for Elfin Cove). Other events, among the mild tsunamis of recent years, were only weakly felt in the region. The number of test cases for model validation at Elfin Cove is further reduced by weather and wave-related noise background at the tide gages, particularly during the winter months. In addition to sea level itself, the validated 6-minute tide data from CO-OPS provides the standard deviation of the 1-second subsamples used to form each reported value. In the upper panel of Figure 7 the standard deviation is plotted for the month (March 2011) during which the Honshu event occurred. The increased high-frequency activity (periods less than 6 minutes) at the gage associated with the tsunamis arrival on March 11 is evident in the sharp rise in subsample variability as well as in the detided 1-minute gage record (highlighted in red). There is however another period of high variability

(highlighted in blue), of similar duration though of smaller amplitude which we refer to as a “noise burst”. Such bursts are not rare; referring to Figure 8 where an entire year of the subsample standard deviation is employed as a measure of high-frequency variability, the sole tsunami event does not stand out from the numerous bursts that occur particularly during the winter months.

The detided 1-minute record for one day extracts are contrasted in Figure 7, both in the time domain and through a spectral analysis. The spectrum is presented in “energy-preserving” format in the lower panel. Here the area beneath the curves indicates the partition of energy with wave period. With the exception of a broad peak near 100 minutes and another near 8 minutes, the energy of the noise burst is concentrated near the shortest periods detectable. By contrast during the Honshu event the bulk of the energy is in a tsunami band with periods between 10 and 60 minutes. The 100 minute and 8 minute peaks are present together with some other “lines” that may represent resonances associated with the topography.

A similar analysis to that shown in Figure 7 was performed for the month of February 2010 when the Chile-2010 tsunami occurred. One-day subsamples, representing the tsunami (red) and a noise burst (blue), are extracted from the Kalman-filtered, 1-minute record. Longer-period energy again dominates the tsunami subset while the noise burst is dominated by high-frequency energy. There is however more energy in the “tsunami band” than was the case during March 2011. Figure 10 exposes the limitations of the Elfin Cove tide gage in discriminating weak tsunami signals in the presence of noise. The first wave peak of the Kuril-2006 event is barely visible and later waves are lost in the high-frequency noise. In the energy-preserving spectra, in the lower panel of Figure 10, the tsunami band is barely visible.

The detiding, referred to above and used throughout this report, was achieved using the same procedure applied to tide removal in the DART[®] records (Percival et al., 2011) with an R-code script (Percival, personal communication). Based on the spectra presented in Figures 7, 9, and 10, subsequent smoothing of the residuals seems best achieved with a low-pass filter with a cutoff near 10 minutes. This is applied with a Butterworth filter implemented in Matlab and provided by Elena Tolkova (personal communication) .

3.4 The CFL Condition and other considerations for grid design

Water depth dependent wave speed, in conjunction with the spacing of the spatial grid representation, place an upper limit on the time step permissible for stable numerical solutions employing an explicit scheme. This is the CFL limit (Courant-Friedrichs-Levy), which requires careful consideration when the grids employed for a reference or forecast model are being designed. Finer-scale spatial grids, or greater water depths, require shorter time steps thereby increasing the amount of computation required to simulate a specific real time interval.

Another feature of the application of gridded numerical solutions to the tsunami wave problem is the shortening that the wave train encounters in moving from deep water onto

the shelf. In deep water a grid spacing of 4 arc-seconds (of latitude and longitude, corresponding to ~7km) is normally used to represent propagating wave trains whose wavelength is typically of the order of a few hundred kilometers. The stored results of such propagation model runs are typically decimated by a factor of 4, resulting in a database of ~ 30km spacing (and 1 minute temporal sampling) with which to generate the boundary conditions for the outermost of the nested grids in a model solution. The extraction of the boundary conditions (of wave height and the two horizontal velocity components) is achieved by linear interpolation in space and time. To provide realistic interpolated values the stored fields for these variables must be smoothly varying, and have adequate sampling in space and time to resolve their structure. This necessitates the placement of the offshore boundary of the forecast model domain well offshore.

3.5 Specifics of the model grids

After several rounds of experimentation, the extents and resolutions of the nested grids were chosen, and are illustrated in Figures 11 and 12; details are provided in Table 3.

Table 3. Specifics of the Reference (RM) and Forecast model (FM) grids employed for Elfin Cove, AK. For the paired values in the resolution and grid point columns, the zonal (East to West) value is listed first, followed by the meridional (North to South).

Elfin Cove, AK Reference Model (RM)						
Grid	Zonal Extent		Meridional Extent		Resolution	Grid Points
A	138.203°W	129.750°W	54.190°N	59.610°N	48"x24"	635 x 814
B	137.310°W	135.409°W	57.830°N	59.110°N	5.333"x2.667"	1284 x 1729
C	136.430°W	136.260°W	58.090°N	58.330°N	$\frac{4}{3}" \times \frac{2}{3}"$	460 x 1297

Elfin Cove, AK Forecast Model (FM)						
Grid	Zonal Extent		Meridional Extent		Resolution	Grid Points
A	138.210°W	132.210°W	56.010°N	59.610°N	120"x72"	181 x 181
B	136.630°W	136.050°W	57.840°N	58.390°N	8" x 4"	262 x 496
C	136.410°W	136.337°W	58.18°N	58.210°N	$\frac{4}{3}" \times \frac{2}{3}"$	199 x 163

The outermost A-grid encompasses the same northern and western limits in both the Reference Model (RM) and Forecast Model (FM) versions. The RM A-grid extends about two degrees further east and south to permit confirmation that the multiple passages there can be safely excluded from the operational model. The expanded domain includes the Canadian tide gage sites of Prince Rupert and Henslung Cove (on Haida Gwaii, see Figure 1) for validation purposes. For the B-grid the FM domain was somewhat curtailed from its FM equivalent in order to improve operational run times while retaining sufficient resolution to reasonably represent the Inian Passes. The initial choice for the RM B-grid (Figure 11) included more of Dundas Bay to the north but the broad tidal flats, barely submerged with the MHW datum, caused numerous minor local instabilities that, in longer runs, impacted areas further afield. Finally, for the innermost C-grid domains, the same resolution was employed for both the RM and FM versions in order to reasonably represent inner Elfin Cove and its entrance. The RM version is far more

extensive, as seen in Figure 10, extending south into the Port Althorp inlet (see Figure 4a) where a strong response to tsunami waves is felt. For all of the grids, both in the RM and FM versions, the convergence of the meridians at this northerly latitude allows a reduction of a factor of about two in the east-west direction, achieving almost square grid cells in distance units and a considerable saving in computational effort.

Both C-grids lie entirely within the NGDC-provided DEM for Elfin Cove; A and B-grids incorporate bathymetry and topography from other DEM datasets available at NCTR. Some smoothing and editing were necessary to eliminate features that tend to cause model instability. For example, “point” islands where an isolated grid cell stands above water are eliminated, as are narrow channels or inlets one grid unit wide; these tend to resonate in the numerical solution. Large depth changes between adjacent grid cells can also cause numerical problems; customized tools (such as “bathcorr”) are available to correct many of these grid defects. An additional constraint on the bathymetry is the SSL (Elena Tolikova, personal communication), which identifies excessive depth changes in the discrete representation.

Table 4. Grid file names and grid-related parameters for the Elfin Cove model. The time steps for the A and B-grids must be integer multiples of the basic time C-grid time as indicated in parentheses.

Grid	Filename	Maximum Depth (m)	Minimum CFL (s)	Model Time Step (s)	Water Cells
A	ElfinCoveAK_RM_A	3445	4.031	3.0 (12x)	225,975
	ElfinCoveAK_FM_A	2949	11.661	5.0 (12x)	13,142
B	ElfinCoveAK_RM_B	469.6	1.215	1.0 (4x)	743,650
	ElfinCoveAK_FM_B	347.8	2.119	1.667 (4x)	50,619
C	ElfinCoveAK_RM_C	295.1	0.383	0.25	323,566
	ElfinCoveAK_FM_C	204.2	0.461	0.41667	22,301

Table 4 lists the maximum depth, the CFL time step requirement that must not be exceeded, and the actual time steps chosen for the reference and forecast model runs. Since in the current version of MOST, employed by SIFT, the numerical solutions in the three grids proceed simultaneously, there is a requirement that the A and B-grid time steps be integer multiples of the (innermost) C-grid time step in addition to satisfying the appropriate CFL requirement. For both reference and forecast models the CFL requirement for the C-grid was the most stringent. The time step chosen are shown in the fifth column of Table 4 and are such that an integer multiple of each time step is exactly 30 seconds, the chosen output time interval for both models. When run on an Intel® Xeon® E5670 2.93GHz processor the Elfin Cove, AK forecast model simulates four hours in 13.57 minutes, exceeding the 10-minute target for this metric. This is somewhat compensated for by the narrow continental shelf, which reduces the overall simulation time requirement, but the wide range of communities included in the model domain is the main argument against curtailment of the grids to achieve shorter run times.

3.6 Model Run Input and Output Files

In addition to providing the bathymetry file names and the appropriate time step and A, B grid multiples as provided in the tables above, the designer must provide a number of additional parameters in an input file. These include the Manning Friction Coefficient, a depth threshold to determine when a grid point becomes inundated, and the threshold amplitude at the A-grid boundary that will start the model. An upper limit is specified in order to terminate the run if the wave amplitude grows beyond reasonable expectation. Standard values are used: 0.0009 for the friction coefficient and 0.1m for the inundation threshold. The latter causes the inundation calculation to be avoided for insignificant water encroachments that are probably below the uncertainty in the topographic data. Inundation can, optionally, be ignored in the A and B-grids, as is the norm in the (non-nested) MOST model runs that generate the propagation database. When A and/or B-grid inundation is excluded, water depths less than a specified “minimum offshore depth” are treated as land; in effect a “wall” is placed at the corresponding isobath. When invoked, a value of 5m is applied as the threshold, though A and B inundation is normally permitted as a way to gain some knowledge of tsunami impact beyond the scope of the C-grid domain. Other parameter settings allow decimation of the output in space and/or time. As noted earlier, 30-second output has been the target and output at every spatial node is preferred. These choices avoid aliasing in the output fields that may be suggestive of instability (particularly in graphical output), when none in fact exists.

Finally the input files (supplied in Appendix A) provide options that control the output produced. Output of the three variables: wave amplitude, and the zonal (positive to the east) and meridional (positive to the north) velocity components can be written (in netCDF format) for any combination of the A, B, and C-grids. These files can be very large! A separate file, referred to as a “SIFT” file, contains the time series of wave amplitude at discrete cells of a selected grid. Normally the time series at a “reference” or “warning point”, typically the location of a tide gage is selected to permit validation in the case of future or historical events. Also output in the SIFT file is the distribution of the overall minimum and maximum wave amplitude and speed in each grid. By contrast with the complete space-time results of a run, the SIFT file (also netCDF) is very compact and, if more than a single grid point is specified, a broader view of the response is provided.

By default several additional output files are generated: a listing file, which summarizes run specifications, progress, and performance in terms of run time and files that detail modifications to the grid files applied internally by MOST. The listing file provides information on the cause, should a run not start or terminate early. Finally a “restart” file is produced so that a run can be resumed, beginning at the time it ended, either normally or by operator intervention. During execution MOST looks for the presence of a file that signals the operators desire for a controlled termination of a run. A restart file is created allowing the run to be resumed if appropriate.

The input files described above are specific to the model itself. For an actual run, the program must be pointed toward the files that contain the boundary conditions of wave

amplitude (HA), and velocity components (UA, VA), to be imposed at the A-grid boundary. Time varying conditions are generally extracted as a subset of a basin-wide propagation solution (either a single unit source or several, individually scaled and linearly combined) that mimic a particular event. These boundary-forcing files typically consist of 24 hours of values (beginning at the time of the earthquake), sampled at 1-minute intervals and available on a 16 arc-minute grid. Occasionally, for more remote seismic sources (or when delayed arrival of secondary waves due to reflections are a concern, as has been seen at Hawaii), the time span of the propagation run available for forcing is extended beyond one day.

DRAFT

4.0 Results and Discussion

Before proceeding to an extensive suite of model runs, that explore the threat to Elfin Cove and Southeast Alaska from various source regions, the stability of the model is tested in both low and extreme amplitude situations. The former we refer to as “null source” testing: where the boundary forcing is at such a low level (but not precisely zero of course) that the response is expected to be negligible. These tests can be highly valuable in revealing localized instabilities that may result from undesirable features in the discretized bathymetric representation. Inlets or channels that are only one grid cell wide may “ring” or resonate in a non-physical way in the numerical solution. An instability may not grow large enough to cause the model to fail but, in a run with typical tsunami amplitudes, may be masked by actual wave variability.

Forcing by extreme events should also be tested. In addition to the need to test model stability under such circumstances, there is a parameter in the input file that truncates the run if a prescribed threshold is exceeded. For operational use, the threshold must be set high enough so that an extreme event run is not unnecessarily terminated. Both tests should be done for synthetic sources whose waves enter the model domain from different directions since, although stable for one set of incoming waves, instability may result for others. The “null” and “extreme” case testing of the forecast and reference models are reported in the following subsections; the placement of the test sources for these tests is illustrated in Figure 13. Further evidence of stability for the forecast model is provided by a more extensive set of extreme scenarios, described later in the report, and in independent testing by other members of the NCTR team before the model was released for use by the Warning Centers.

4.1 The “Null” Tests

Three null test cases (see Table 5) were run representing sources in the western Aleutians, the Philippines, and south of Japan. Based on sources from the propagation database (Gica et al., 2008), their amplitudes were scaled down by a factor of 100 so as to mimic an $M_w=6.17$ / Slip 0.01m source rather than the $M_w=7.5$ / Slip 1m standard. A number of grid cells in the B and C grids emerged as potential sources of instability. These were generally minor indentations of the coastline, barely resolved by the grids, or narrow channels. The region contains several inlets extending far inland and straits that, at a practical level of spatial resolution, proved difficult to accommodate. Minor grid corrections were made to retain features of potential importance, for example the branch of Lisianski Strait extending westward from near the community of Pelican along the south shore of Yakobi Island. Also retained was Peril Strait, between Chichagof and Baranof Islands, which though narrow in places is a route serving Sitka for the Alaska Ferry System (see Figure 2). A limited number of grid cells in the outermost (A) grid required correction. Generally these were associated with non-physical features in the topographic database, such as where a track of ship-based soundings were improperly merged with other data sources.

Table 5. Synthetic tsunami events employed in Elfin Cove testing. The Reference and Forecast model solutions of those shown in bold text were inter-compared extensively.

Scenario Name	Source Zone	Tsunami Source	α [m]
Mega-tsunami Scenario			
KISZ 1-10		A1-A10, B1-B10	25
KISZ 22-31	Kamchatka-Yap-Mariana-Izu-Bonin	A22-A31, B22-B31	25
KISZ 32-41		A32-A41, B32-B41	25
KISZ 56-65		A56-A65, B56-B65	25
ACSZ 6-15		A6-A15, B6-B15	25
ACSZ 16-25		A16-A25, B16-B25	25
ACSZ 22-31	Aleutian-Alaska-Cascadia	A22-A31, B22-B31	25
ACSZ 40-49		A40-A49, B40-B49	25
ACSZ 50-59		A50-A59, B50-B59	25
ACSZ 56-65		A56-A65, B56-B65	25
CSSZ 1-10		A1-A10, B1-B10	25
CSSZ 37-46	Central and South America	A37-A46, B37-B46	25
CSSZ 89-98		A89-B98, B89-B98	25
CSSZ 102-111		A102-A111, B102-B111	25
NTSZ 30-39	New Zealand-Kermadec-Tonga	A30-A39, B30-B39	25
NVSZ 28-37	New Britain-Solomons-Vanuatu	A28-A37, B28-B37	25
MOSZ 1-10	ManusOCB	A1-A10, B1-B10	25
NGSZ 3-12	North New Guinea	A3-A12, B3-B12	25
EPSZ 6-15	East Philippines	A6-A15, B6-B15	25
RNSZ 12-21	Ryukus-Kyushu-Nankai	A12-A21, B12-B21	25
M_w 7.5 Scenario			
NTSZ B36	New Zealand-Kermadec-Tonga	B36	1
Micro-tsunami Scenarios			
EPSZ B19	East Philippines	B19	0.01
RNSZ B14	Ryukus-Kyushu-Nankai	B14	0.01
ACSZ B6	Aleutian-Alaska-Cascadia	B6	0.01

After an iterative process of grid correction and retesting using these “null” sources, both of the reference (RM) and forecast model (FM) grids were deemed satisfactory and the testing of realistic events could begin. The lower panel of Figure 14 illustrates a step in the process where a deficiency in the RM grid generated a mild instability in the ACSZ B06 micro-tsunami scenario (see Table 5) causing the RM time series at the reference point, initially in close agreement with the FM, to develop unrealistic, high frequency oscillations. Though still generally tracking the FM result, and not growing without bound, the feature could behave erratically in simulating real events. Modification of the RM bathymetry, to exclude the upper portion of Dundas Bay, eliminated the problem, as seen in the third panel of Figure 14, and “null” tests involving other sources (RNSZ B14 and EPSZ B19) did not reveal other issues.

4.2 The Extreme Case Tests

The record of tsunami impact on the southeast Alaskan coast, included in the comprehensive report on the region by Lander (1996) and searchable in the online NGDC catalog (www.ngdc.noaa.gov/hazard/) reveals that sources around the entire periphery of the Pacific can be felt. Indeed the catastrophic Indian Ocean tsunami of 2004 was detected at nearby Sitka and Yakutat though it preceded the current installation of the Elfin Cove gage. A broad suite of 20 extreme events (so-called mega-tsunamis) whose locations are standard for testing of Pacific basin forecast models, are described in Table 5. The normal list is supplemented by one, ACSZ 40-49, which overlays the study area (see Figure 6) and is expected to generate the largest response at Elfin Cove. The locations of the full set can be seen in Figure 31, later in this report, where the impacts to Elfin Cove are presented graphically. To simulate each mega-tsunami source, ten A-B pairs of unit sources (as illustrated in Figure 13) are used, with an evenly distributed slip of 25m in each. As described by Gica et al. (2008), each unit source represents a 100x50km area of the fault surface with the long axis parallel to the plate boundary. The B-row is shallowest, sloping from a nominal depth of 5km (unless a depth estimate has been provided by the USGS based on the earthquake catalogs), row-A is deeper, followed by rows Z, Y, X, ... where appropriate. Thus, the extreme case sources represent 1,000 km long ruptures with a width of 100km; the corresponding moment magnitude is $M_w=9.3$. Note that recent (and future) additions to the propagation database extend portions of the source domain seaward as a C row. The aim is to represent outer-rise earthquake events where they are likely to occur, such as off the Kuril Islands as evidenced by the January 2007 normal fault event.

Discussion of the entire set of mega-tsunamis in greater detail is provided later in the report, once the validity of the Forecast Model has been established by the modeling of historic events. Here we focus on a subset of four, highlighted in Figure 13 and Table 5, to contrast the Forecast Model (FM) with the more highly resolved Reference Model (RM). Results are presented in Figures 15-18, which share a common format. Part a) contrasts the RM and FM maximum amplitude fields in the sub-region of the FM C-grid. The larger C-grid of the reference model is shown at the right to broaden the scope of the result and confirm that nothing untoward happens at the smaller C-grid's boundary. The lower panel compares the time series at the reference point (the Elfin Cove tide gage);

black and red curves represent the RM and FM respectively. Part b) is similar but contrasts the maximum speed fields with the speed time series at the tide gage in the lower panel. Finally part c) for each scenario compares the speed and velocity fields for a single time step, identified by the green line in the lower panel.

It is noticeable that, in the lower panels of part a) for all four of the cases shown, the Reference (RM) and Forecast Model (FM) are in almost perfect agreement for the amplitude of the earliest waves. Phase differences appear later, though the envelope of later wave amplitude is in essential agreement. However there is a tendency for the largest peaks and troughs to appear in the RM solution. This bias is reflected in the maximum wave distributions. Though the structure of the RM and FM maximum amplitude fields is similar, the common color bar can suggest a greater disparity.

The level of agreement for speed is less for the local event ACSZ 40-49 than was seen for its amplitude. After initially close agreement, reference model speeds can be several times larger than those of the forecast model later in the event (Figure 15b). For the more remote sources tested, the level of speed mismatch is far less pronounced. The velocity comparison of Figure 15c is for an early time in the record, as the first wave ebbs. The circulation patterns of the two model results are quite similar though, away from Elfin Cove itself, the RM speeds are somewhat higher.

This larger response of the reference model version quite likely reflects a physical reality: the more highly resolved bathymetry and coastline of the RM provide greater scope for non-linear features or reflected waves to develop. This observation suggests a caveat to operational use of the FM. While accurate portrayal of the early history of an event is to be expected, the duration of the event and the amplitude of some later waves may be under-estimated. Tide gage data will be needed to verify this conjecture, which is pursued later in the report. It is worth noting too that, although the ACSZ 56-65 mega-event represents a massive Cascadia tsunami, the scale of its impact to the Elfin Cove area (~60 cm) is not substantially different from those caused by remote sources: CSSZ 102-111 off southern Chile or MOSZ 1-10 near New Guinea.

In Figure 17c the comparison time was intentionally chosen much later in the CSSZ 102-111 mega-tsunami scenario, although still at a time where the amplitudes at the tide gage are in good agreement. This agreement clearly extends to the velocity field throughout the C-grid domain of the FM. The same is true when, in the case of the MOSZ 1-10 synthetic event (Figure 18c), the comparison time is at the leading edge of the wave's arrival at the tide gage. Note that in Figure 18a the spatial structure of maximum amplitude is consistent between the RM and FM solutions though peaks in the former raise the level. In conclusion it would appear that, while the solutions may temporarily deviate from each other, overall they maintain general agreement over several hours of simulation.

One further confirmatory test of the agreement between the Reference and Forecast versions of the model is usual: a mild source of magnitude 7.5 at a remote location. A single unit source near Samoa (NTSZ-B36) was employed for this purpose and its

representations by the RM and FM are compared in Figure 19. Such an event results in a response of less than a centimeter in Elfin Cove sea level and there is excellent agreement between both model representations in the early portion of the record. Later there is an onset of a high frequency, but low-level, instability in the Reference Model result. Since the forcing fields for NTSZ B36, drawn from the propagation database terminate at 24 hours, it appears that the Forecast model more realistically represents the tapering to zero of the forcing imposed in the MOST model.

4.3 Model Inter-comparison using Historical Cases

Several historical scenarios will be employed in model validation, using observed records from tide gages within the model domain. The issue of validation is somewhat different from that of comparing the predictions of the Reference (RM) and Forecast (FM) versions of the model. Both versions are forced with the same fields, derived in recent events from a fit to DART[®] observations of propagation model results. No tsunami observations along the boundary of the model domain are available and so it is not possible to directly inter-compare the RM and FM response to known forcing.

Thus, and as a means to reduce the volume of graphics in the validation phase, we treat several historical cases as further scenarios (but now based on real situations) with which to inter-compare the models. Similar graphical presentations are employed to those described earlier for the mega-tsunami scenarios. In Figure 20 the maximum amplitude and speed distributions and time series at the Elfin Cove tide gage, and the vector velocity at a single time step, are contrasted for a hindcast of the Honshu-2011 event. The results are quite satisfactory though, as before, the Reference Model tends to produce greater excursions, particularly for speed at the tide gage (Figure 20b). Figure 21 illustrates the Chile-2010 event; the conclusions are similar, though an excessive speed value at low water in the southeast corner of the FM C-grid may indicate a shoal that is not well represented. Figure 22 represents the Alaska-1964 event, the largest event with observations to impact the region. The results are very satisfactory with good agreement between the Reference and Forecast Model renditions of the massive historic event. Finally, in Figure 23, the RM and FM results for a representation of the Chile-1960 event are represented. The unit source representation of this event is based solely on the reported epicenter and moment magnitude of the earthquake, rather than observations of the tsunami it generated. As seen later (Figure 28), the predicted wave amplitude at Sitka is considerably overestimated by the model, though the arrival time is reasonable. However the agreement between the solutions, reflected in Figure 23, is again satisfactory, particularly in Elfin Cove.

These historical cases, together with the mega-tsunami scenarios described earlier, confirm that the Forecast (FM) version of the model captures the essential features of the more highly resolved (and slower running) Reference Model (RM). It may reduce somewhat the extreme amplitudes and speeds within the domain, but does perhaps, produce more realistic results for later waves.

4.4 Model Validation: The Honshu-2011 Tsunami

In addition to its disastrous impact on the coast of Japan, the Honshu tsunami of March 11, 2011 radiated waves throughout the Pacific Basin. Those arriving at nearby DART[®]s were of unprecedented amplitude and their signal/noise ratios facilitated accurate and early source characterization. Further afield, the waves were detectable at all operational DART[®]s in the basin (26 in all) and, while major damage was mainly confined to Japan, significant signals were obtained at multiple coastal tide gages. Prior to this event, the Kuril-2006 tsunami event was the best available for model validation. For the U.S. West Coast and Southeast Alaska at least, that role has now been taken by Honshu-2011. The adequacy of the composite propagation solution can be assessed by comparison with the BPR signal from the closest DART[®] 46410, some 440 km west of Elfin Cove. Located 1,140 km to the south of Elfin Cove, the northernmost West Coast DART[®], 46419, was unfortunately out of action in early 2011.

In Figure 24 the eastward progression of predicted tsunami waves from the Honshu-2011 event across the North Pacific, as observed by the DART[®] array, is illustrated and compared with the forecasts produced in real-time using SIFT. As described earlier, the first phase in the forecast process is to ingest observations from the closest DART[®](s), and determine the linear combination of unit sources from the propagation database that best matches those observations. In addition to providing the boundary conditions for the community-specific forecast models, the linearly-combined propagation solution can be directly interrogated to provide forecasts for DART[®]s not involved in its selection. It is this set of forecasted DART[®] time series that are compared with the observations in Figure 24.

There is clearly a strong agreement between the first wave of the tsunami as detected by the DART[®] sensors (drawn as black curves) and model predictions (drawn in red), although the observations increasingly lag the predictions and the ratio of their amplitudes varies with location. Ultimately, on reaching DART[®] 46410, the model “waves” are seen to be about nine minutes early, a difference that is small compared to the several hours of transit time. Perhaps coincidentally the amplitude ratio for the leading wave (denoted by R in Figure 24) is closest to unity for the DART[®] (46410) closest to Elfin Cove. Four DART[®]s between Oregon and southern California (46404, 46407, 46411 and 46412, not shown in Figure 24) have amplitude ratios of approximately 1.5 – 2.0 and time lags of about 8 minutes. Early arrival model is typical and is associated with the limited resolution of the basin-wide bathymetry. Finer-scale features in the actual bathymetry, such as the Emperor Seamount chain in the western Pacific (south of ACSZ B06 in Figure 13), slow down the real wave trains. As part of the ongoing testing and evaluation (OT&E) process to determine the suitability of SIFT for operational use, the forecast procedures are applied in hindsight using accuracy metrics based on the success of a set of forecast models in replicating tide gage observations. While such ongoing efforts may determine the “best” propagation solution, for the purpose of model validation in this report, we employ the real time source characterization defined in Table 6. It is one of the sources employed by Tang et al. (2012) in characterizing the energy released by the Honshu-2011 event.

Figure 25 compares Reference (RM) and Forecast (FM) predictions with observations, at several sites within the model domain (Ketchikan falls outside the FM grids though it is available to the RM.) The observed time series are 1-minute tide gage data (6-minute in the case of Skagway), detided using the Kalman Filter (Percival et al., 2011) and low pass filtered. Black and red curves represent Reference (RM) and Forecast Model (RM) predictions; the green curves are the detided and filtered observations. Runup values, from the NGDC catalog, are indicated in this and subsequent figures. At Elfin Cove itself, the focus of the innermost C-grid, the result is satisfactory: the model waves arrive early and slightly under-estimate the amplitude of the leading wave (but consistent with expectation based on Figure 24), and the later waves sustain a level consistent with the data. The other sites are in the outermost A-grid, whose reduced spatial resolution has limited ability to reflect complex topography. In particular the Gastineau Channel leading to Juneau is not resolved at all in the FM A-grid and only poorly in the RM version.

Nonetheless the results for these A-grid sites are, in most cases, quite gratifying (Skagway and Ketchikan are underestimated by the model). For Sitka, close to the open ocean, the results are best both for the leading wave and the amplitude of the later waves. At Port Alexander the match for the leading wave is acceptable but the excessive noise in the observed record obscures the later waves. For the remaining sites, which currently do not have dedicated forecast models, the degree of agreement is such as to suggest their utility as a significant improvement over a Green's Law coastal forecast. When the forecast models specific to Sitka and Port Alexander are validated the degree of agreement with the Elfin Cove A-grid results should be used to cast further light on this conjecture. The main reason that the Elfin Cove A-grids are so extensive is to ensure that tsunami waves entering Cross Sound and Icy Strait, from the east are appropriately represented. The relative success in replicating the observations from Juneau and Skagway suggest that this goal has been met.

Table 6. Source characterization for historical tsunami events employed in Elfin Cove model testing. Those in bold text were used in RM/FM inter-comparison. Sources identified as “ad hoc” may not be identically defined in other Forecast Model reports.

Event	Earthquake / Seismic				Model			
	USGS		CMT		Tsunami Magnitude	Subduction Zone	Tsunami Source (Reference/Derivation)	
	Date Time (UTC) Epicenter	Date Time (UTC) Centroid	Magnitude M_w					
1946 Unimak	01 Apr 12:28:56 52.75°N 163.50°W		8.5		8.5	ACSZ	7.5×B23 + 19.7×B24 + 3.7×B25 (López & Okal, 2006)	
1952 Kamchatka	04 Nov 16:58:26.0 52.76°N 160.06°E		9.0		9.0	KISZ	19.71 × (A4 + Y4 + Z4 + A5 + Y5 + Z5 + A6 + Y6 + Z6) (ad hoc)	
1957 Andeanof	09 Mar 14:22:31 51.56°N 175.39°W		8.6		8.7	ACSZ	31.4×A15 + 10.6×A16 + 12.2×A17 (Preliminary)	
1960 Chile	22 May 19:11:14 38.29°S 73.05°W		9.5		9.5	CSSZ	125×(A93 + B93 + Z93 + A94 + B94 + Z94 + A95 + B95) Kanamori & Cipar (1974)	
1964 Alaska	28 Mar 03:36:00 61.02°N 147.65°W		9.2		8.9	ACSZ	15.4×A34 + 18.3×B34 + 48.3×Z34 + 19.4×A35 + 15.1×B35 (Tang et al., 2006, 2009)	
1994 East Kuril	04 Oct 13:22:58 43.73°N 147.32°E	04 Oct 13:23:28.5 43.60°N 147.63°E	8.3		8.1	KISZ	9.0×A20 (ad hoc)	
1996 Andeanof	10 Jun 04:03:35 51.56°N 175.39°W	10 Jun 04:04:03.4 51.10°N 177.410°W	7.9		7.8	ACSZ	2.40×A15 + 0.80×B16 (Preliminary)	
2001 Peru	23 Jun 20:33:14 16.26°S 73.64°W	23 Jun 20:34:23.3 17.28°S 72.71°W	8.4		8.2	CSSZ	5.7×A15 + 2.9×B16 + 1.98×A16 (Preliminary)	
2003 Hokkaido	25 Sep 19:50:06 41.77°N 143.904°E	25 Sep 19:50:38.2 42.21°N 143.84°E	8.3		8.3	KISZ	3.95 × (A22 + B22 + A23 + B23) (ad hoc)	
2003 Rat Island	17 Nov 06:43:07 51.13°N 178.74°E	17 Nov 06:43:31.0 51.14°N 177.86°E	7.7		7.8	ACSZ	2.81×B11 (Real-time)	
2006 Tonga	03 May 15:26:39 20.13°S 174.16°W	03 May 15:27:03.7 20.39°S 173.47°W	8.0		8.0	NTSZ	6.6×B29 (ad hoc)	
2006 Kuril	15 Nov 11:14:16 46.607°N 153.230°E	15 Nov 11:15:08 46.71°N 154.33°E	8.3		8.1	KISZ	4.0×A12 + 0.5×B12 + 2.0×A13 + 1.5×B13 (Real-time)	
2007 Kuril	13 Jan 04:23:20 46.272°N 154.455°E	13 Jan 04:23:48.1 46.17°N 154.80°E	8.1		7.9	KISZ	-3.64 × B13 (Real-time)	
2007 Solomon	01 Apr 20:39:56 8.481°S 156.978°E	01 Apr 20:40:38.9 7.76°S 156.34°E	8.1		8.2	NVSZ	12.0×B10 (Preliminary)	
2007 Peru	15 Aug 23:40:57 13.354°S 76.509°W	15 Aug 23:41:57.9 13.73°S 77.04°W	8.0		8.1	CSSZ	0.9×A61 + 1.25×B61 + 5.6×A62 + 6.97×B62 + 3.5×Z62 (Preliminary)	
2007 Chile	14 Nov 15:40:50 22.204°S 69.869°W	14 Nov 15:41:11.2 22.64°S 70.62°W	7.7		7.6	CSSZ	1.65×Z73 (Real-time)	
2009 Samoa	29 Sep 17:48:10 15.509°S 172.034°W	29 Sep 17:48:26.8 15.13°S 171.97°W	8.1		8.1	NTSZ	3.96×A34 + 3.96×B34 (Real-time)	
2010 Chile	27 Feb 06:34:14 35.909°S 72.733°W	27 Feb 06:35:15.4 35.95°S 73.15°W	8.8		8.8	CSSZ	17.24×A88 + 8.82×A90 + 11.84×B88 + 18.39×B89 + 16.75×B90 + 20.78×Z88 + 7.06×Z90 (Real-time)	
2011 Honshu	11 Mar 05:47:24 38.297°N 142.372°E	11 Mar 05:47:47.2 38.486°N 142.597°E	9.0		9.0	KISZ	4.66 × B24 + 12.23×B25 + 26.31×A26 + 21.27×B26 + 22.75×A27 + 4.98×B27 (Real-time; Tang et al., 2012)	

4.5 Further Historical Simulations

Before proceeding with the discussion of the historical simulations, the contents of Table 6 should be defined. Two specifications of source location and time are given: one based on the epicenter and reported early in the event, the other coming later as seismic waveforms from a more widespread set of stations are assimilated. The latter Centroid-Moment-Tensor (CMT) solution provides details of the source mechanism, moment magnitude (listed in Table 6). The right hand side of Table 6 provides the specifics of the combination of unit sources employed to represent the tsunami waves. The subduction zone in which the event occurred is given by a 4-character acronym: ACSZ for example refers to a line of unit sources extending from the western Aleutians to Cascadia. Individual unit sources are identified by a character-number combination. Further detail on each unit source can be found in Gica et al., (2008) and in Appendix B of this report.

As discussed earlier, a linear combination of unit source functions provides the time varying forcing of the model that simulates a tsunami event. The coefficient applied to each source function is a weight assigned to the 100x50km sub-fault it represents. Thus, in the final column of Table 6, the term “7.5xB23” in the characterization of the 1946 Unimak event implies a scaling by a factor of 7.5 of unit source B23 in the Aleutian to Cascadia subduction zone. Each unit source represents a moment magnitude 7.5 event; by combining the coefficients a “Tsunami Magnitude” can be produced. It should be stressed that this is not an alternate estimate of the magnitude of the seismic event. Rather it summarizes the combined effect of the unit sources in generating tsunami waves.

Since the advent of the tsunameter array, and the SIFT system to invert its observations, the “recipes” (linear combinations of unit source functions) for events are being produced in “real-time” and are classified as such in Table 6. The tsunamigenic description of earlier events have in some instances been reconstructed from tide gage observations and reported in the literature. Others in Table 6 are listed as “preliminary” in the sense that they have not been thoroughly studied but show some skill in representing an event. Included in Table 6 are several sources considered “ad hoc”. Generally chosen as equally-weighted groupings of unit sources whose location and scaling are based on the epicenter and magnitude of an event, they should be considered as exploratory providing a “reality check” on the waves that might be hindcast for the model domain. Since in reality tsunami waves may be less than the magnitude of the earthquake would suggest, or exceed expectation if for example a submarine landslide were triggered, the quality of the ad hoc cases will likely be poor. The arrival time of the simulated waves may be of use for comparison with observations.

Model validation, based on a DART[®]-derived propagation solution, is possible for the Chile-2010 event and is illustrated in Figure 26. The source characterization given in Table 6 was derived in real-time as the waves were detected at DART[®] sites in the southeast Pacific and were successfully employed to forecast impacts to Hawaii and the U.S. West Coast. With regard to timing and overall amplitude the model predictions are satisfactory in the Gulf of Alaska, but neither the Reference (RM) nor Forecast (FM) versions capture the leading trough apparent in the observed time series at Elfin Cove and

Sitka. Port Alexander is again noisy but at the remaining sites the amplitude at least of the response is reasonably rendered for all of the sites shown.

For south and southeast Alaska the defining tsunami event to date has been that associated with the 1964 earthquake in Prince William Sound. Though preceding open ocean tsunami detection, the source characteristics were elucidated through a number of studies incorporating seismic and tide gage records. The unit source selection and slip assignments provided in Table 6 are discussed by Tang et al., (2006, 2009) and used successfully in modeling the impact on Hawaii. In Figure 27 the predictions of the impacts at several sites in the Elfin Cove model domain are presented. Only for Sitka is an observed time series available but several runup values are available from the NGDC catalog. The Sitka time series is based on a digitized marigram, available in the WCATWC archives and detided and filtered using the same methods employed throughout this study. The comparison with the reported runup values at Sitka, Juneau, and Ketchikan is satisfactory. At Elfin Cove itself the model results are only about 50% of the reported runup. This was derived from the tide gage but the marigram is not available. The Skagway runup (eyewitness report) is also under-predicted by the model but overall, the success in replicating the character of this huge event, together with the results from the Honshu-2011 analysis, discussed earlier, strongly support the validity of the Elfin Cove models.

Two other historical events are represented by digitized marigrams for Sitka in the WCATWC archives: Kamchatka-1952 and Chile-1960. The results for these are provided in Figure 28. Perhaps because these are remote events, so that the source characterizations (in Table 6) are less appropriate to the Gulf of Alaska, the level of success in validating the Elfin Cove model with these cases is much less than for the local Alaska-1964 tsunami. The model prediction at Sitka for the Chile-1960 event is too large by a factor of 4-5, as is that for Kamchatka-1952! Further effort is clearly needed to more appropriately define these source in terms of the propagation database when the application of the model to these historically important events should be revisited.

Next, in Figure 29, simulated historical events from Table 6 since the advent of the DART[®] array are presented. The results are disappointing at best, though they do confirm a feature of the region noted earlier: Elfin Cove is less impacted by trans-basin tsunami sources than other U.S. interests in the Pacific. On a less positive note the frequent noise bursts in recorded sea level, associated with wind and waves and illustrated in Figure 8, limit the suitability of Elfin Cove as a monitoring site for weak tsunami signals thereby limiting the number of recent events available for model validation.

The modeling results for the remaining standard cases, those prior to the advent of the DART[®] array and lacking any time series in the vicinity of Elfin Cove, are presented in Figure 30. The time series represent Elfin Cove but NGDC runup values from nearby Sitka are shown when available. These model time series do little beyond demonstrating the absence of stability issues in the application of the model.

A number of other local events, not included in Table 6 but mentioned earlier in the context of seismic hazard, deserve investigation. On September 10, 1899 a major earthquake occurred in Yakutat Bay, and was one of the earliest events measured by seismograph. Several tsunami observations outside the immediate vicinity of Yakutat were reported (Lander, 1996) though some may have been associated with secondary generation through landslides. An icefall was reported in Glacier Bay but no tide gages were operational in Alaska at the time. On October 24, 1927 a magnitude 7.1 earthquake occurred that affected the Alexander Archipelago with widespread qualitative, but no quantitative reports. The Queen Charlotte earthquake of August 22, 1949 had reported observations in the Sitka area but only an unreliable 8 cm measurement on the marigram. The Fairweather earthquake of July 10, 1958 is best known for the Lituya Bay landslide and tsunami it triggered. There were reports of seiching in Cross Sound and a weak wave of about 10 cm was reported on the Sitka tide gage. A magnitude 7.6 earthquake near Sitka on July 30, 1972 was felt over a wide area but registered only 10cm at Juneau and 8cm at Sitka itself. The Cross Sound sequence of earthquakes in mid-1973 have been discussed in the seismological literature (Doser and Lomas, 2000) but no reports appear in the tsunami catalogs.

None of these local events are well enough described or observed to merit a full investigation, or inclusion in Table 6 as well-documented tsunami sources. Instead approximate (ad hoc) source definitions were adopted and run to ensure no untoward behavior of the model. The results are summarized in Table 7 and, where observations at Sitka are reported in the catalogs, they are approximately confirmed. When sources are designated as “ad hoc” in Table 6, they may not be uniformly implemented in other Forecast Model reports.

Table 7. Ad hoc unit source representation of several local events for southeast Alaska investigated using the Elfin Cove forecast model, with Sitka observations where available.

Event	M _w Estimate	Date	Location	Unit Sources Used	Maximum Amplitude (cm)		Sitka Reports (cm)
					ElfinCove	Sitka	
Yakutat Bay	8.2	10 Sep 1899	60N, 140W	40-42 A,B	17.4	30.5	n/a
Sitka Region	7.4	24 Oct 1927	57.7N, 136.1W	44 B	7.4	5.5	n/a
Queen Charlotte	8.1	22Aug 1949	53.6N, 133.3W	47-51B	4.1	16.4	8
Fairweather Fault	7.7	10 Jul 1958	58.3N, 136.5W	43A	26.8	12.2	10
Sitka Region	7.6	4 Aug 1972	56.2N, 135.3W	46B	6.1	33.4	8
Cross Sound	6.7	1 Jul 1973	57.8N, 137.3W	43B	1.2	0.9	n/a

One other event was noted in the run-up catalog statistics for Sitka: on November 29, 1975 a magnitude 7.2 earthquake on the island of Hawaii triggered the Kalapana landslide off the southeast coast, generating waves which were seen at several sites around the Pacific, Sitka AK was among them with an amplitude of about 10cm. The marigram shown in Lander (1996) was digitized. Although the MOST model in its current form does not apply to landslide-generated tsunamis and there are not unit sources near Hawaii, a similar modeling approach to ours was applied by Ma et al. (1999) to study the local impact. An ad hoc source was created (Newman, personal communication), mimicking that of Ma et al. (1999), and applied to the Elfin Cove model. The result was of the appropriate amplitude and consistent with the reported arrival time. Given the typical noise environment of the Gulf of Alaska in November, this side exercise is not conclusive but does perhaps provide indirect support to the model.

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4.6 Simulation of the remaining Synthetic Mega-events

We conclude this section with a summary of other model runs that were made in order to verify its stability, but which provide useful information on the exposure of the Elfin Cove region to potentially hazardous future events within the Pacific. As noted earlier, the sparse instrumental record of actual events needs to be augmented with credible scenarios to permit risk assessment. While not pretending to be a full-blown risk assessment for the region, the full set of mega-tsunamis modeled during stability testing can provide some early estimates.

Table 8. Comparison of the response at Elfin Cove, AK to that of Point Reyes, CA (Spillane, 2011) for synthetic (M_w 9.3) mega-tsunami scenarios, The maximum amplitude at the reference point is used as the measure of response which is generally far weaker at Elfin Cove than at Point Reyes. The ratio, expressed as a percentage is tabulated below; the Elfin Cove responses are illustrated graphically in Figure 31.

Scenario Name	Source Region	Response (cm) Elfin Cove	Response (cm) Point Reyes	Ratio (%)
KISZ 1-10	Kamchatka	27.6	354	7.8
KISZ 22-31	Japan Trench	42.9	251	17.1
KISZ 32-41	Bonin Trench	31.3	318	9.8
KISZ 56-65	Mariana Trench	33.9	166	20.4
ACSZ 6-15	West Aleutians	26.3	134	19.6
ACSZ 16-25	Aleutian Trench	37.9	266	14.2
ACSZ 22-31	Aleutian Trench	59.8	239	25.0
ACSZ 40-49	Cross Sound	495.7	n/a	n/a
ACSZ 50-59	Cascadia-North	65.2	202	32.3
ACSZ 56-65	Cascadia-South	59.6	159	37.5
CSSZ 1-10	Mid-America Trench	11.5	99	11.6
CSSZ 37-46	Colombia-Ecuador	43.2	42	102.9
CSSZ 89-98	Chile Trench	11.9	140	8.5
CSSZ 102-111	South Chile	28.0	265	10.6
NTSZ 30-39	North Tonga Trench	38.9	402	9.7
NVSZ 28-37	New Hebrides Trench	56.4	258	21.9
MOSZ 1-10	Manus, West Melanesia	55.3	460	12.0
NGSZ 3-12	New Guinea	42.6	162	26.3
EPSZ 6-15	East Philippines	34.9	246	14.2
RNSZ 12-21	Ryukyu	15.8	209	7.6

Mega-tsunami sources, not highlighted in Table 5, were investigated with the Forecast Model alone; results for the entire set of twenty are provided in Table 8 and Figures 31 and 32. Each source is a composite of 20 unit sources (see Figure 13) from the A and B rows with an evenly distributed slip representing an M_w 9.3 event. A color-coded square, drawn at the geometric center of each synthetic source, is used to represent the impact at

the Elfin Cove tide gage predicted for that source. The measure of impact employed, in Table 8 and Figure 31, is the maximum amplitude of the predicted time series at the reference point. Great circle distances to Elfin Cove are provided and a vector, normal to the source line, is drawn as a crude indicator of the initial main beam orientation. The impact of the local mega-source (ACSZ 40-49) dominates all others. Moderate impacts are associated with the closer sources (AC 22-31 near the Alaskan Peninsula, and ACSZ 50-59 and 56-65 representing the northern and southern portions of Cascadia) but otherwise the impacts are only loosely related to distance. Sources in the southwest Pacific (NVSZ 28-37 near the New Hebrides, and MOSZ 1-10 near Manus) have almost as large an impact although, with one exception beyond the local source, the impact predicted for Elfin Cove is much less than that expected along the U.S. West Coast (see Table 8, where Point Reyes, CA is used for comparison).

The results provided in Table 8 and Figures 31 and 32 are specific to the reference site: the Elfin Cove tide gage. Based on the 20 mega-tsunami simulations, impact statistics were extracted for several communities in the region. The results are presented in Table 9, whose footnote identifies the site name abbreviations. Values provided for Sitka and Port Alexander would be better represented by their specific forecast models which better resolve local bathymetry. With the exception of Elfin Cove itself, the other sites are represented by A-grid cells close to their geographic coordinates. Several of the communities are marked in Figure 2. Pelican, though unlabeled in Figure 2, is at the north-western terminus of the Alaska ferry routes shown and can also be seen in Figure 4a. Bartlett Cove, north of Point Gustavus in Figure 4a, is offshore of the Visitor Center where cruise ships take on their National Park guides at the entrance to Glacier Bay. Auke Bay, also unlabeled in Figure 2, is northwest of Juneau and home to an Alaska Fisheries Science Center laboratory.

Figures produced earlier, that showed the distribution of maximum current speed in the Reference Model C-grid, confirmed the strength of tsunami-induced currents in the Inian Passes north of Elfin Cove. Since these are already well known for strong tidal currents, are traversed by ferries and cruise ships plying the Alaska Marine Highway, and have potential for tidal power generation, it seems worthwhile to extract from the model results estimates of the additional rapidly varying current speeds that might accompany a major tsunami event. A comprehensive treatment would jointly model tides and tsunami so the results provided in Table 10 are incomplete. Results are given for a selection of sites, shown in Figure 33, instrumented by NOAA's EcoFOCI program during 2010 and 2011. The sampling interval of the Acoustic Doppler current profilers is not suited to tsunami study and the instruments were not deployed during the Honshu-2011 event. The final row of Table 10 provides an estimate of the maximum current at each site, based on the 95th percentile of the depth average (only 5% of the currents exceed the tabulated value).

The strongest observed tidal currents are at the shallower locations: South Inian Pass and the mouth of Glacier Bay. Even shallower depths in the 30-40 meter range are found south of the latter marking the terminal moraine of the Glacier Bay glacier which protruded into Icy Strait in the mid-1700s at the end of the Little Ice Age. Only for the local mega-event scenario (ACSZ 40-49) do the maximum tsunami current speed

predictions exceed those associated with the tides. However, with their rapid changes in direction, tsunami-induced currents are potentially of concern. In Figure 33, the greatest currents are to be expected near the western end of South Inian Pass with predicted currents in excess of 10 knots for the ACSZ 40-49 scenario.

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Table 10. Maximum speeds at various locations from Cross Sound to Icy Strait in megatsunami simulations using the Elfin Cove forecast model (FM/RM in the rows with bold text). Speeds are given in knots for ease of comparison with the NOAA chart warnings of tidal currents of 8-10 knots that are frequently encountered in North and South Inian Passes. Observed maxima (and water depths) are based on NOAA EcoFOCI current meter data from 2010 and 2011.

Scenario Name	Cross Sound	North Inian Pass	South Inian Pass	Glacier Bay	Icy Strait
KISZ 1-10	0.10	0.26	0.58	0.17	0.22
KISZ 22-31	0.13	0.28	0.61	0.15	0.17
KISZ 32-41	0.14	0.26	0.60	0.12	0.20
KISZ 56-65	0.11	0.34	0.80	0.13	0.26
ACSZ 6-15	0.08	0.18	0.39	0.14	0.21
ACSZ 16-25	0.12	0.34	0.78	0.23	0.30
ACSZ 22-31	0.17	0.45	0.97	0.23	0.38
ACSZ 40-49	1.39 / 1.43	3.52 / 3.35	5.63 / 6.78	1.93 / 1.55	2.33 / 2.77
ACSZ 50-59	0.23	0.69	1.56	0.35	0.48
ACSZ 56-65	0.19 / 0.23	0.71 / 0.61	1.40 / 1.39	0.29 / 0.42	0.29 / 0.46
CSSZ 1-10	0.04	0.15	0.28	0.08	0.08
CSSZ 37-46	0.07	0.19	0.34	0.08	0.09
CSSZ 89-98	0.12	0.32	0.67	0.22	0.15
CSSZ 102-111	0.18 / 0.17	0.42 / 0.32	0.87 / 0.71	0.24 / 0.20	0.23 / 0.23
NTSZ 30-39	0.12	0.27	0.54	0.18	0.21
NVSZ 28-37	0.15	0.39	0.83	0.17	0.27
MOSZ 1-10	0.16 / 0.23	0.35 / 0.35	0.74 / 0.95	0.25 / 0.18	0.25 / 0.18
NGSZ 3-12	0.16	0.36	0.91	0.26	0.48
EPSZ 6-15	0.09	0.30	0.72	0.20	0.25
RNSZ 12-21	0.06	0.16	0.38	0.06	0.14
Observed Maxima (kts)	1.19 (318m)	2.21 (289m)	3.16 (72m)	3.49 (71m)	1.24 (132m)

5.0 Conclusions

To conclude, good agreement between observations and model predictions for a subset of the larger historical events, including the recent Honshu-2011 tsunami, has been established and the stability of the model for numerous synthetic events has been demonstrated. In particular the reliability of the forecast model, designed to run rapidly in a real time emergency conditions, has been proven by the favorable comparison with reference model predictions, particularly during the early hours of an event. The model will be included in the SIFT system employed by the Tsunami Warning Centers, and will permit the Cross Sound - Icy Strait region of southeast Alaska and the community of Elfin Cove to be added to the coastal areas for which forecast capability is available. Additionally it will provide a tool of use in risk assessment studies.

The presence of Icy Strait, linking Cross Sound to the deep north-south channel of Chatham Strait, necessitated a more extensive outermost grid for the Elfin Cove model. While this increases model run-time somewhat, it does provide the benefit of permitting forecasts for communities not presently selected for specific forecast models: Juneau and Skagway for example. Statistics for tsunami wave amplitude were extracted during model development and testing for other communities of southeast Alaska and maximum tsunami-induced currents were extracted for the Cross Sound – Icy Strait region where tidal currents are known to be strong.

Testing of model stability using mega-tsunami ($M_w=9.3$) scenarios from a selection of sites around the Pacific Rim suggest that, with the exception of sources in the vicinity of Elfin Cove, the impact there is considerably less than on the U.S. West Coast. This, in conjunction with recurring episodes of noise at the tide gage, substantially reduced the number of historical events in recent years available for model validation. Tsunami waves emanating from the southwest Pacific result in proportionately greater response in the Alaska Panhandle. The report does not suggest that the mega-event scenarios represent probable tsunami sources and should not be considered a thorough risk assessment study.

In addition to the scenarios run by the author, and reported here, further tests have been made by other members of the group at NCTR, and will continue to be made by staff at the Warning Centers and others, perhaps in training situations. Among the many related tools developed at NCTR is ComMIT (Community Model Interface for Tsunami, nctr.pmel.noaa.gov/ComMIT/), which provides a highly intuitive graphical environment in which to exercise and explore forecast models for any combination of propagation database unit sources. Were any of these avenues to reveal a problem with the model, its origin (most likely in some quirk of the bathymetric files) would be located and corrected and the revised version re-installed at the Warning Centers. The development of the forecast system will be a dynamic process, with new models added (and old ones revisited) from the current list of U.S interests and globally. In the coming years it is expected that further capabilities will be added as algorithms and methodologies mature.

6. Acknowledgments

Many members of the NCTR GROUP provided valuable assistance in the production of this report. In particular Diego Arcas edited the first draft for content and style; Elena Tolkova provided scripts for filtering time series and bathymetry. The modeling could not proceed without the detailed DEMs produced at NGDC by the painstaking combination of numerous bathymetric and topographic surveys. Digitized marigrams for a number of historic events were acquired from the WCATWC archives. Figure 2 was reproduced with the permission of the Alaska Department of Transportation and Public Facilities. Current meter observations from the Cross Sound–Icy Strait region were provided by the EcoFOCI group at NOAA-PMEL. This publication is partially funded by the Joint Institute for the Study of the Atmosphere and Ocean (JISAO) under NOAA Cooperative Agreements NA17RJ1232 and NA10OAR4320148, Contribution No. XXXX. It is PMEL Contribution No. NNNN

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doi:10.1029/2011JB008493, 2012.

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FIGURES

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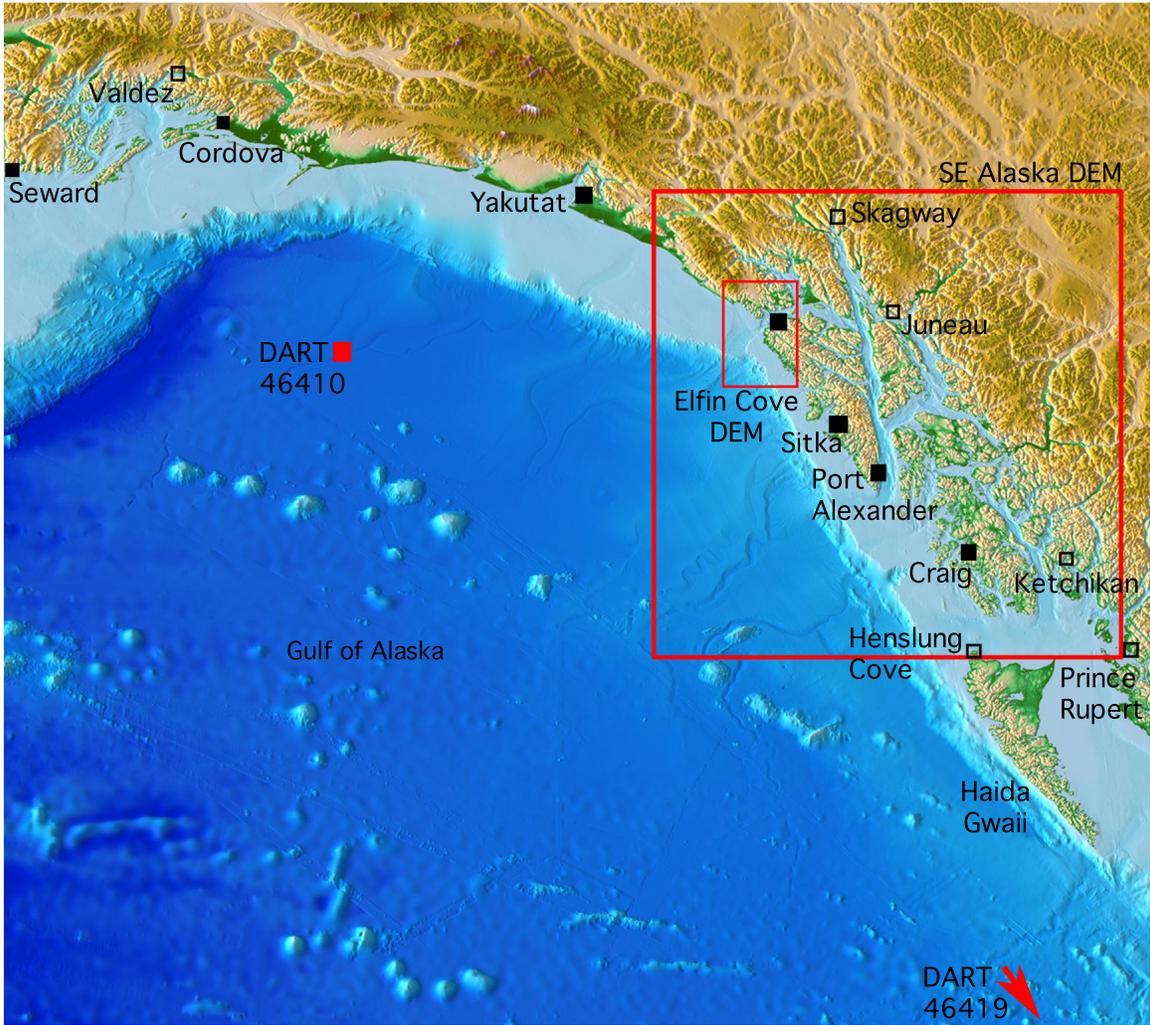


Figure 1. The northern Gulf of Alaska showing regional Digital Elevation Model (DEM) resources, tide gage, and DART® tsunami detection assets.

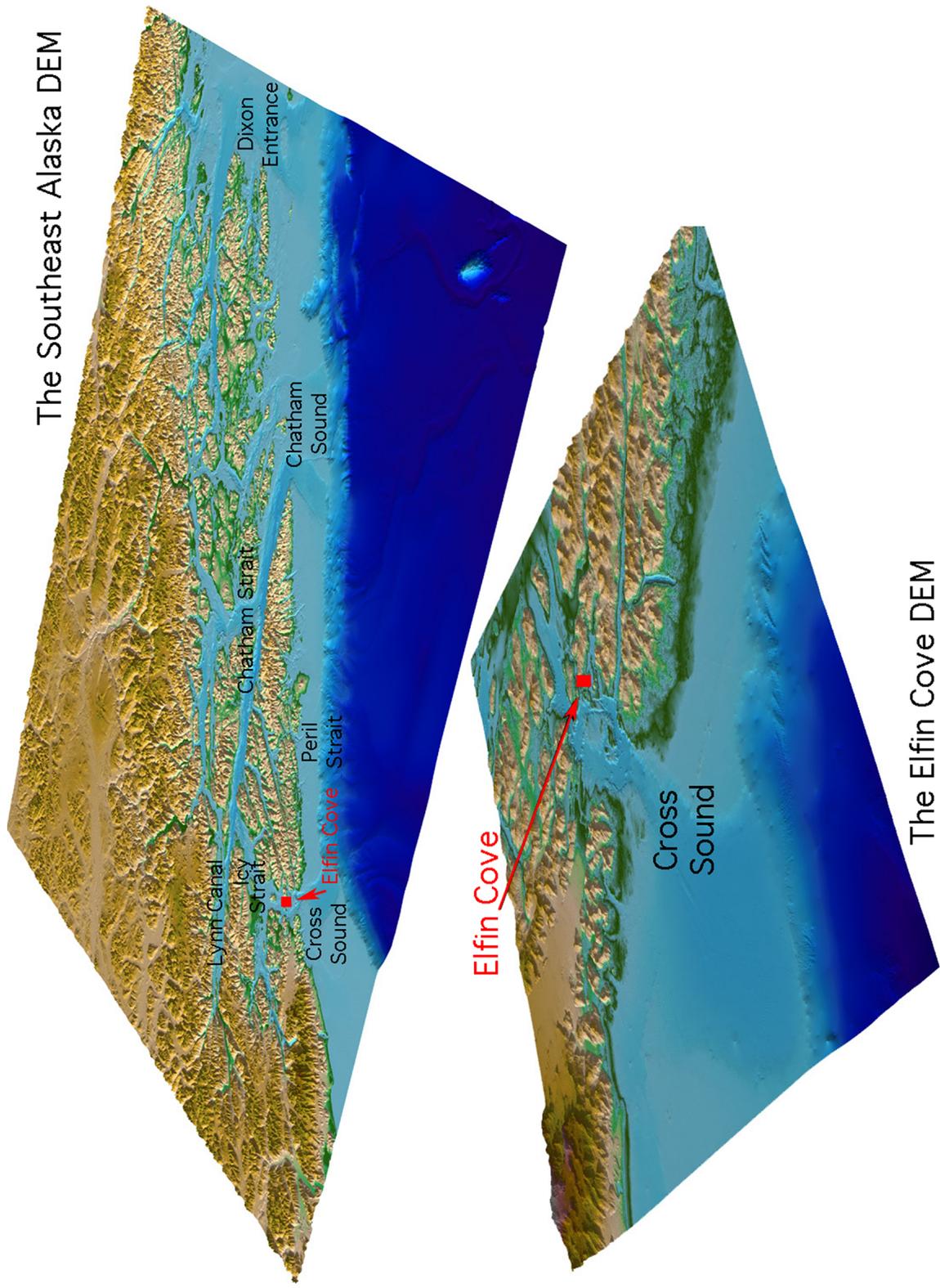


Figure 3. Oblique views of the Southeast Alaska and Elfin Cove Digital Elevation Models developed by the National Geophysical Data Center.



Figure 5. View south east into Elfin Cove's inner cove showing the boardwalks, finger docks (visible in Figure 4b) and other community facilities. (Photograph by Rick Sood <http://roundezvous.com/Images/Alaska2006/ElfinCove.jpg>)

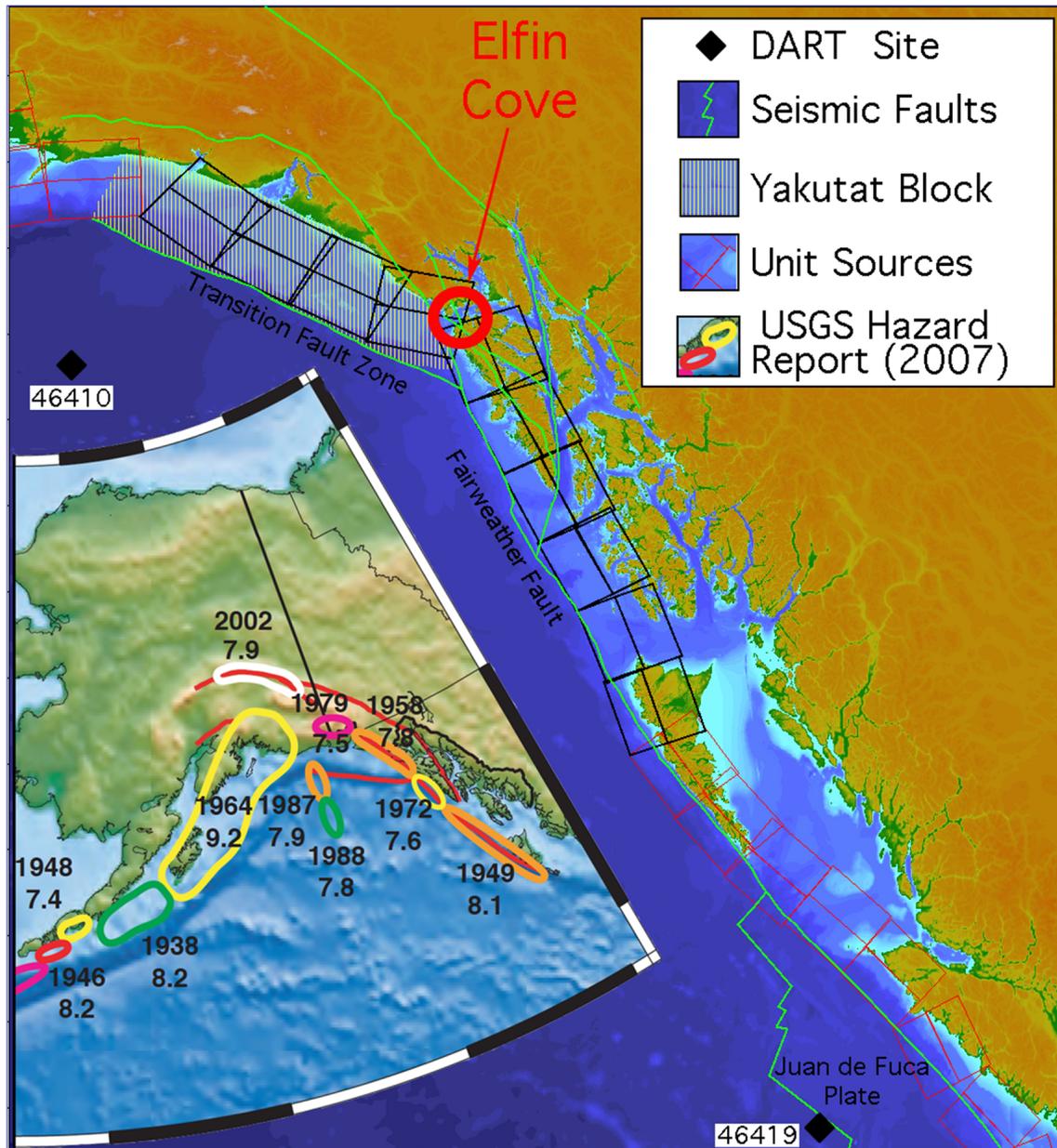


Figure 6. Regional seismic hazards and the unit sources employed to model their tsunamigenic potential. The inset panel is adapted from the USGS Seismic Hazard Maps for Alaska (Wesson et al., 2007).

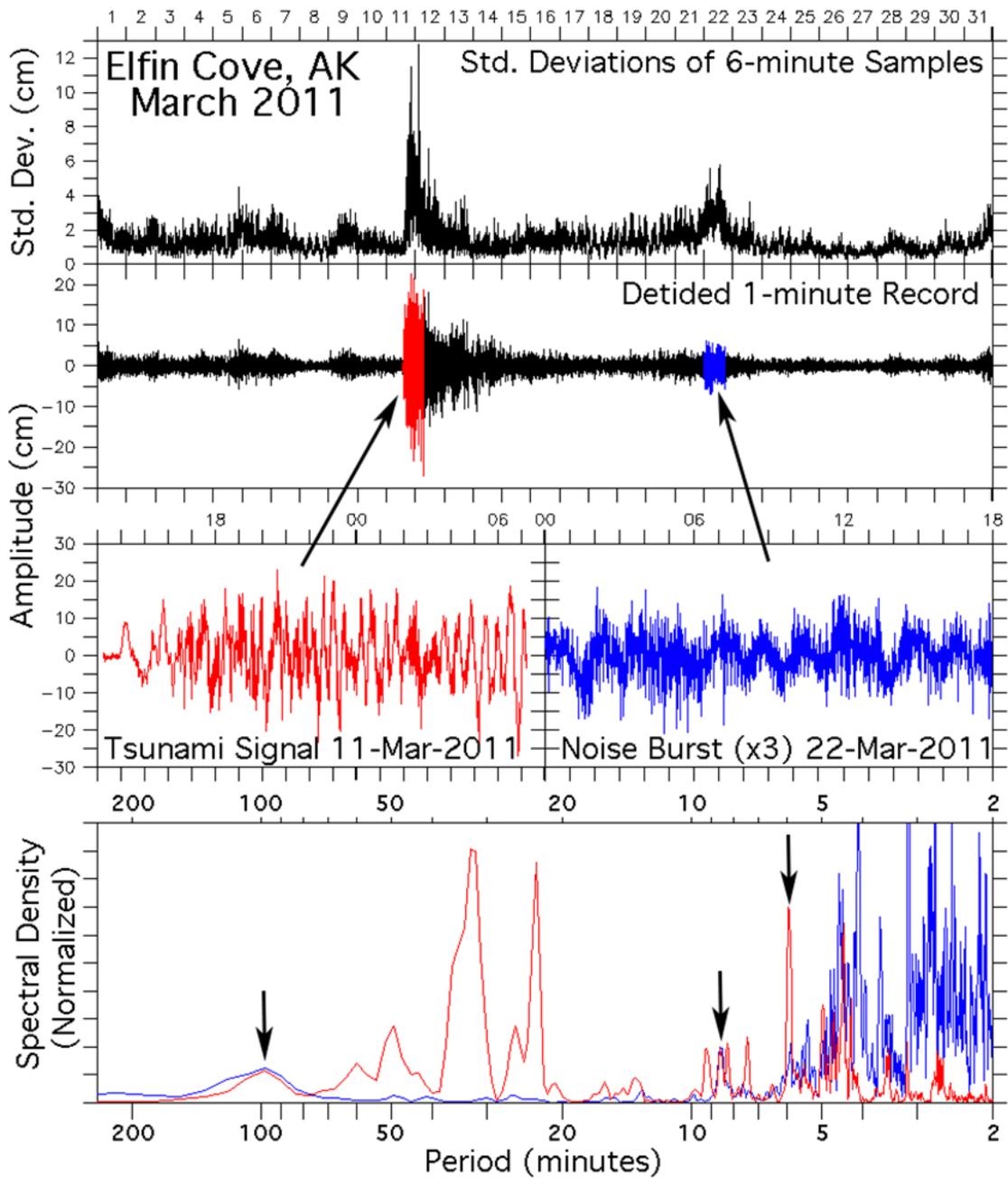


Figure 7. Elfin Cove tide gage data from March 2011 illustrating episodes of high frequency, non-tsunami related signals (blue) that can mask tsunami signals such as that associated with the Honshu-2011 event (red.) The upper panel is the standard deviation of the subsamples employed in computing the published 6-minute data record. The central panels show the 1-minute record, processed with a Kalman filter to eliminate the tidal signal. In the lower panel the spectrum (in energy-preserving form) of two highlighted one-day segments are contrasted.

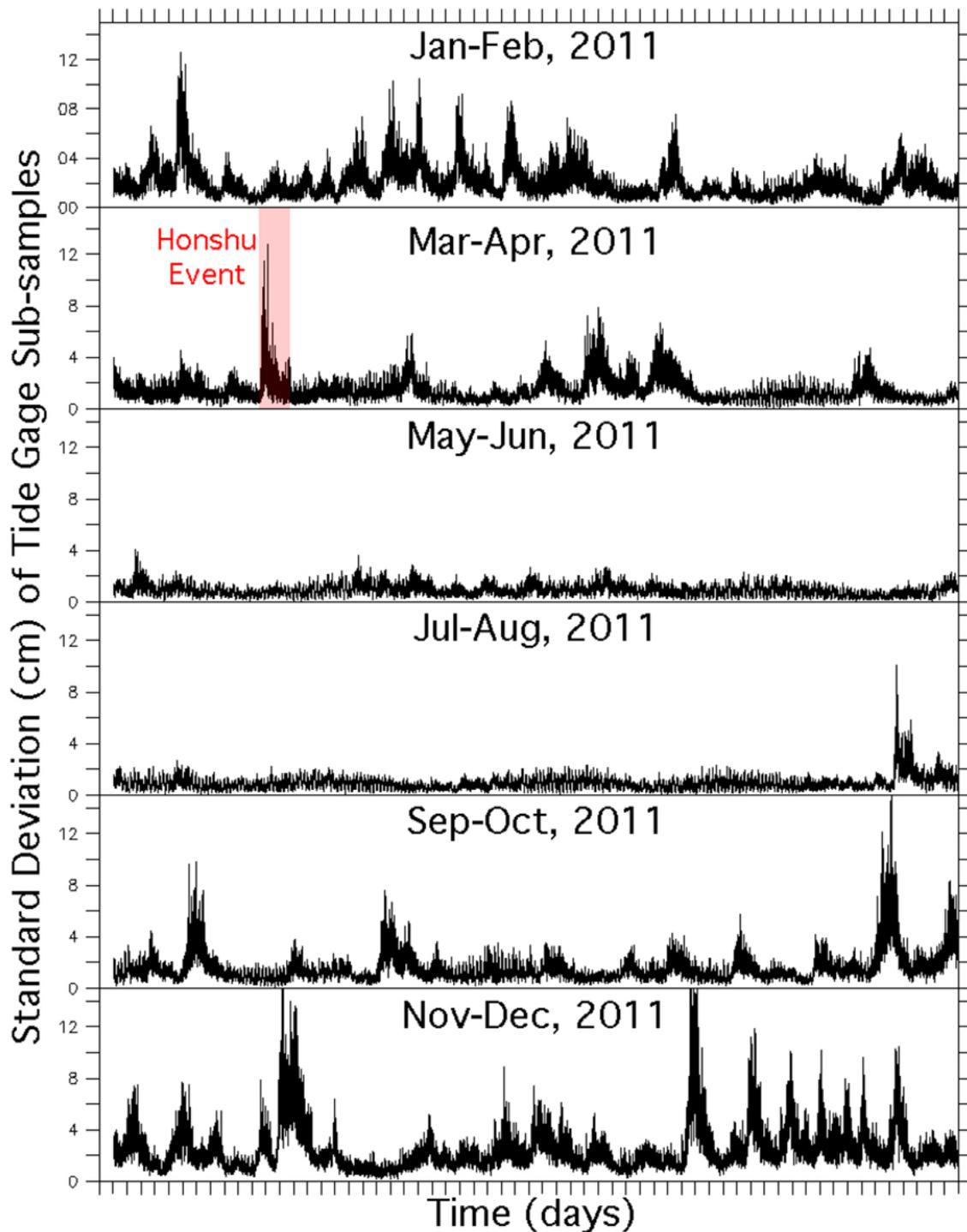


Figure 8. One year of the standard deviation measure of sub-sample noise that accompanies the 6-minute tide gage data from Elfin Cove (in two month strips with a common vertical scale.) Only one tsunami event (highlighted) of significance occurred during the year but noise “bursts” associated with winds and waves are common, particularly during winter months.

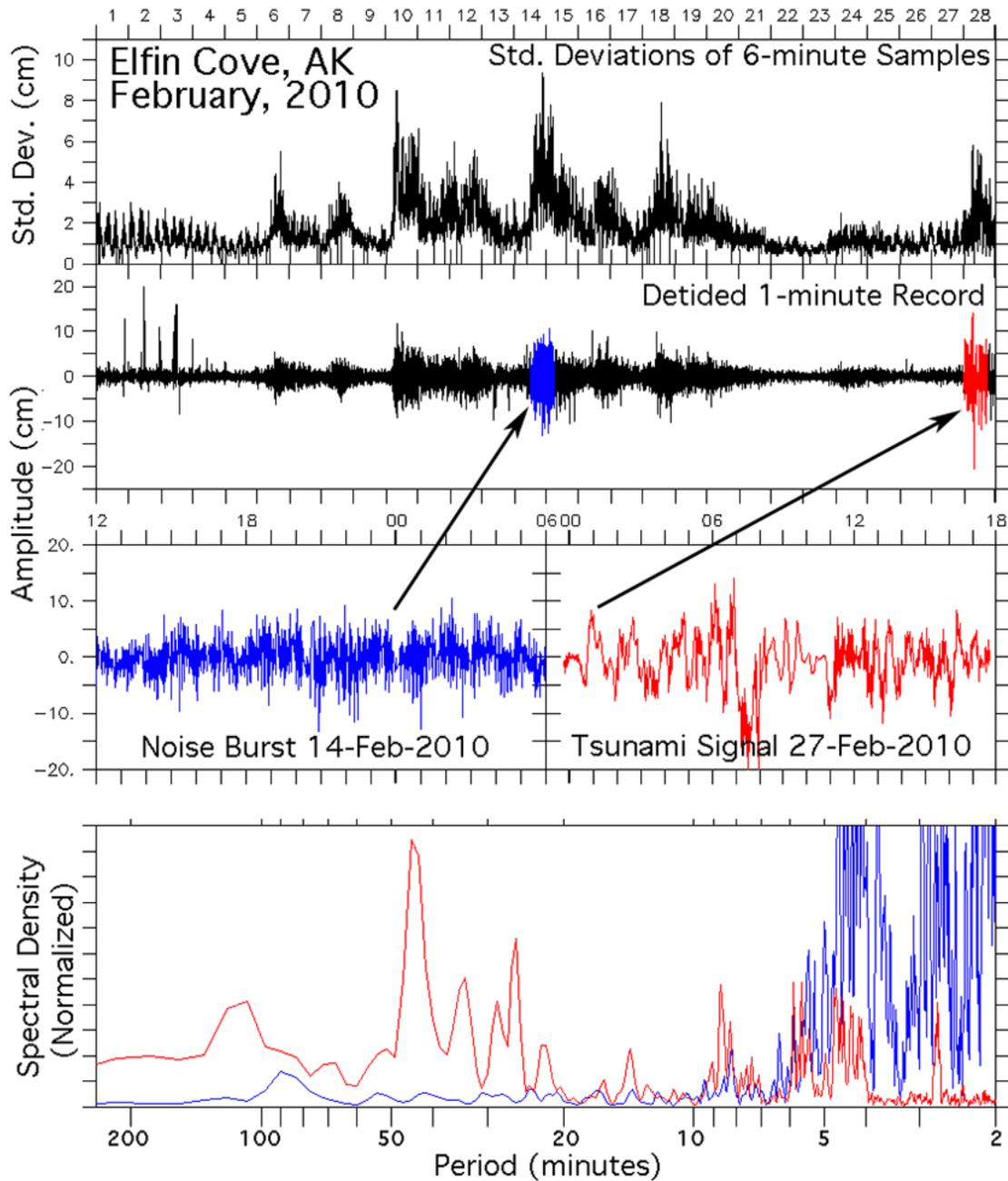


Figure 9. As in Figure 7, but for the Chile tsunami event of February 2010, whose impact in the Gulf of Alaska was comparable to that of Honshu-2011.

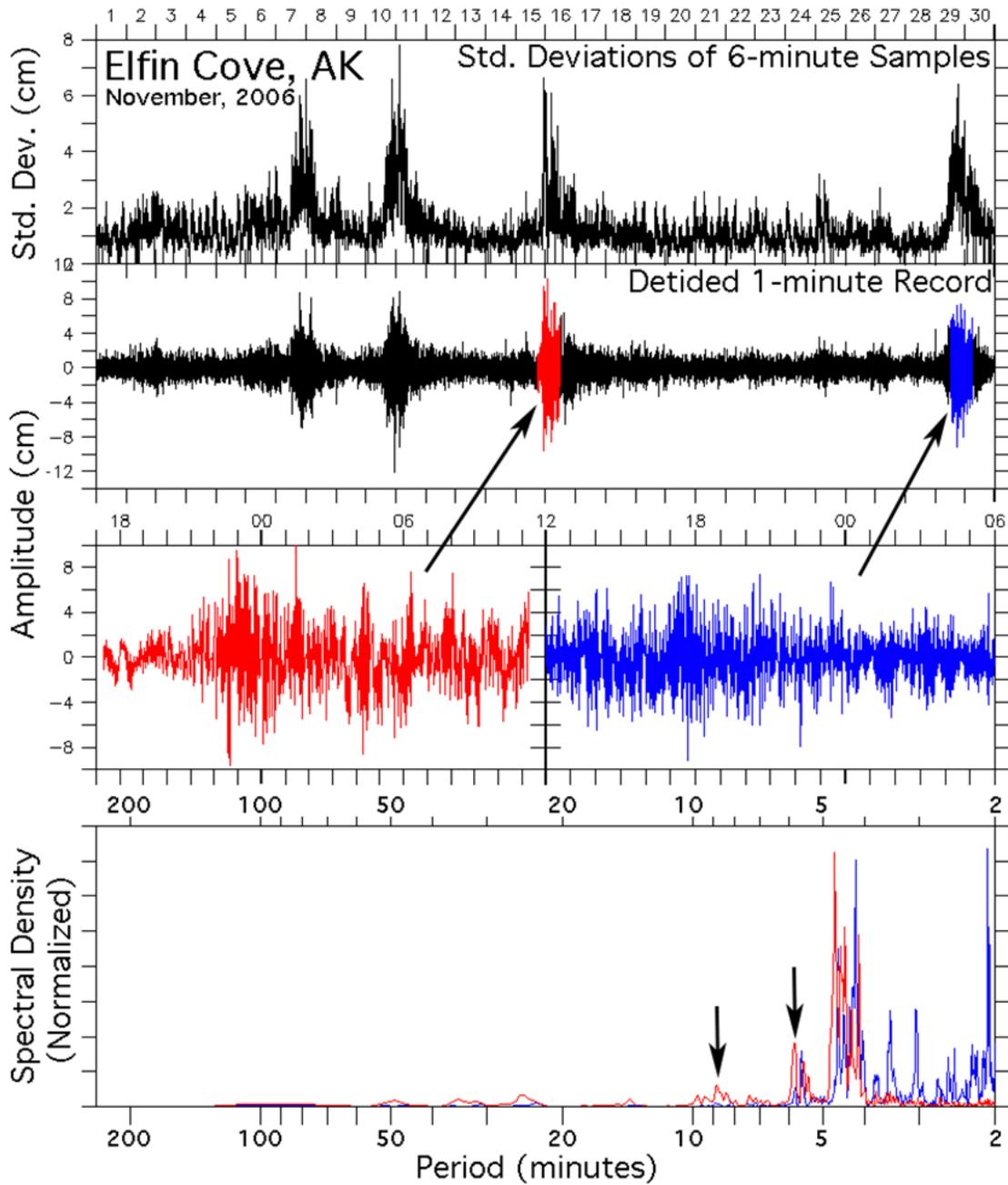


Figure 10. As in Figures 7 and 9, but illustrating the poor signal to noise ratio during the Kuril tsunami event of November 2006. A standard for validation of other Pacific basin forecast models, this event is of limited use for Elfin Cove, AK.

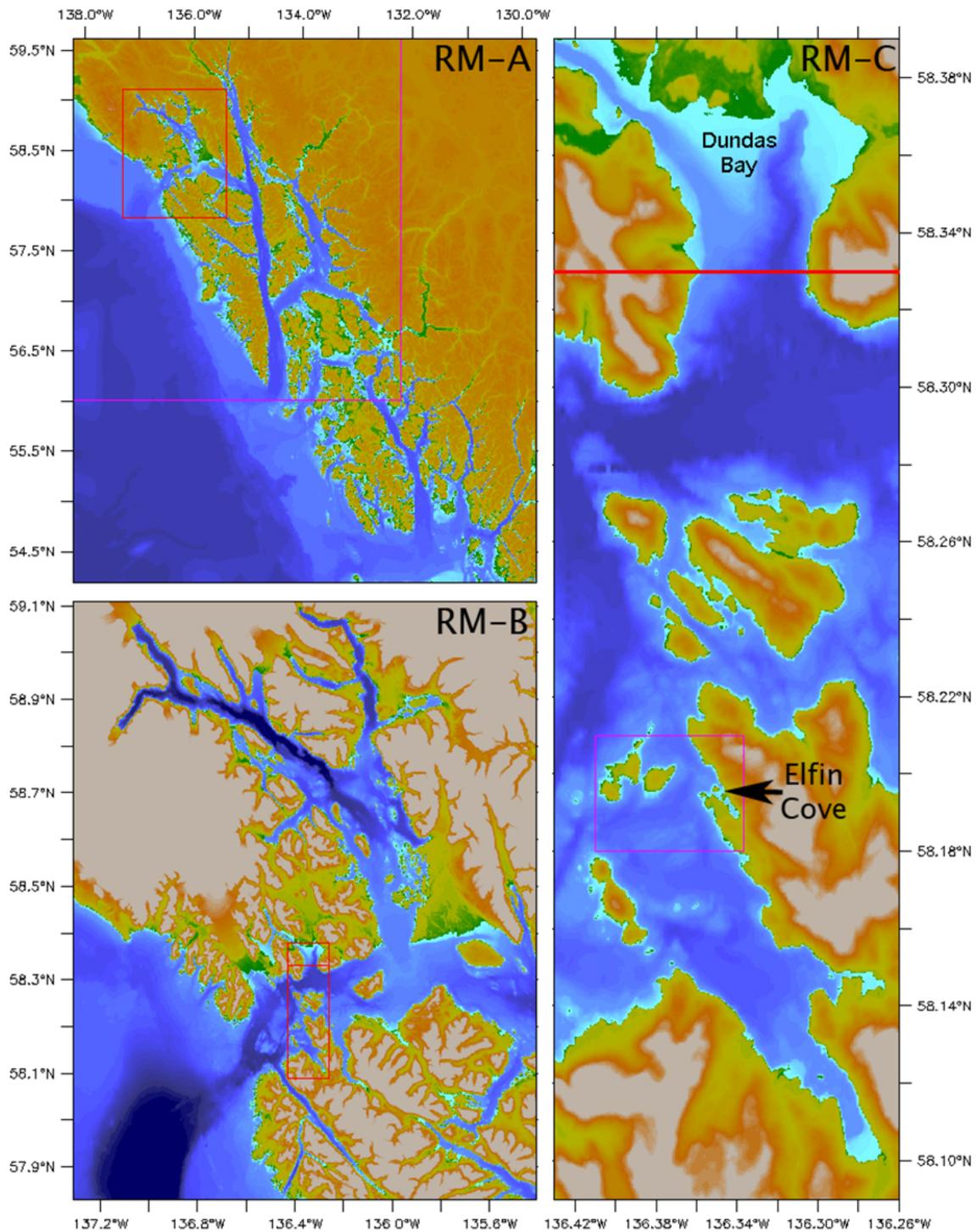


Figure 11. Nested grid representation employed in the Reference (RM) version of the Elfin Cove tsunami model, progressing counterclockwise from the coarsest resolution A-grid in the upper left, through the extensive, medium resolution B-grid which includes all of Glacier Bay, to the finely resolved C-grid that includes the Inian Passes (see Figure 4a.) Red rectangles are used to indicate the inner RM grids; magenta ones indicate the grids of the Forecast Model (FM.) See main text for a discussion of the upper section of Dundas Bay, excluded in the final version of the Reference Model C-grid.

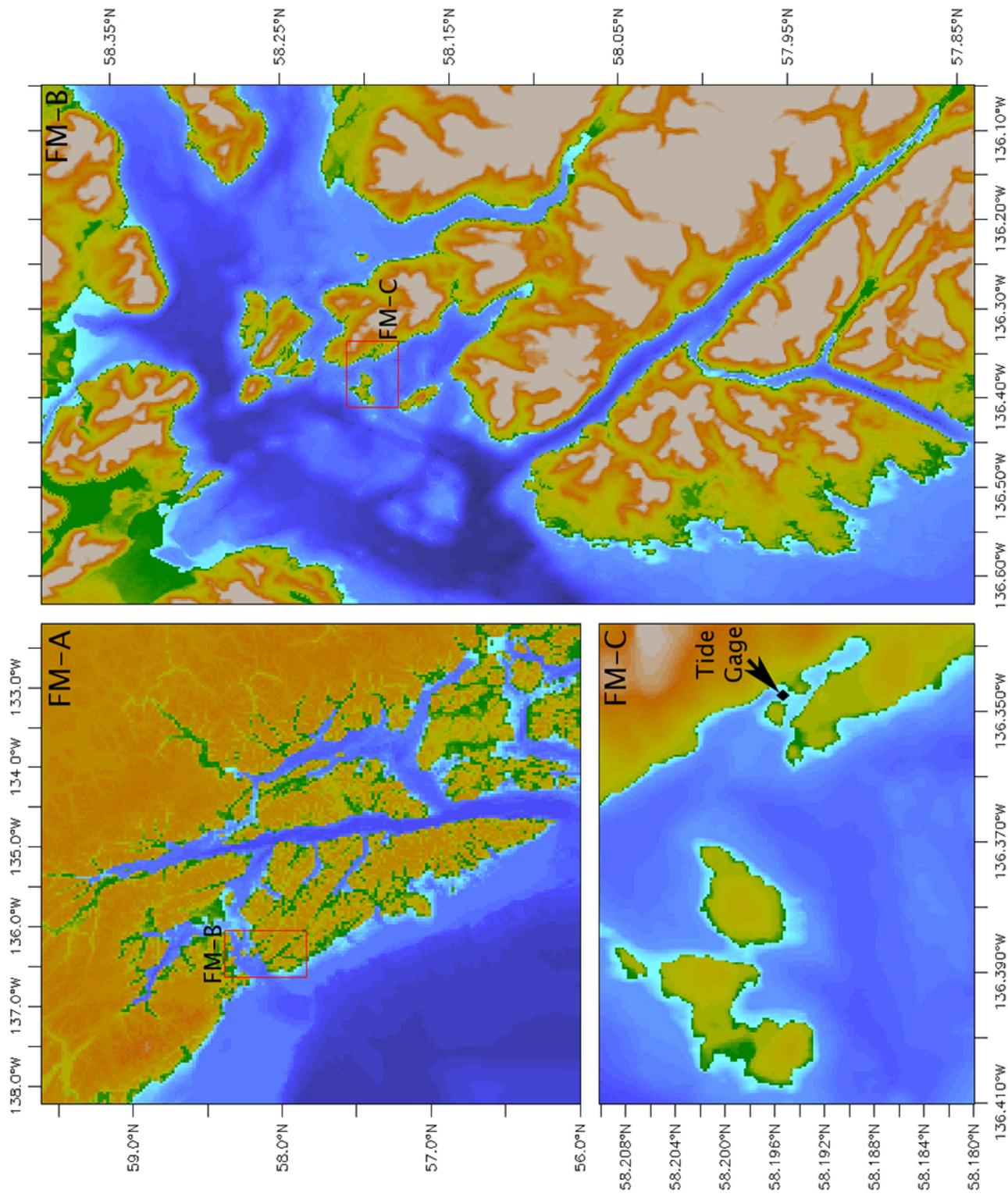


Figure 12. Nested grids of the Forecast (FM) version of the Elfin Cove tsunami model. The progression is clockwise with the innermost C-grid, which is much reduced in extent, appearing in the lower left panel. The Inian Passes are best represented in the B-grid, while Glacier Bay appears only coarsely in the A-grid.

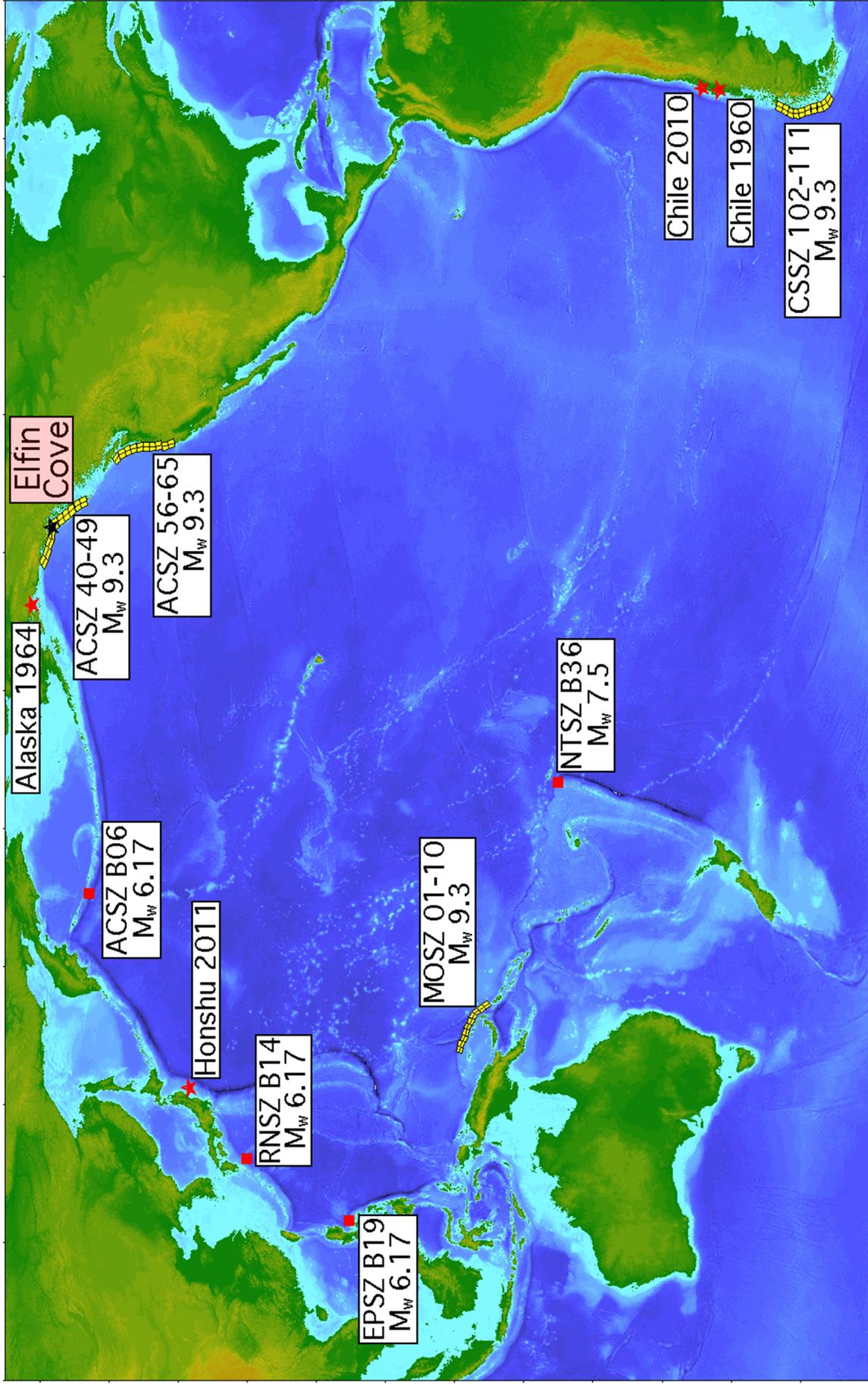


Figure 13. Synthetic and historic event scenarios employed in inter-comparison of the Reference and Forecast versions of Elfin Cove tsunami model. Evenly-distributed slip values, are applied in ten adjacent unit sources (yellow rectangles) of the propagation database to represent mega-tsunami events; single unit sources are used for the other synthetic events. For the historic cases, a linear combination of unit sources is employed as detailed in Table 6.

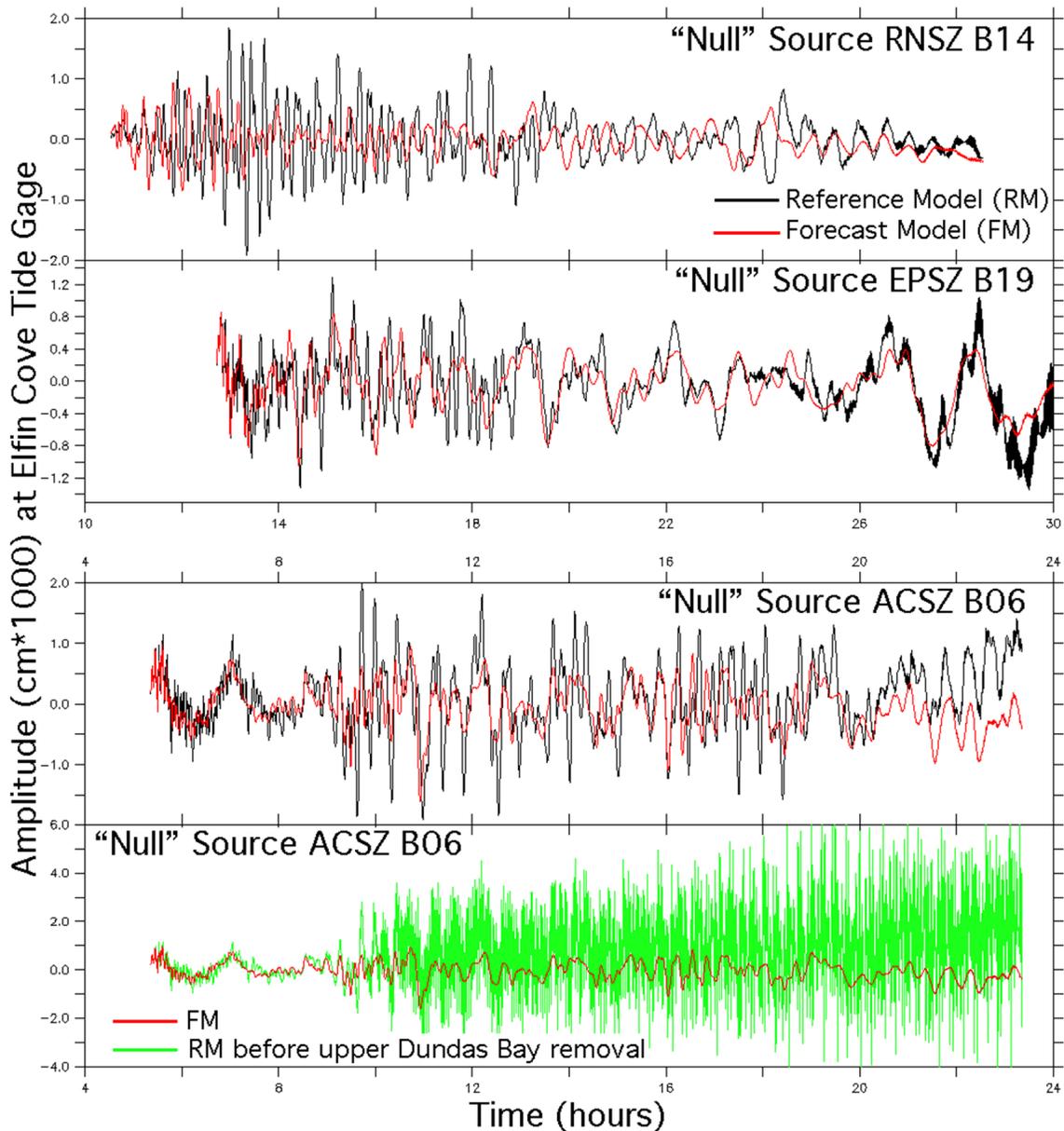


Figure 14. Comparison of Reference (RM) and Forecast Model (RM) predictions for the Elfin Cove tide gage site for three "null" (very low magnitude) sources. Such runs highlight low level model instabilities that might be missed in modeling larger events. The lower panel shows the Reference Model at an early stage of development; instabilities emanating from upper Dundas Bay (see Figure 11) proved difficult to eliminate while employing reasonable time and space steps. These instabilities are essentially eliminated in the final C-grid.

ACSZ 40-49 H

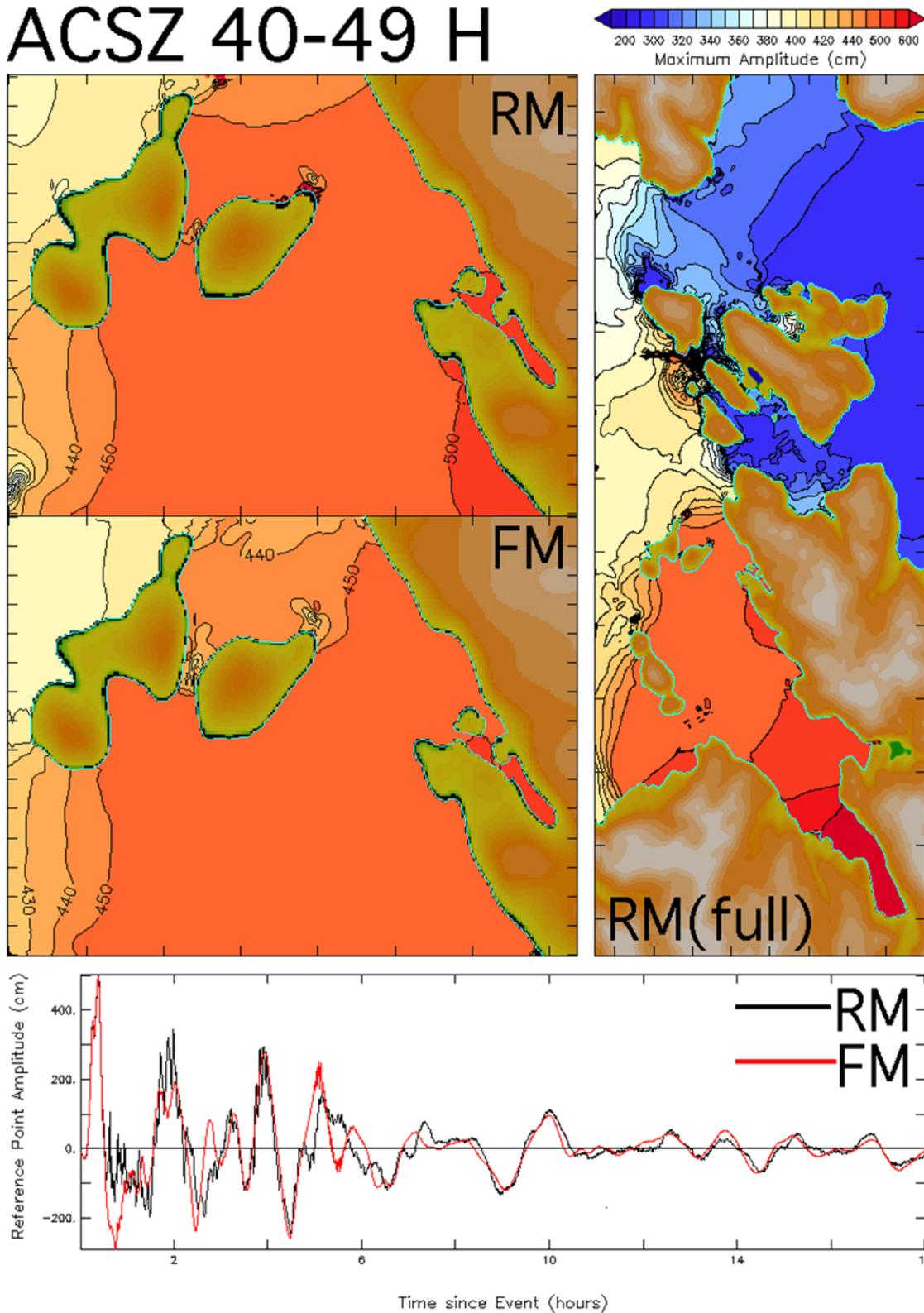


Figure 15. Comparison of Reference (RM) and Forecast (RM) results for the ACSZ 40-49 mega-tsunami scenario, which is local to Elfin Cove. The left hand panels are for the C-grid domain of the Forecast Model; the right hand panel shows the entirety of the Reference Model C-grid. The lower panel contrasts the Reference (black) and Forecast (red) versions of the time series at the Elfin Cove tide gage. a) distribution of maximum amplitude during the 18-hour simulation

ACSZ 40-49 Spd

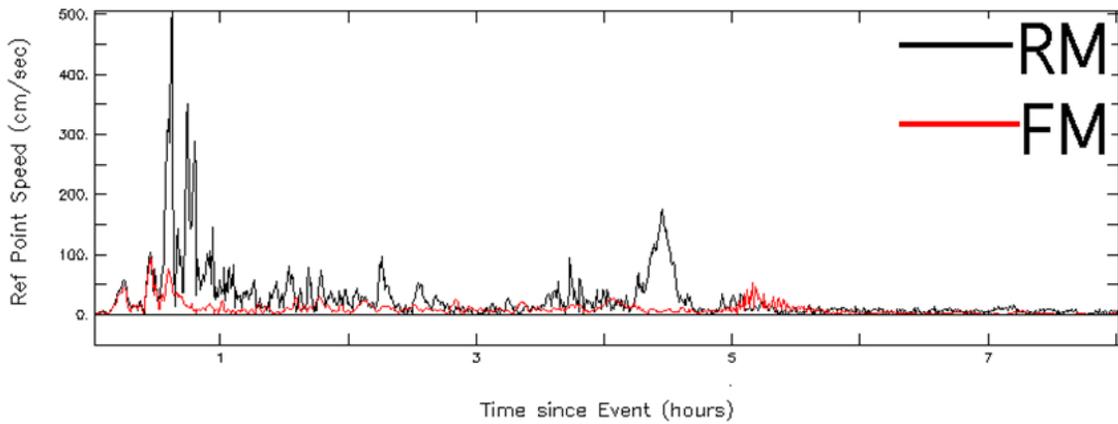
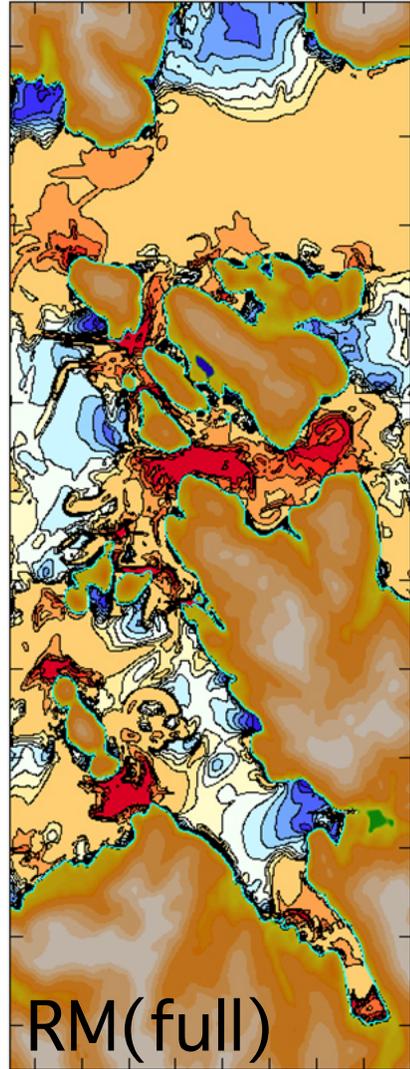
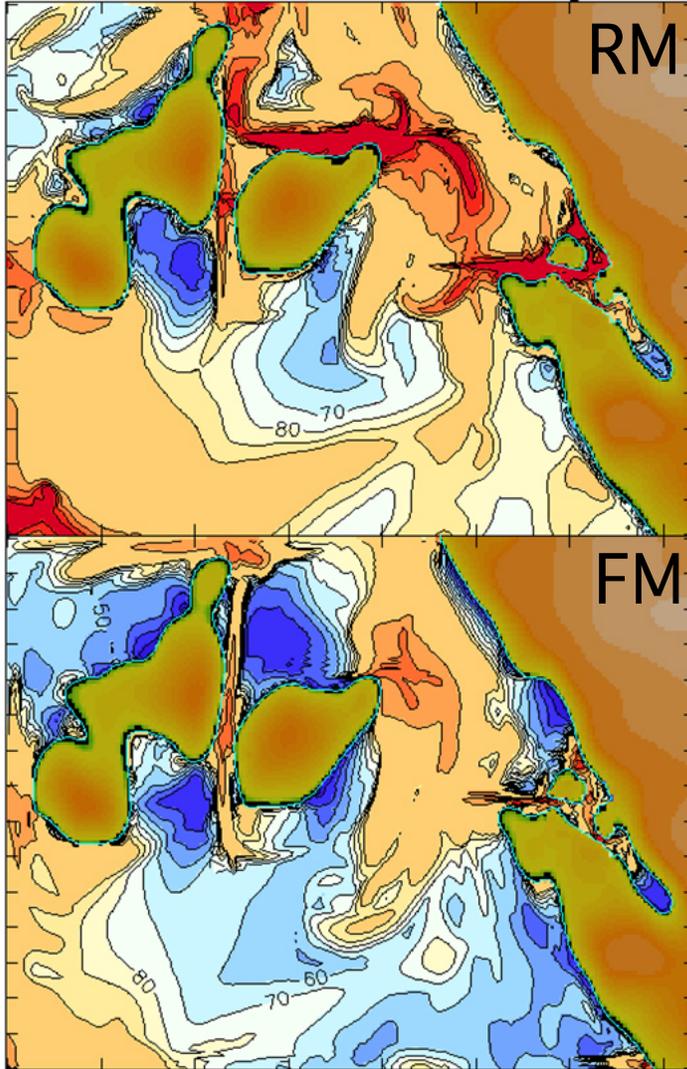


Figure 15 continued. b) distribution of maximum speed.

ACSZ 40-49 U,V

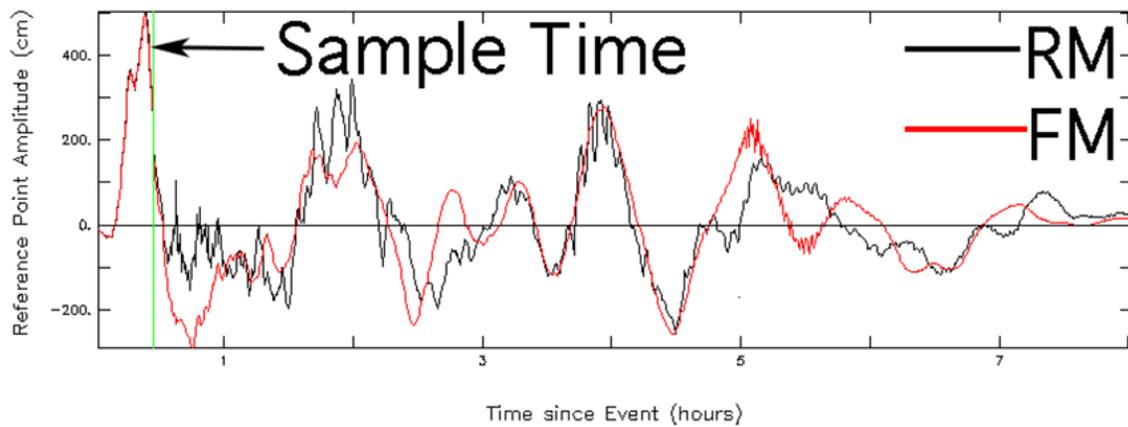
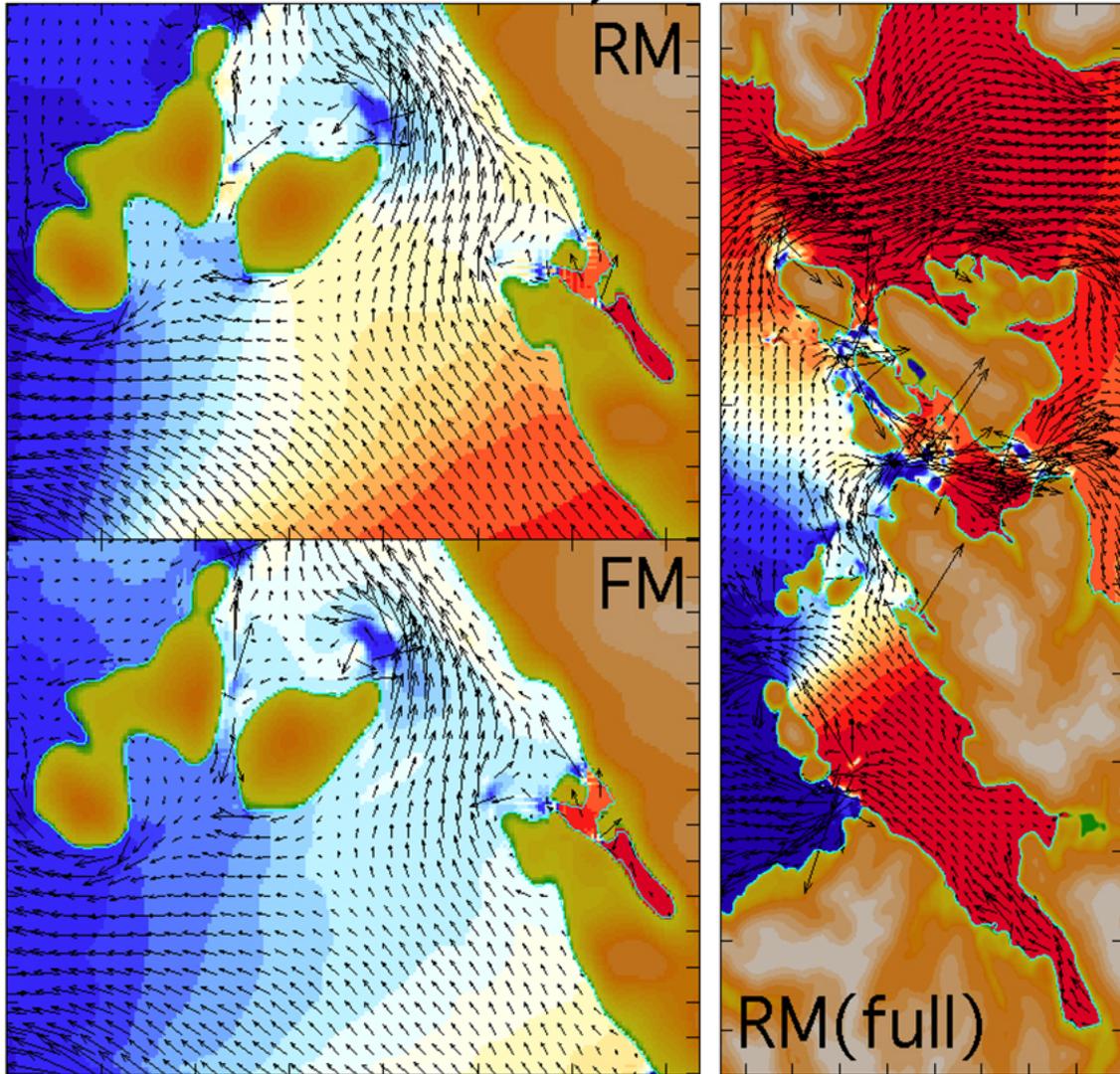


Figure 15 continued. c) a snapshot of the current field at the time indicated by the green line in the lower panel.

ACSZ 56-65 H

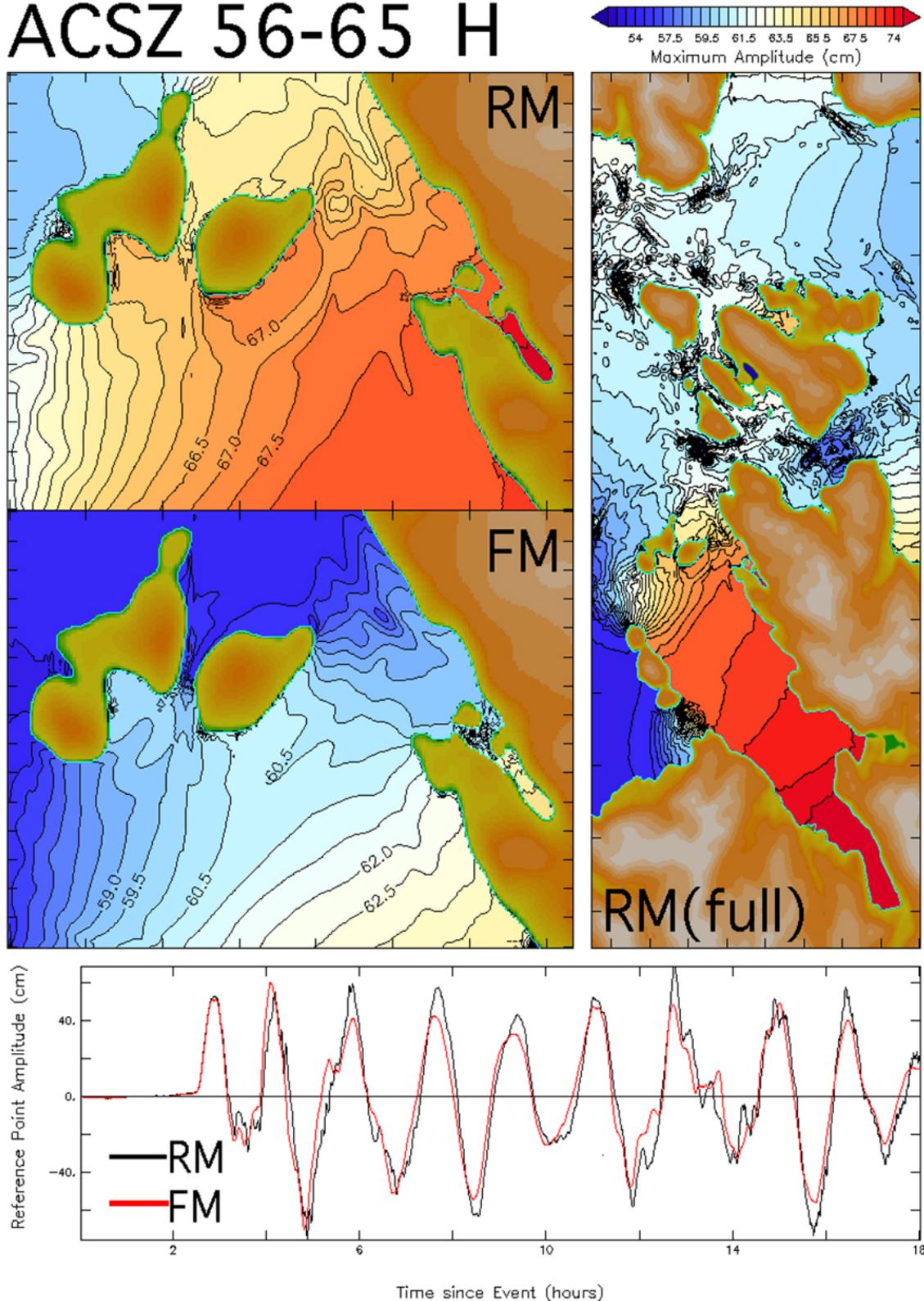


Figure 16. As in Figure 15, but for a synthetic mega-tsunami source, ACSZ 56-65, representative of the Cascadia Subduction Zone.
a) distribution of maximum amplitude during the 18-hour simulation.

ACSZ 56-65 Spd

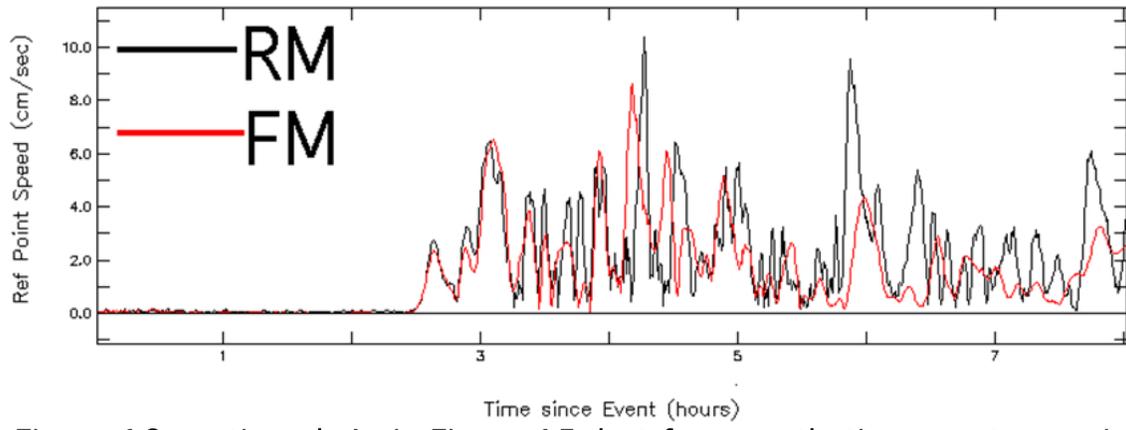
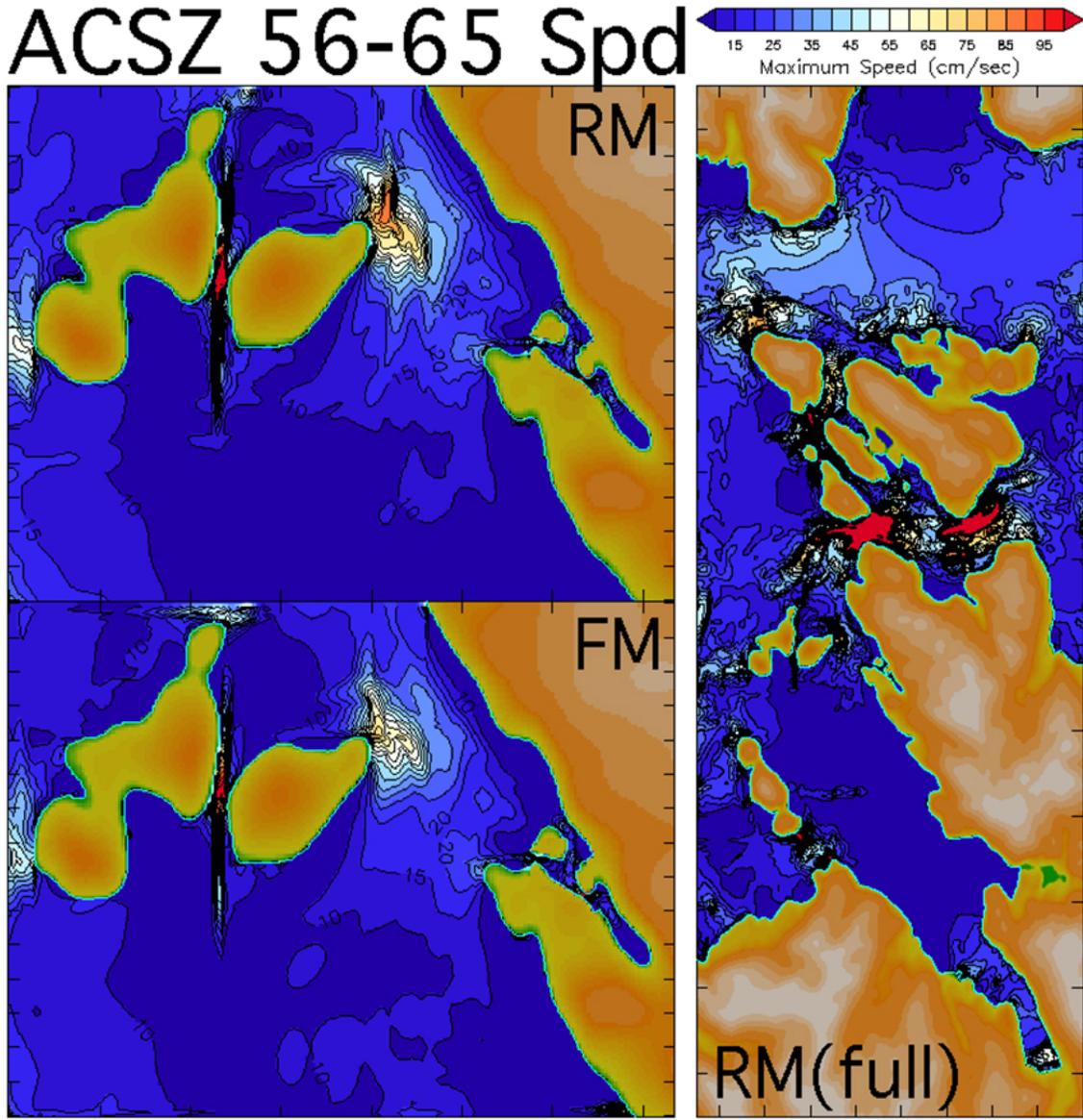


Figure 16 continued. As in Figure 15, but for a synthetic mega-tsunami source, ACSZ 56-65, representative of the Cascadia Subduction Zone. b) distribution of maximum speed.

ACSZ 56-65 U,V

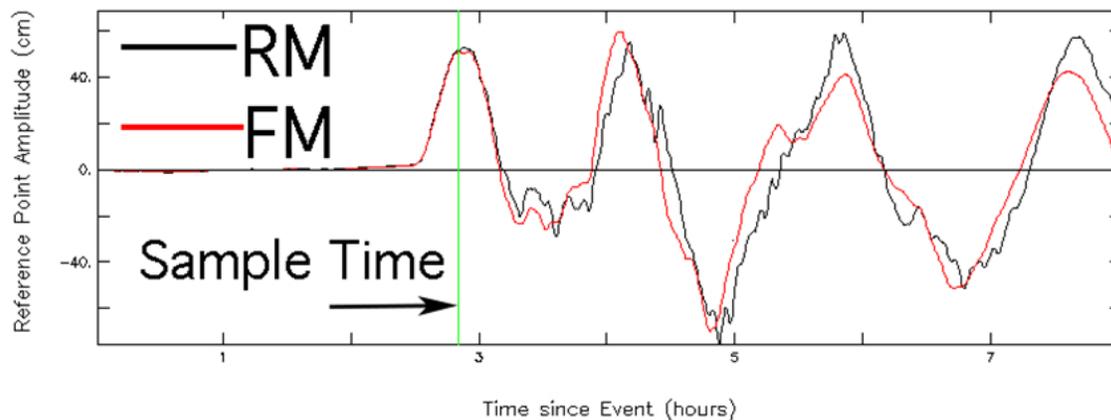
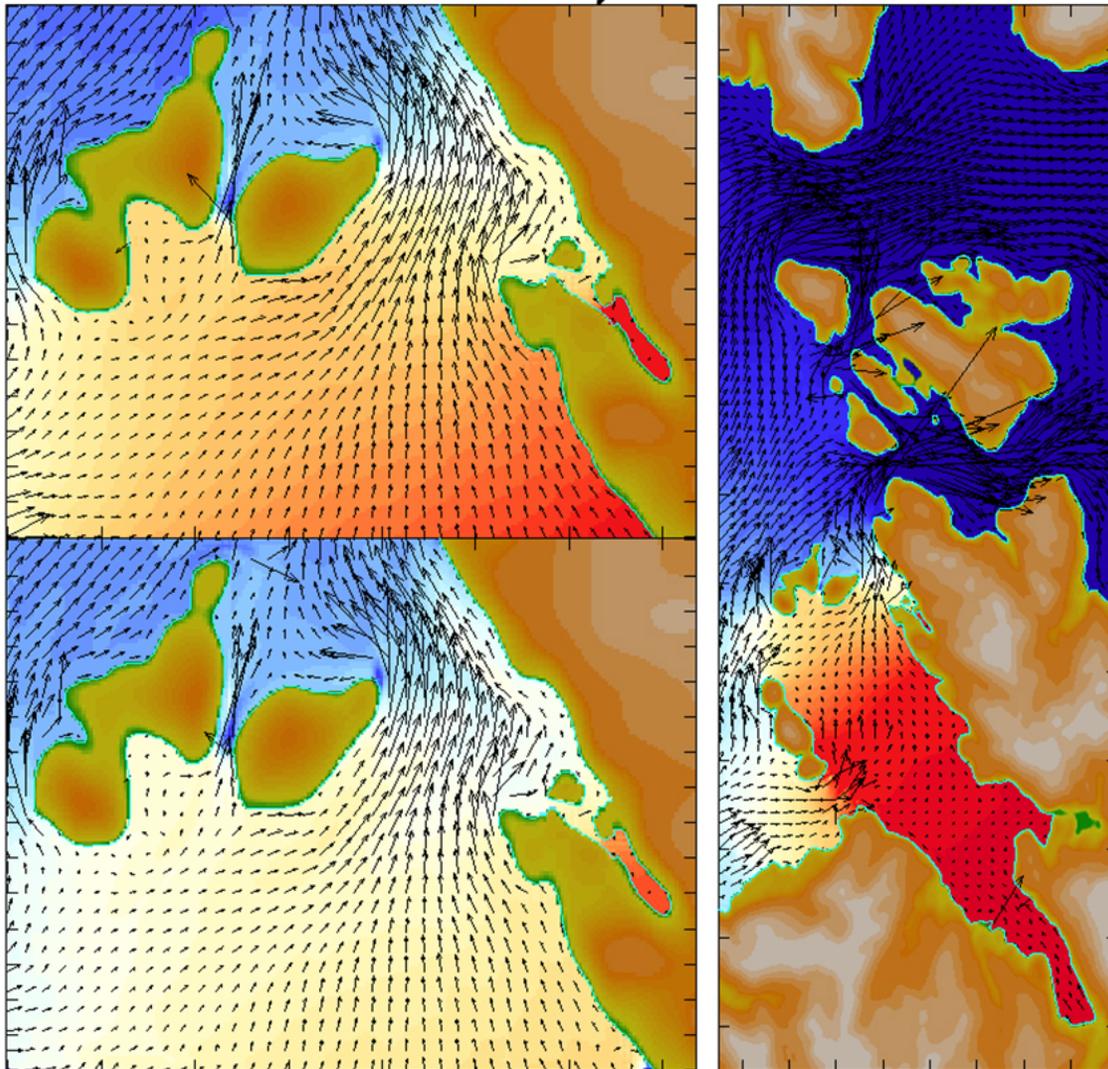
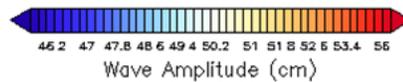


Figure 16 continued. As in Figure 15, but for a synthetic mega-tsunami source, ACSZ 56-65, representative of the Cascadia Subduction Zone. c) a snapshot of the current field at the time indicated by the green line in the lower panel.

CSSZ102-111 H

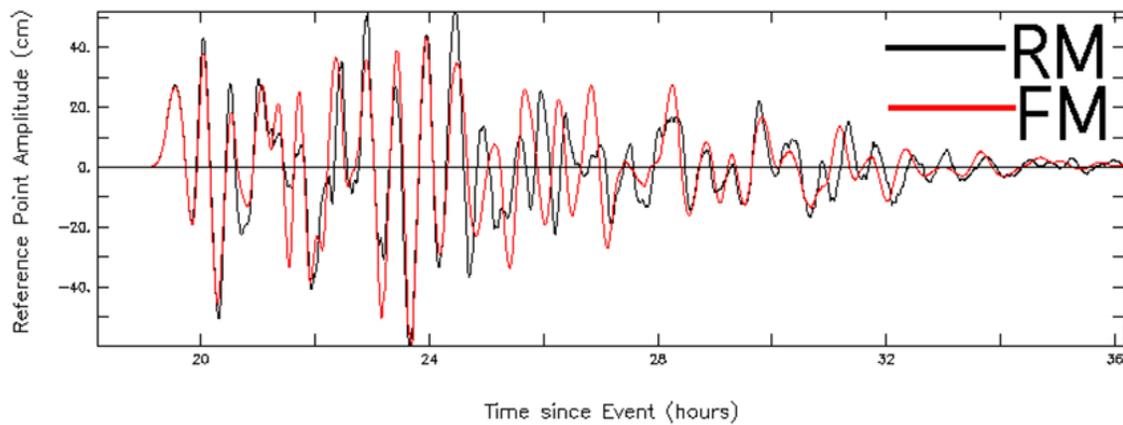
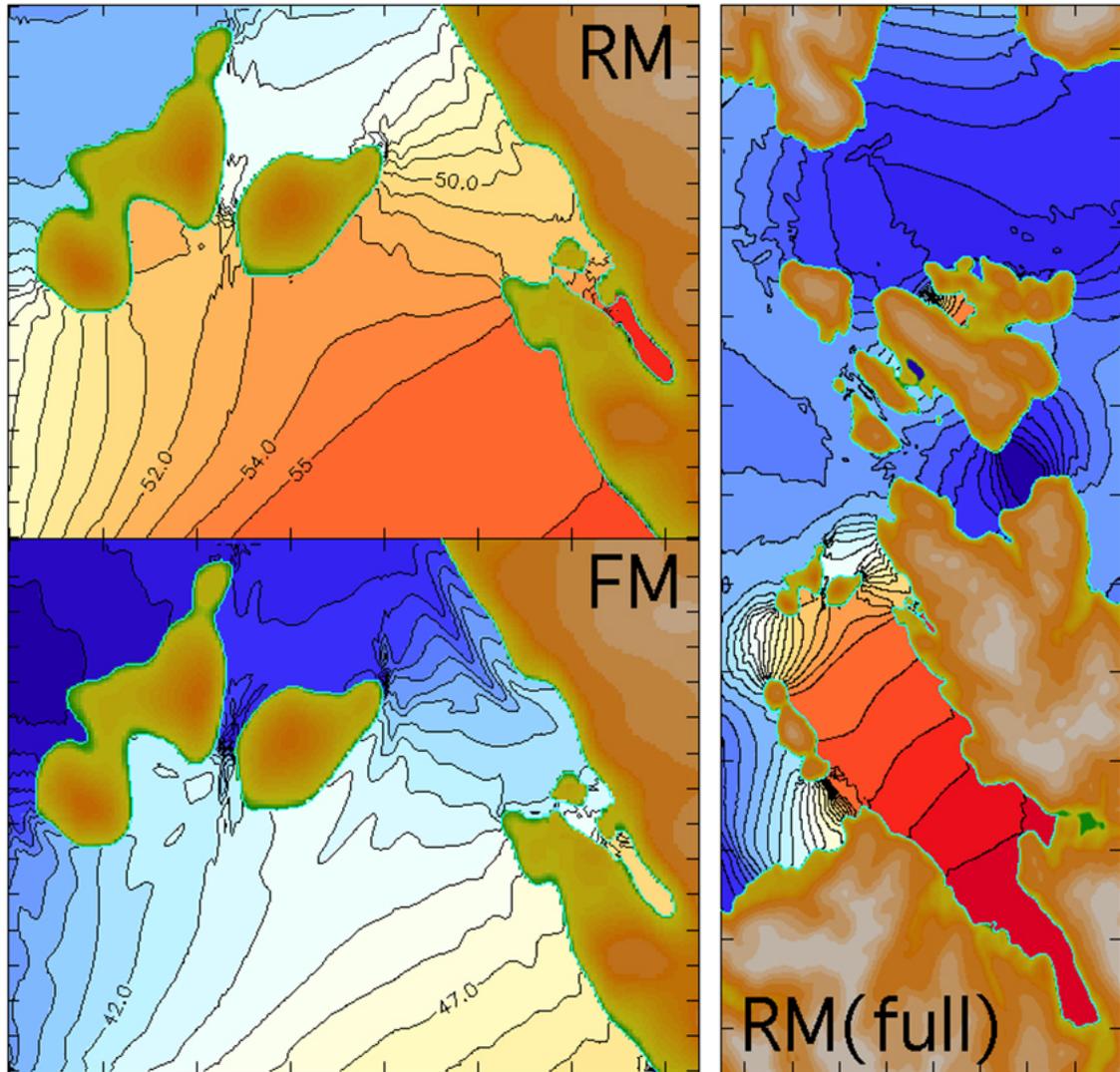
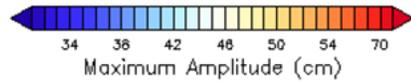


Figure 17. As in Figure 15, but for a synthetic mega-tsunami source, CSSZ 102-111, located in southern Chile.
a) distribution of maximum amplitude during the 18-hour simulation.

CSSZ102-111Spd

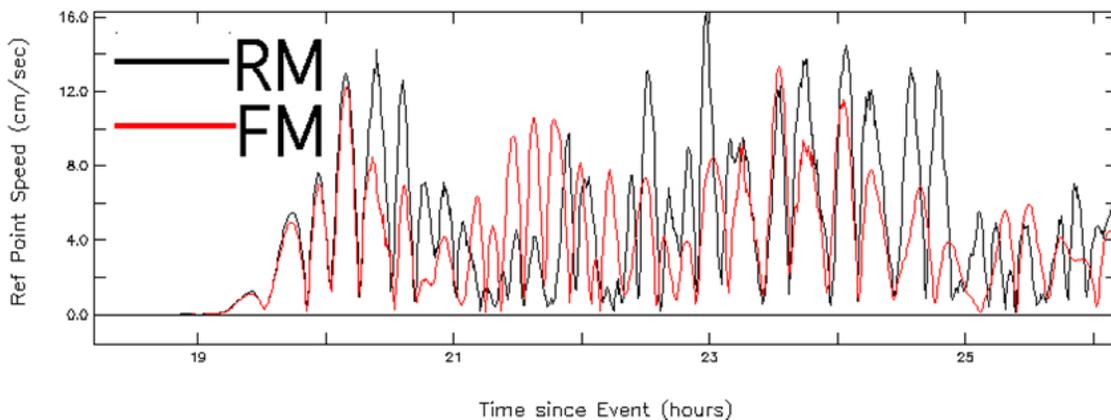
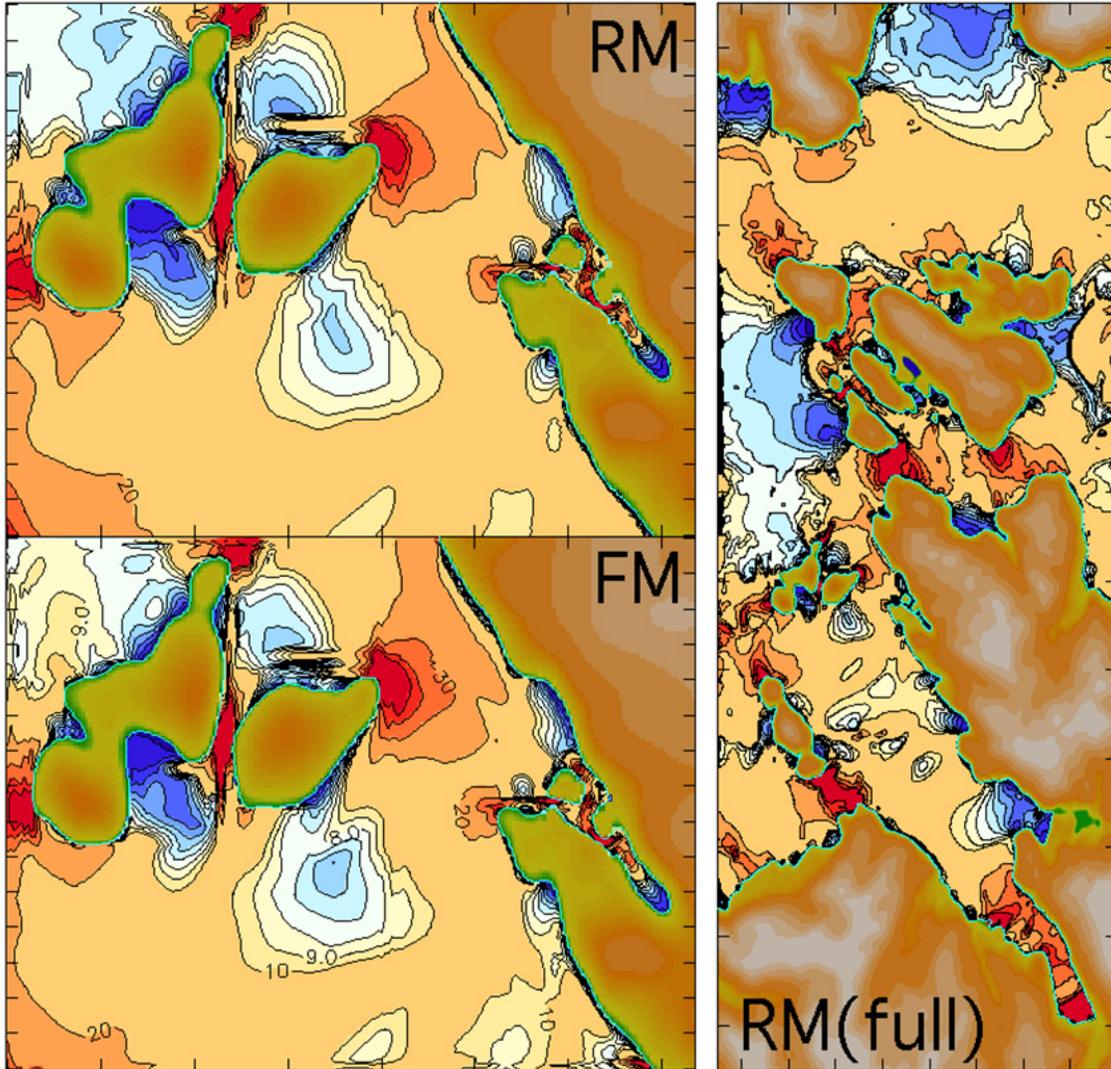


Figure 17 continued. As in Figure 15, but for a synthetic mega-tsunami source, CSSZ 102-111, located in southern Chile.
b) distribution of maximum speed.

CSSZ102-111 U,V

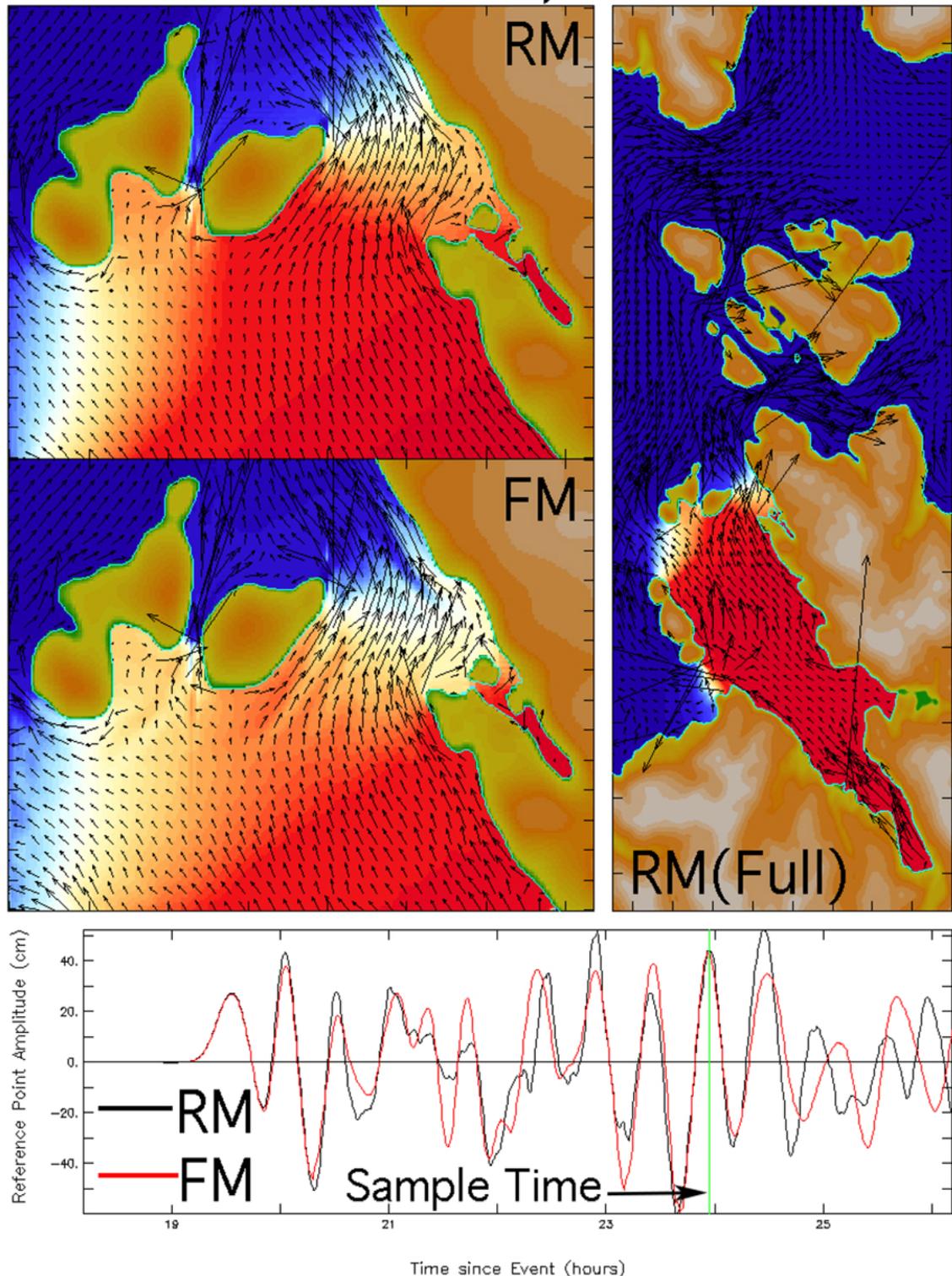


Figure 17 continued. As in Figure 15, but for a synthetic mega-tsunami source, CSSZ 102-111, located in southern Chile.

c) a snapshot of the current field at the time indicated by the green line in the lower panel.

MOSZ 1-10 H

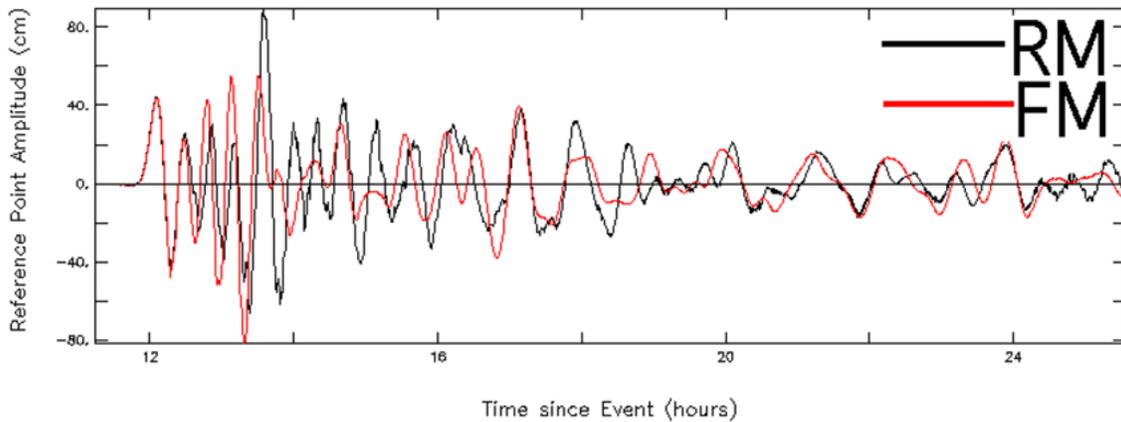
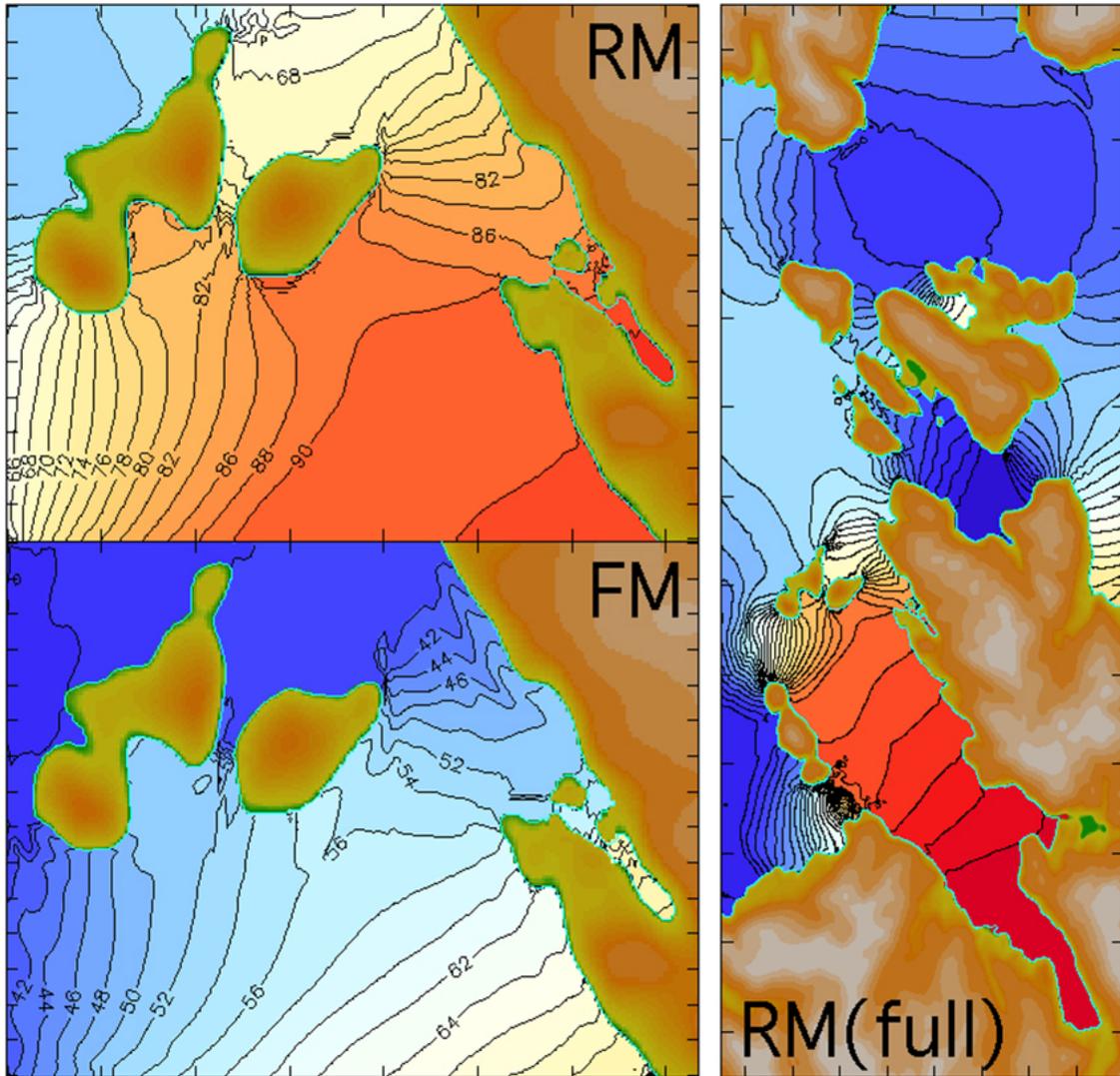
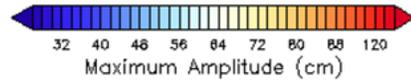


Figure 18. As in Figure 15, but for a synthetic mega-tsunami source, MOSZ 1-10, located in the western Pacific.
a) distribution of maximum amplitude during the 18-hour simulation.

MOSZ 1-10 Spd

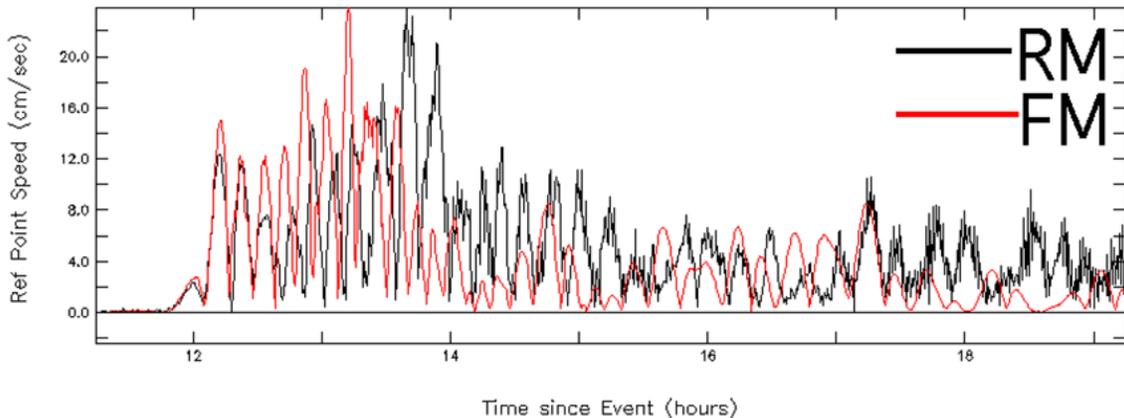
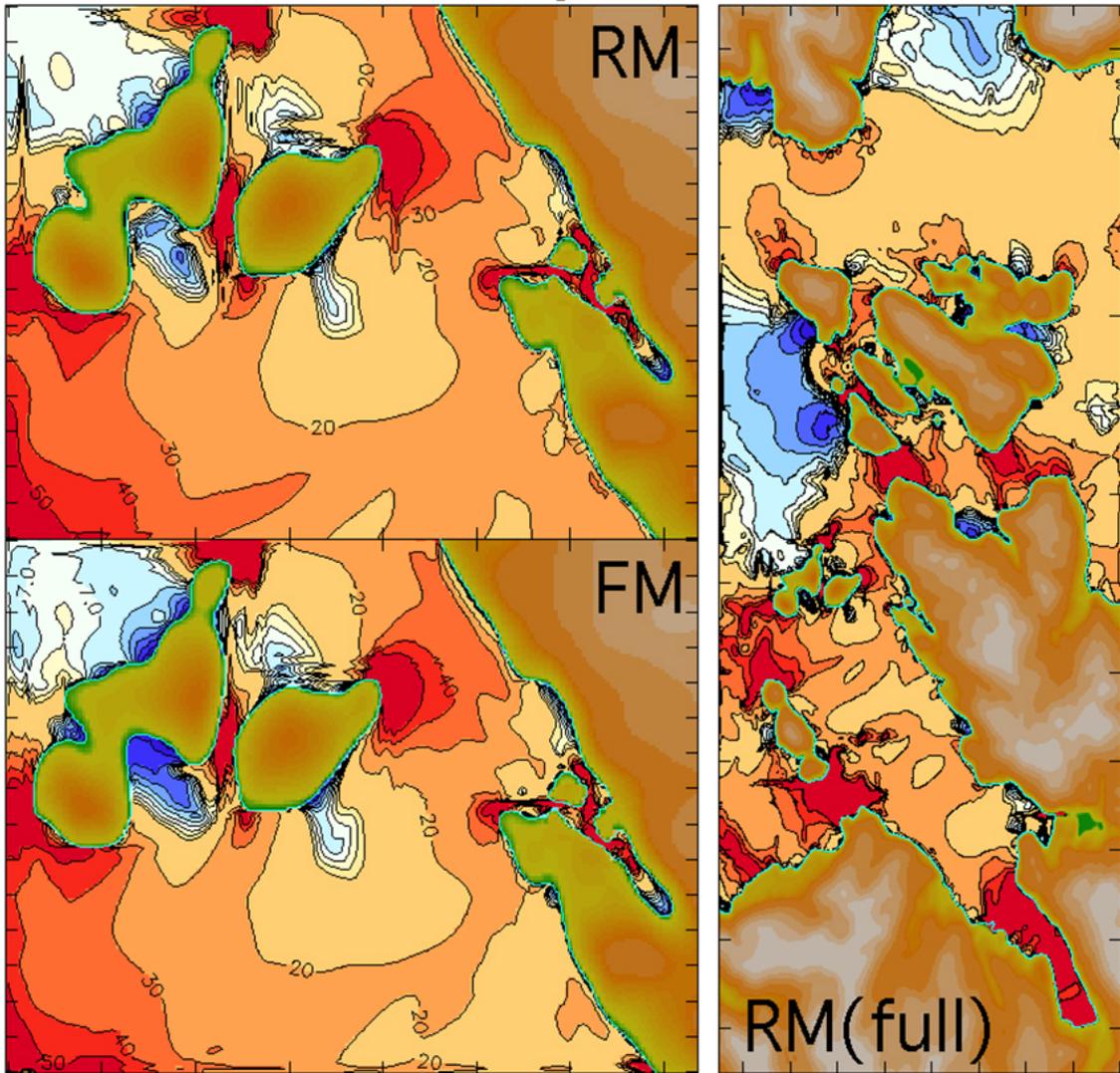


Figure 18 continued. As in Figure 15, but for a synthetic mega-tsunami source, MOSZ 1-10, located in the western Pacific.
b) distribution of maximum speed.

MOSZ 1-10 U,V

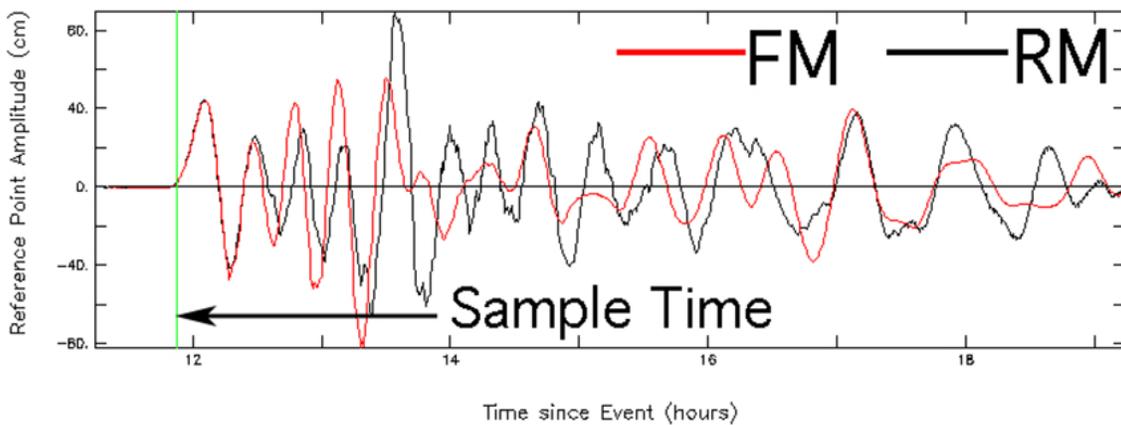
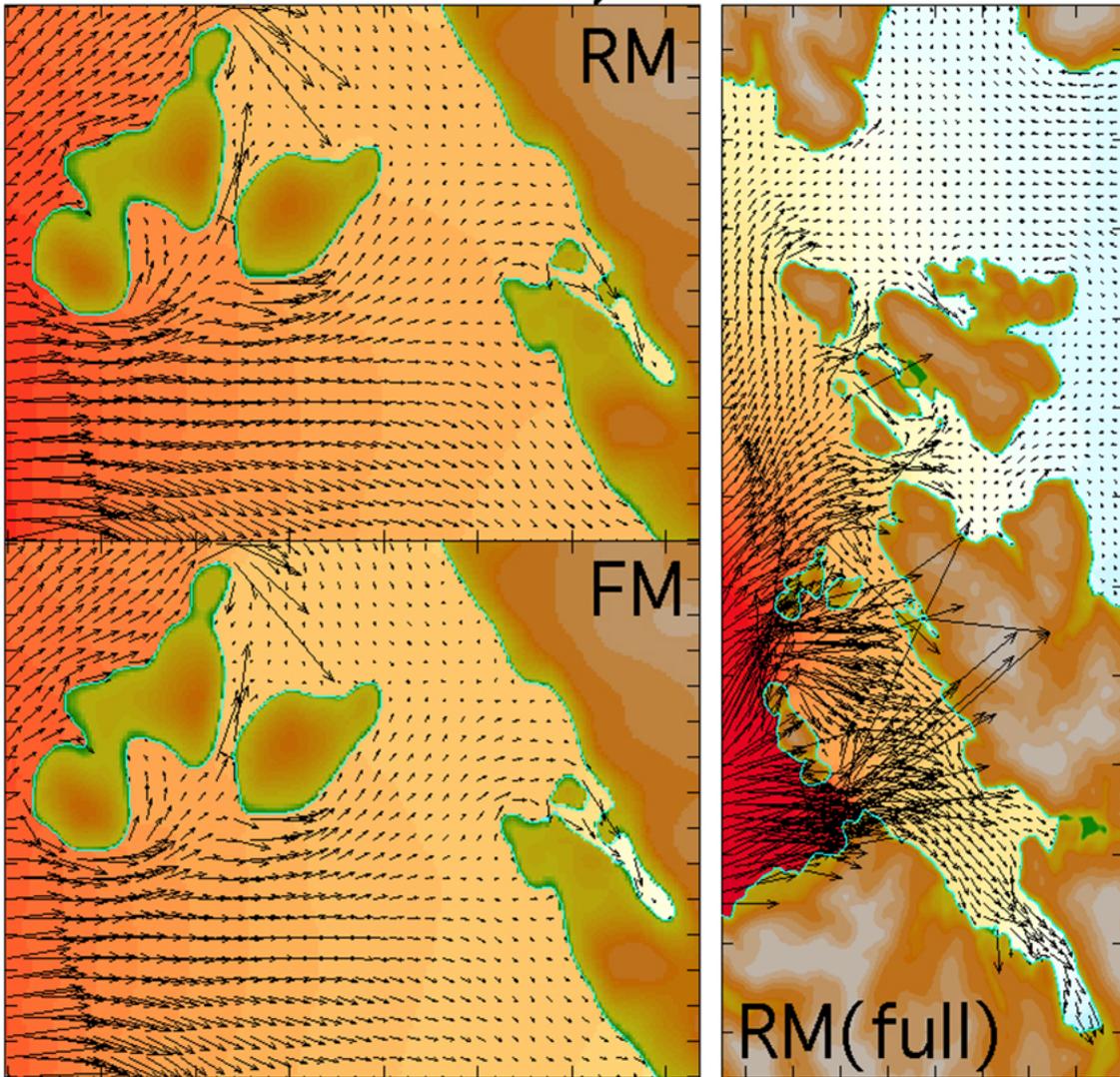
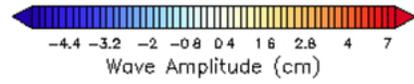


Figure 18 continued. As in Figure 15, but for a synthetic mega-tsunami source, MOSZ 1-10, located in the western Pacific.
c) a snapshot of the current field at the time indicated by the green line in the lower panel

NTSZ B36

H

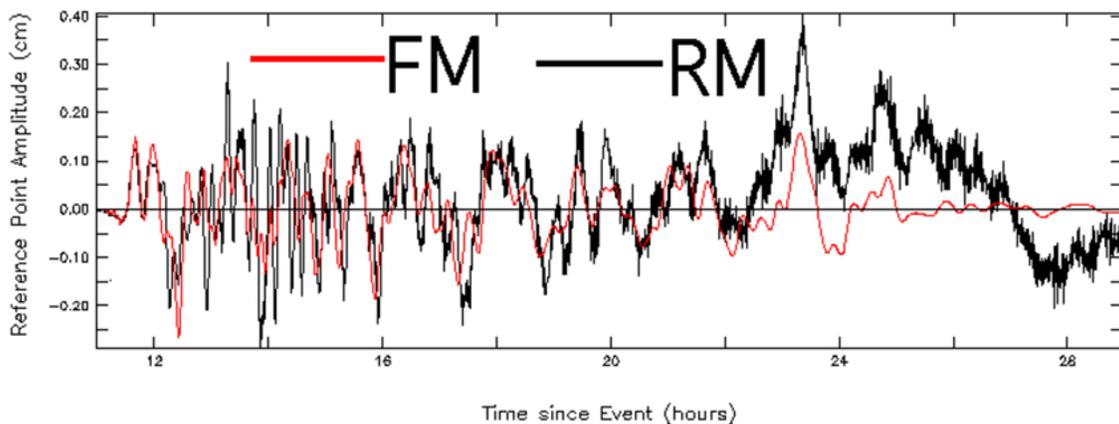
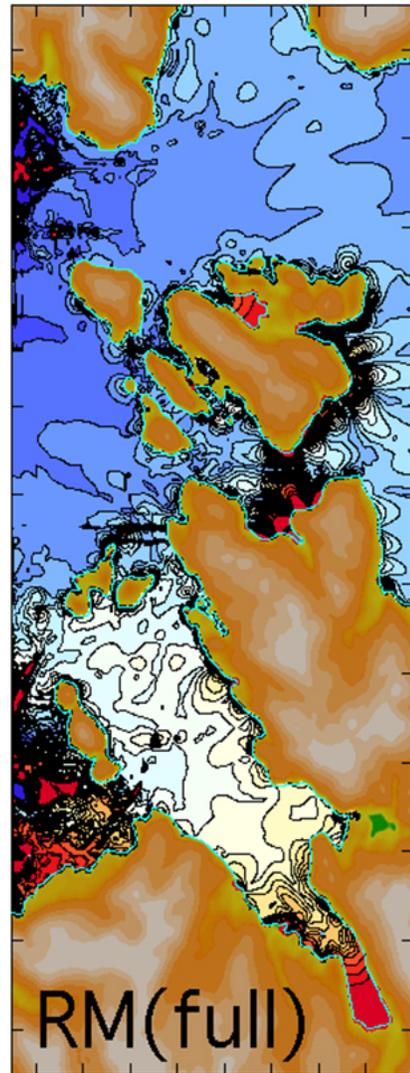
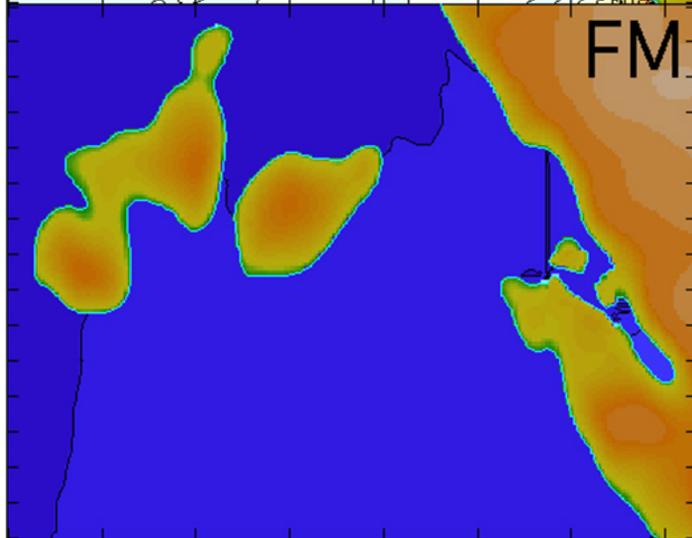
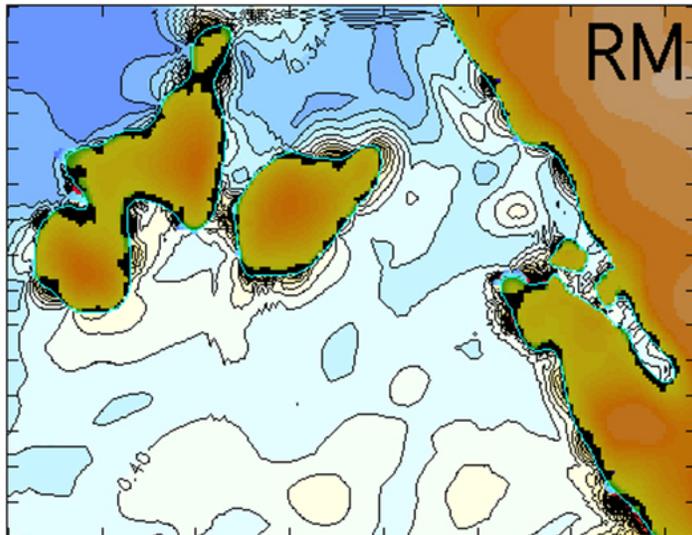
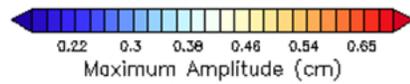


Figure 19. Comparison of Reference (RM) and Forecast Model (FM) solutions for a mild synthetic tsunami near Samoa (the single unit source NTSZ B36.) Though tracking well for 22 hours of the simulation, the time series at the tide gage diverge later and degrade the comparison of the maximum amplitude field.

Honshu 2011 H

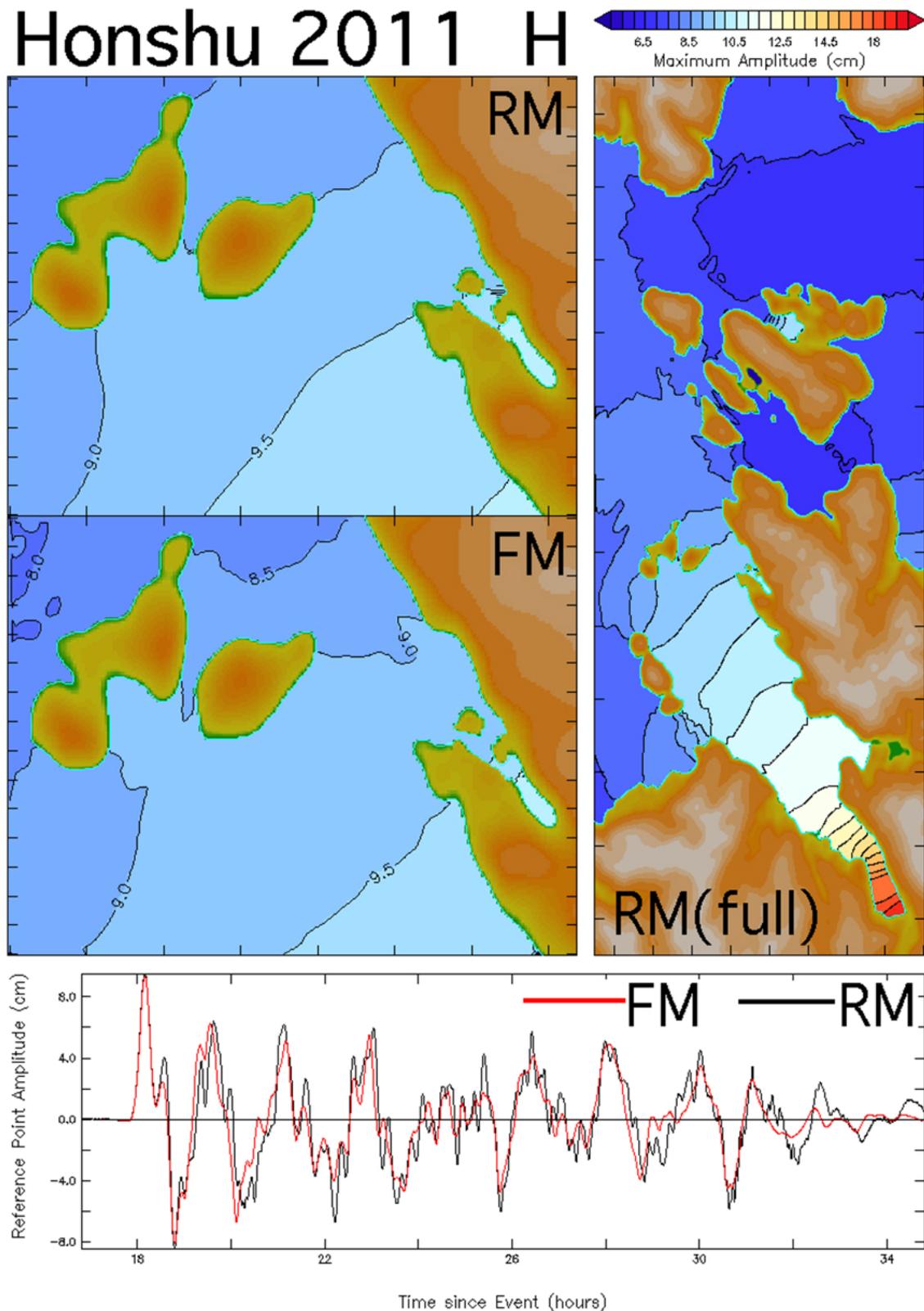


Figure 20. As for Figure 15 but for a hindcast of the Honshu-2011 historic event. The model is forced by a combination of unit sources and slip values selected in real time during the event (see Table 6) using DART® observations near the tsunami source. The Reference (RM) and Forecast Model (FM) predictions are in good agreement; validation results, using data from the Elfin Cove tide gage, are presented later. a) distribution of maximum amplitude during the 18-hour simulation.

Honshu 2011 Spd

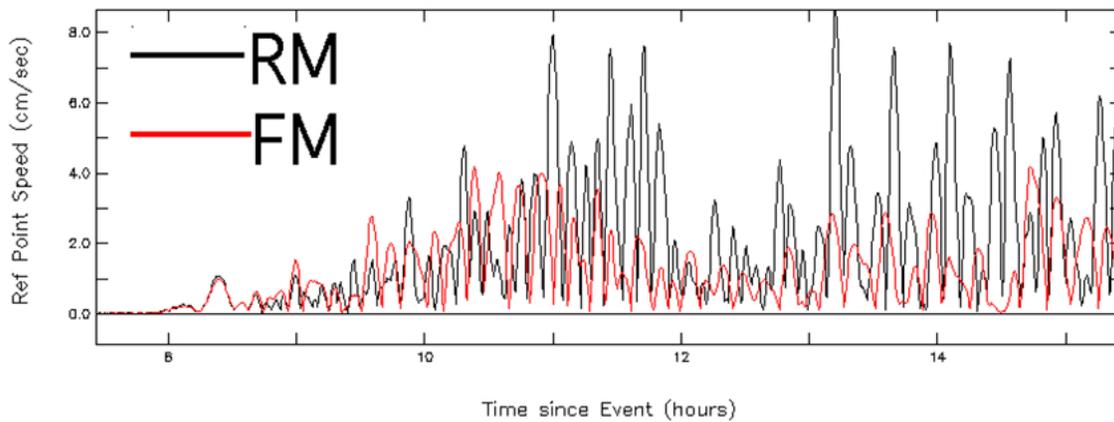
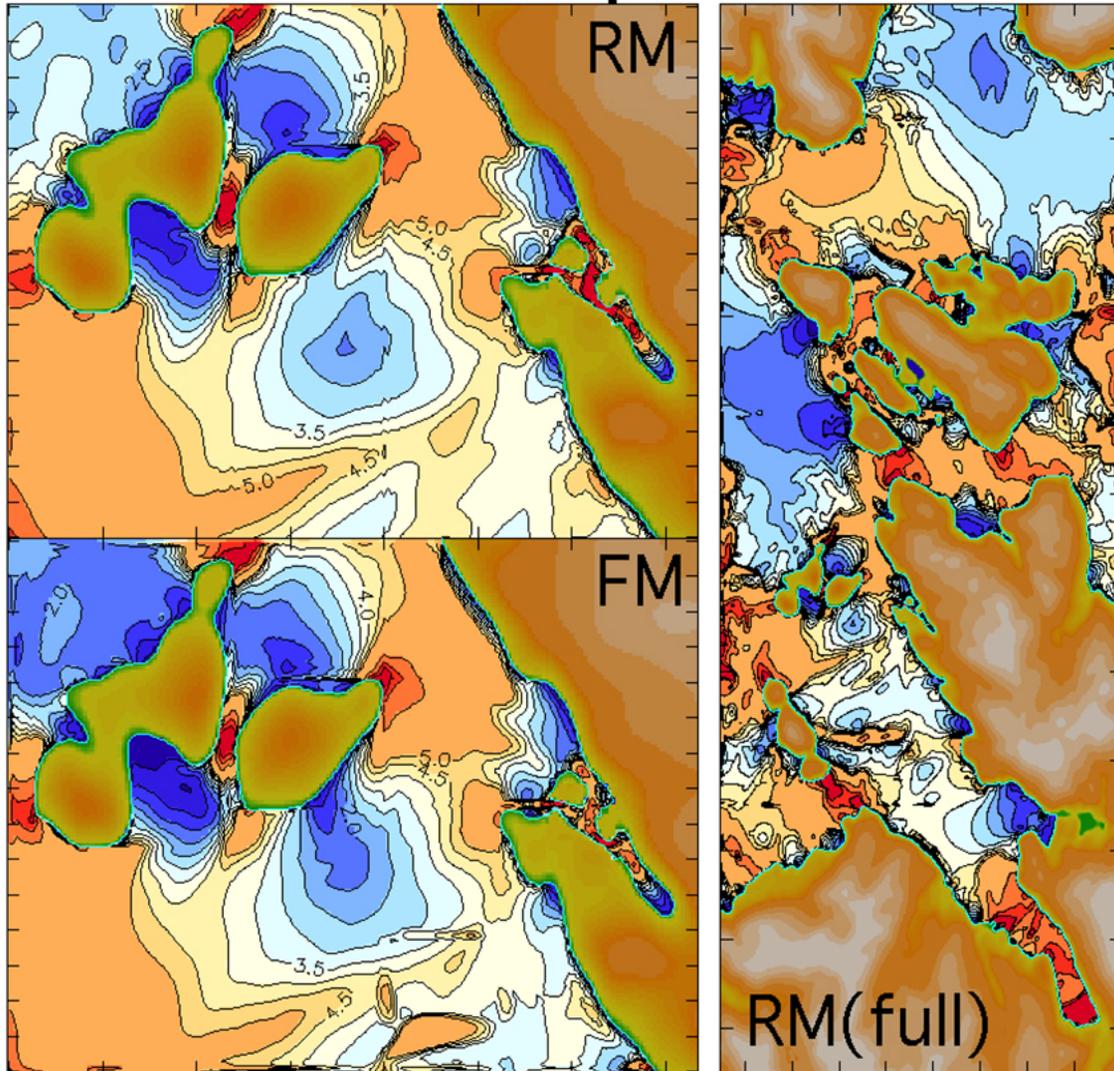
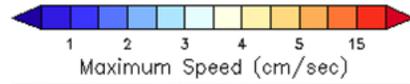


Figure 20 continued. As for Figure 15 but for a hindcast of the Honshu-2011 historic event.
b) distribution of maximum speed.

Honshu 2011 U,V

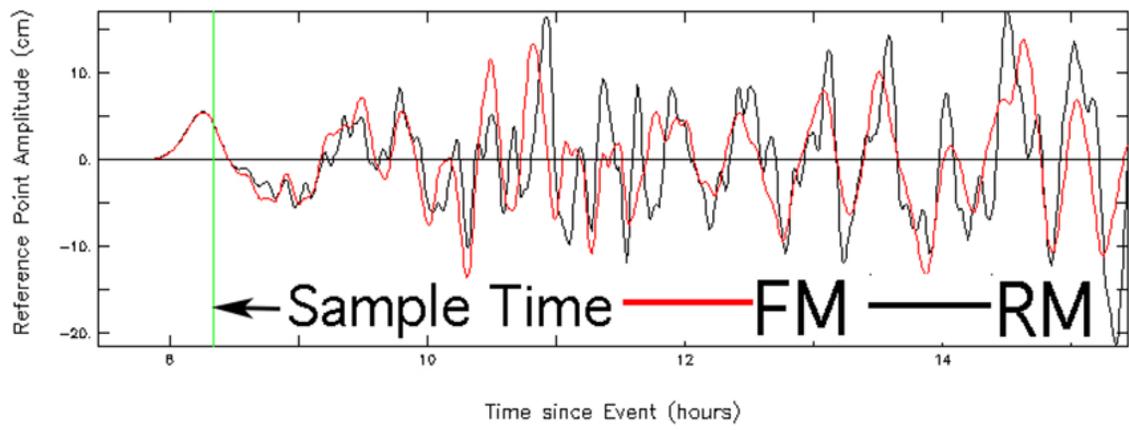
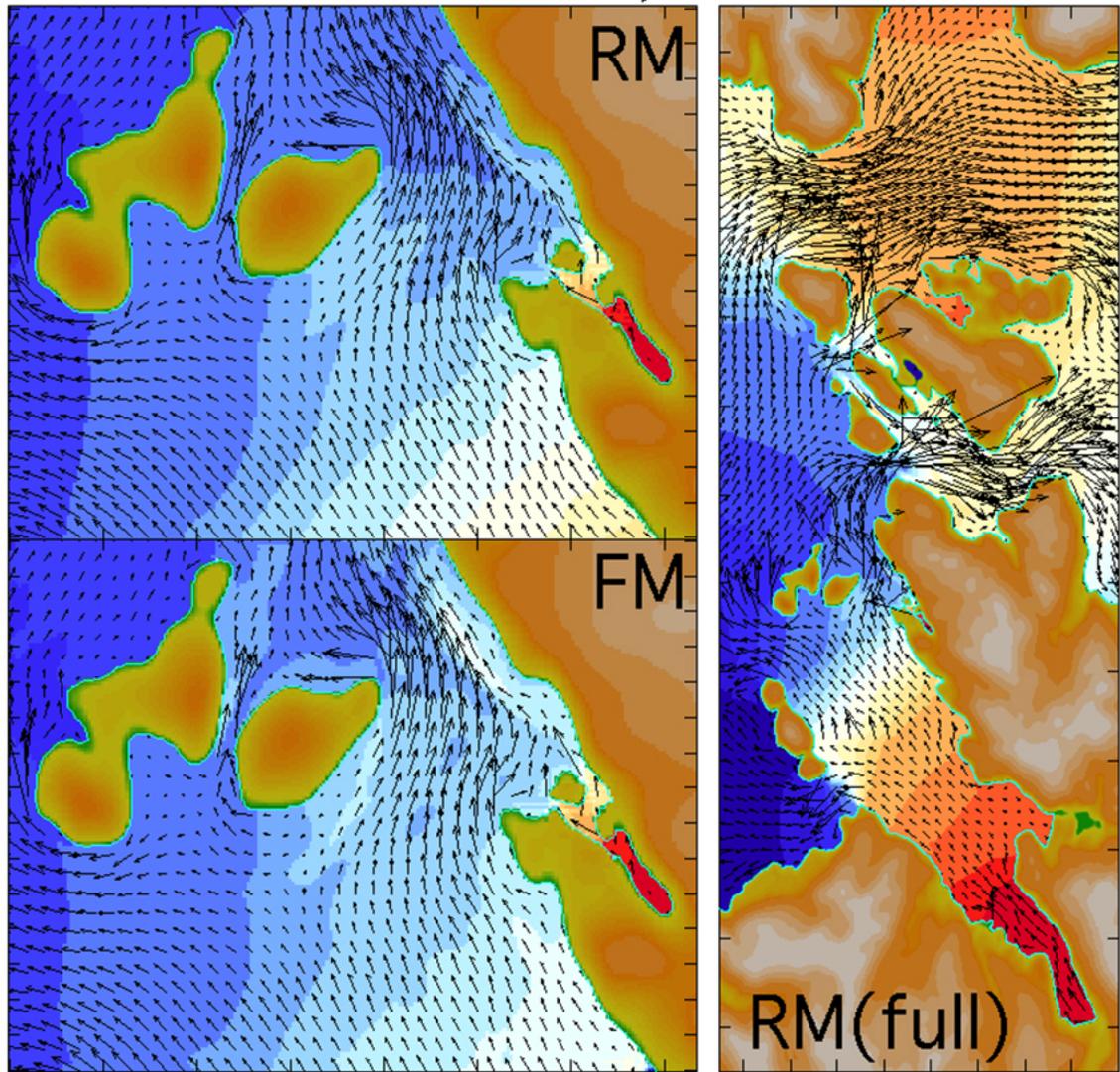


Figure 20 continued. As for Figure 15 but for a hindcast of the Honshu-2011 historic event.
c) snapshot of the current field at the time indicated by the green line in the lower panel.

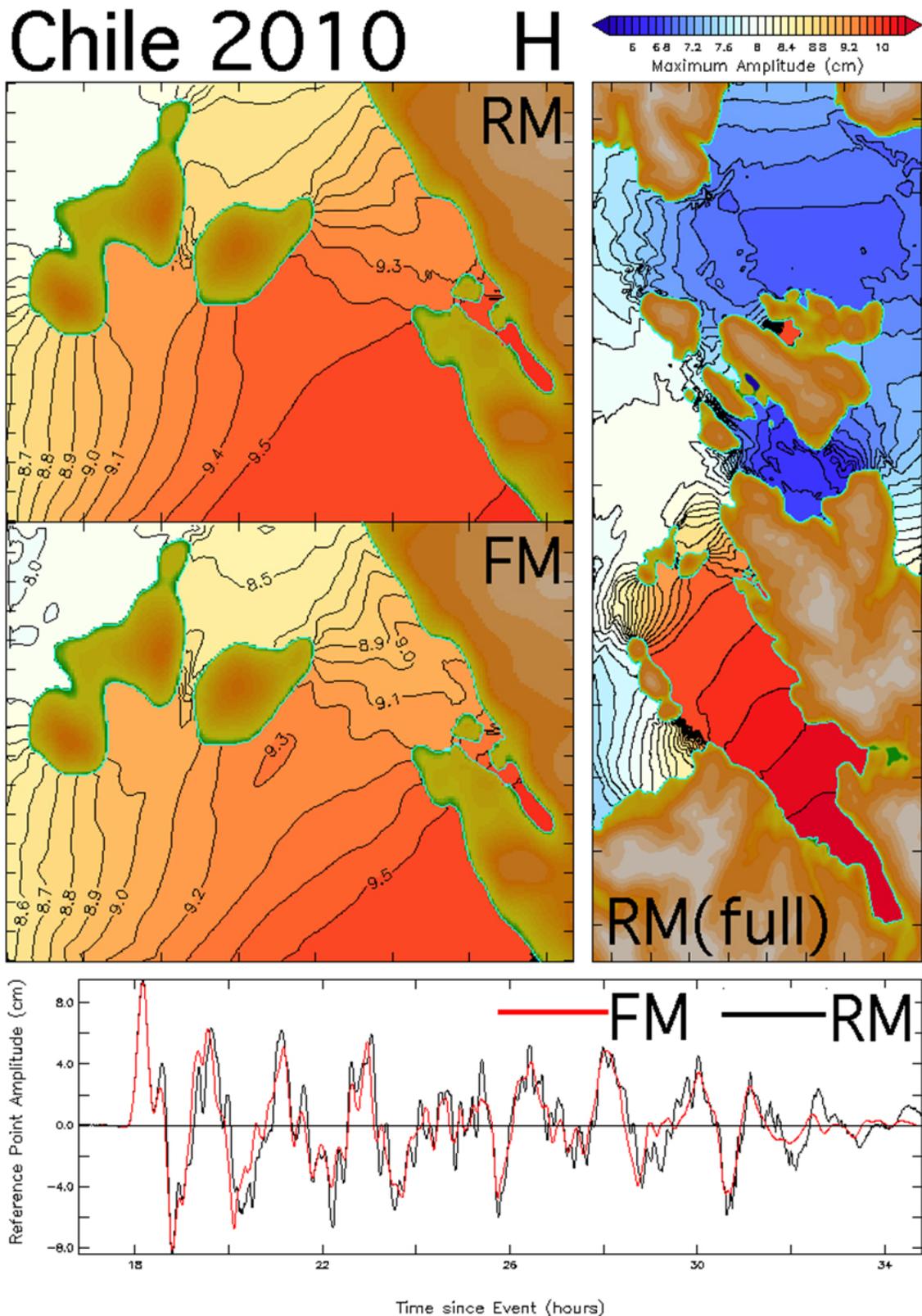


Figure 21. As for Figures 15 and 20, but for a hindcast of the Chile-2010 historic event. The model forcing is based on DART® data collected during the event, and validation results are presented later. a) distribution of maximum amplitude during the 18-hour simulation.

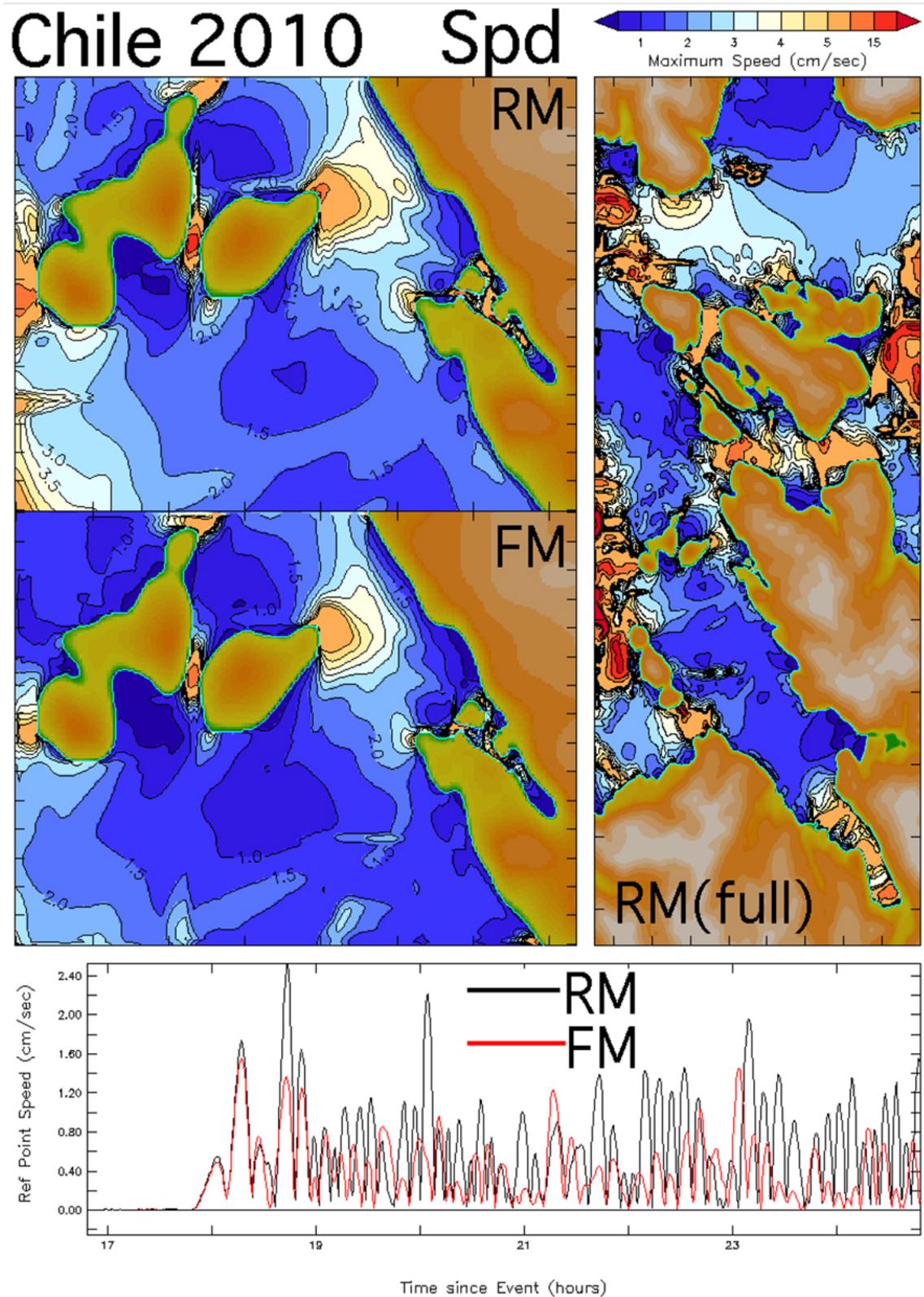


Figure 21 continued. As for Figures 15 and 20, but for a hindcast of the Chile-2010 historic event.
 b) distribution of maximum speed.

Chile 2010 U,V

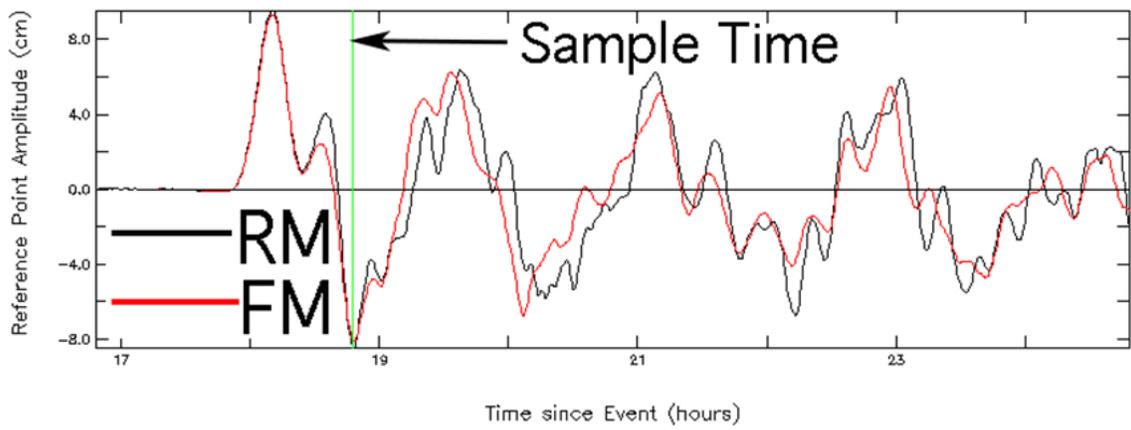
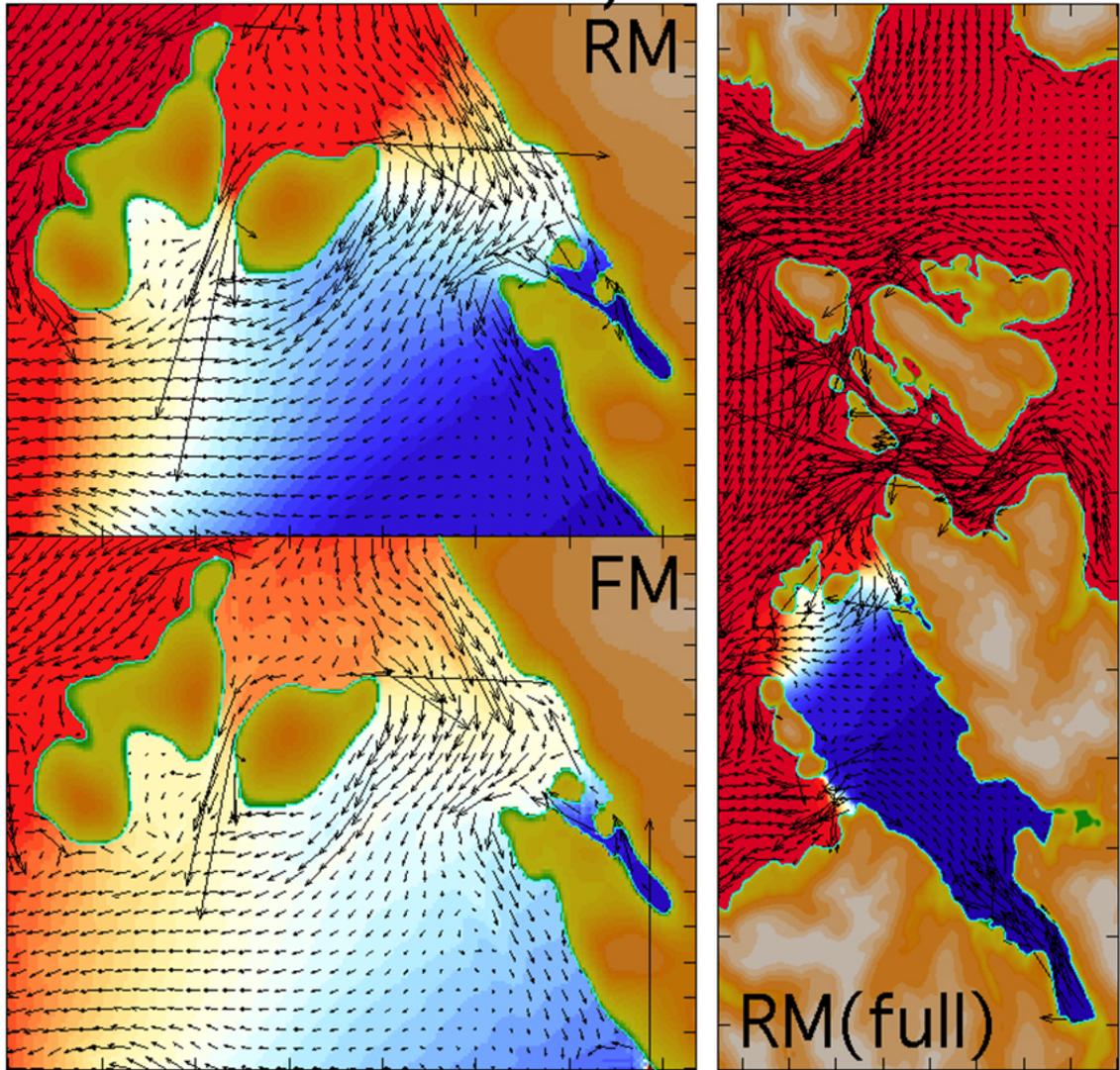
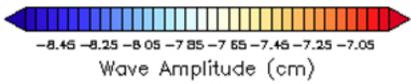


Figure 21 continued. As for Figures 15 and 20, but for a hindcast of the Chile-2010 historic event. c) a snapshot of the current field at the time indicated by the green line in the lower panel.

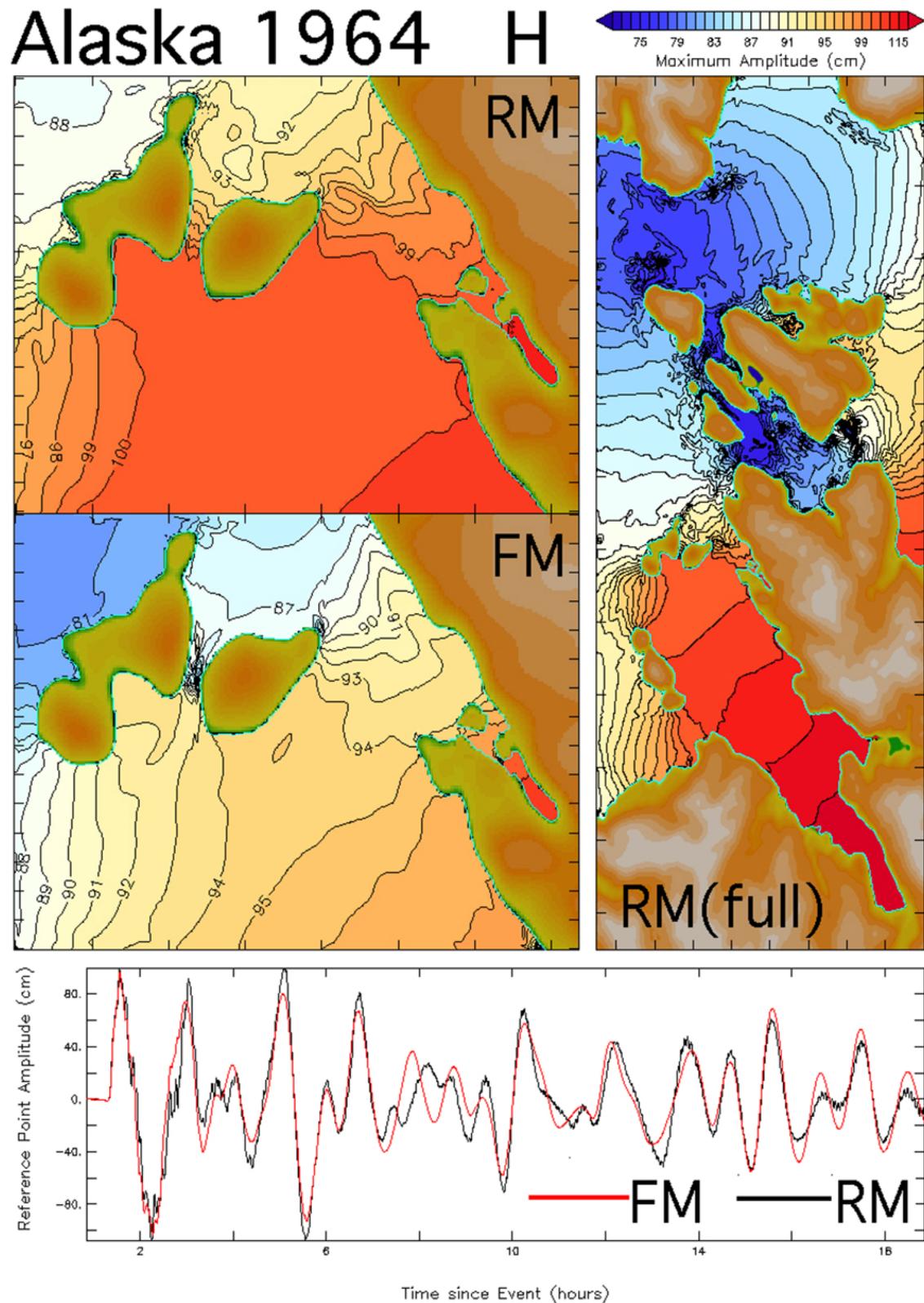


Figure 22. As for Figures 15 and 20 but for a hindcast of the Alaska-1964 tsunami, the largest event impacting Gulf of Alaska communities. The event pre-dated deep ocean tsunami detection capability so the representation of the source is based on post-event studies reported in the literature. a) distribution of maximum amplitude during the 18-hour simulation.

Alaska 1964 Spd

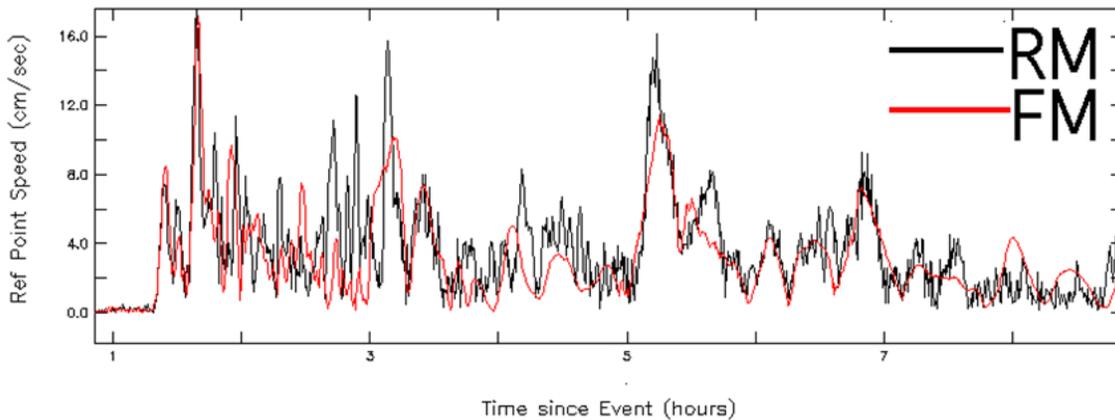
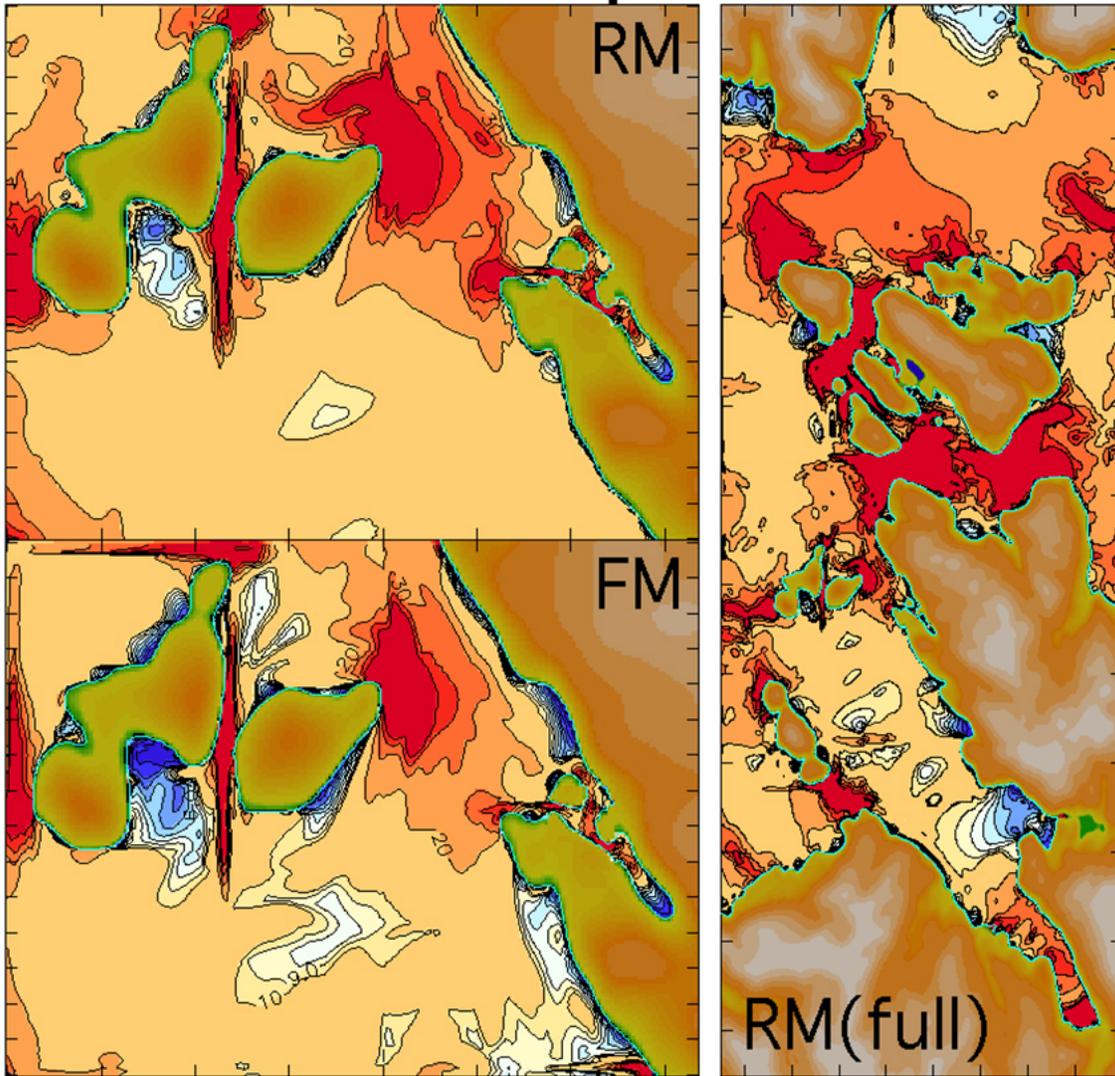


Figure 22 continued. As for Figures 15 and 20 but for a hindcast of the Alaska-1964 tsunami. b) distribution of maximum speed.

Alaska 1964 U,V

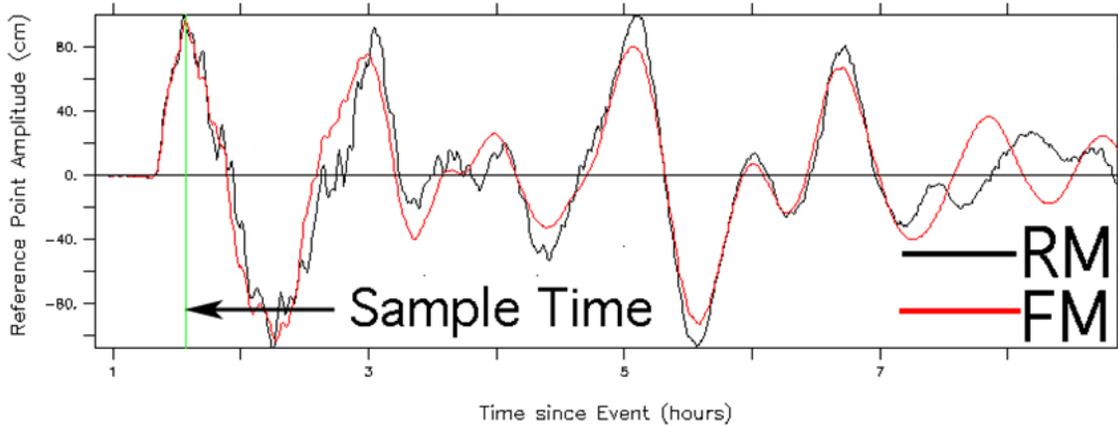
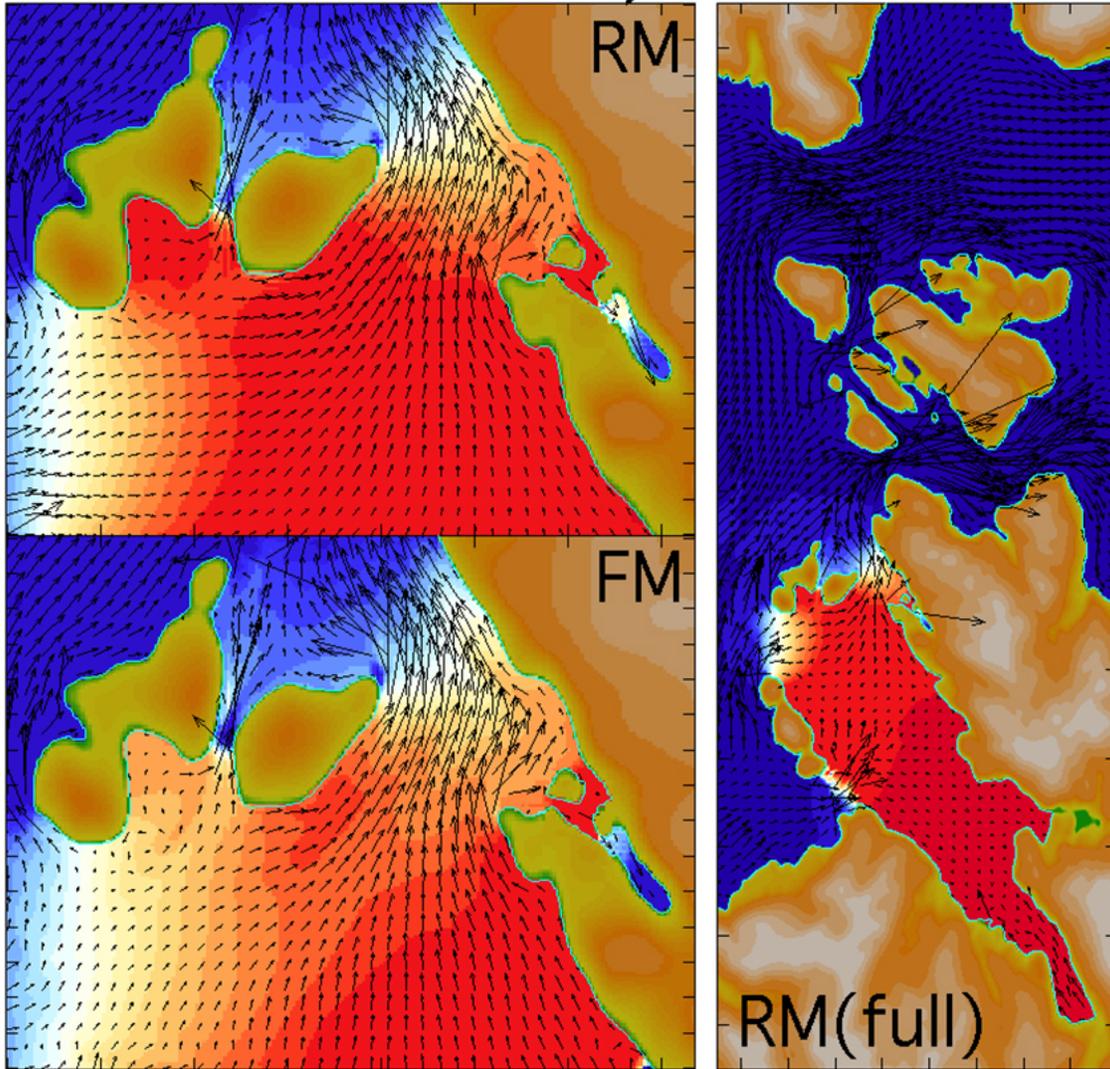
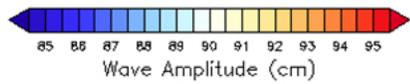


Figure 22 continued. As for Figures 15 and 20 but for a hindcast of the Alaska-1964 tsunami.
c) a snapshot of the current field at the time indicated by the green line in the lower panel.

Chile 1960

H

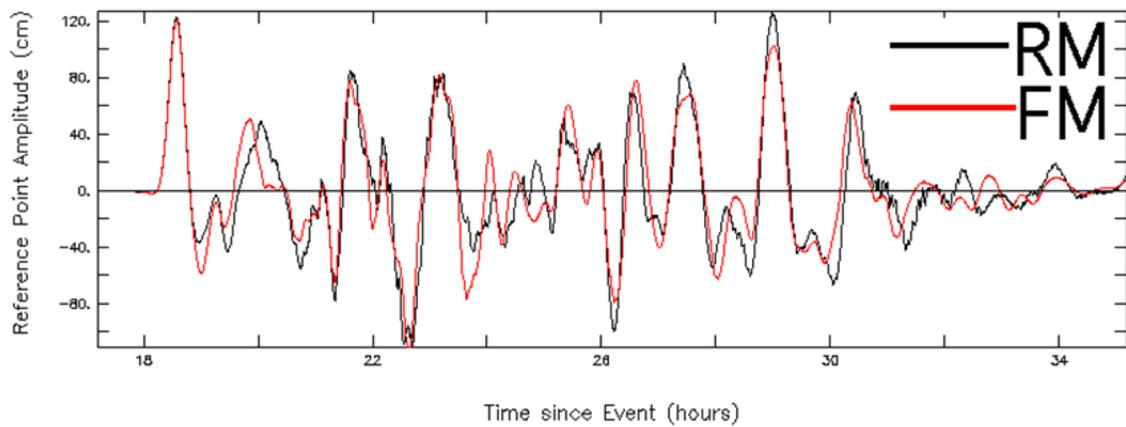
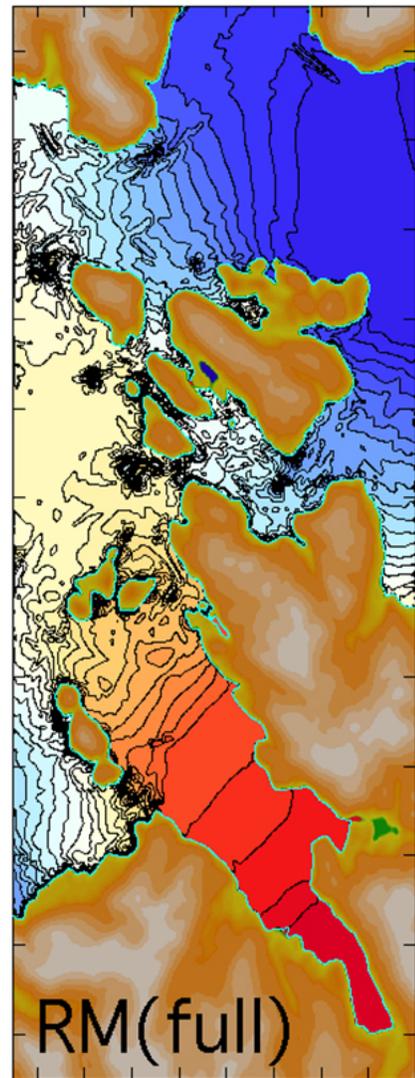
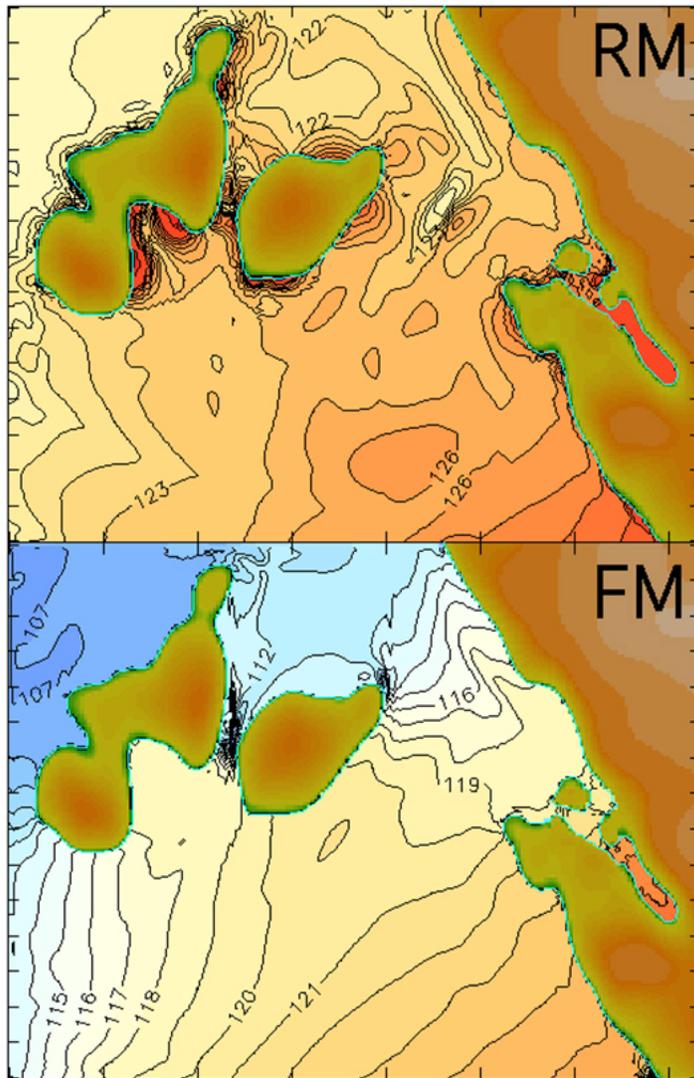
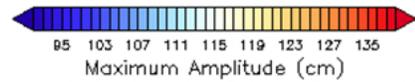


Figure 23. As for Figures 15 and 20 but for a hindcast of the Chile-1960 historic event that was widely felt through the Pacific basin. The source representation is shown later to be poor, but this does not invalidate its use for inter-comparison.
a) distribution of maximum amplitude during the 18-hour simulation.

Chile 1960 Spd

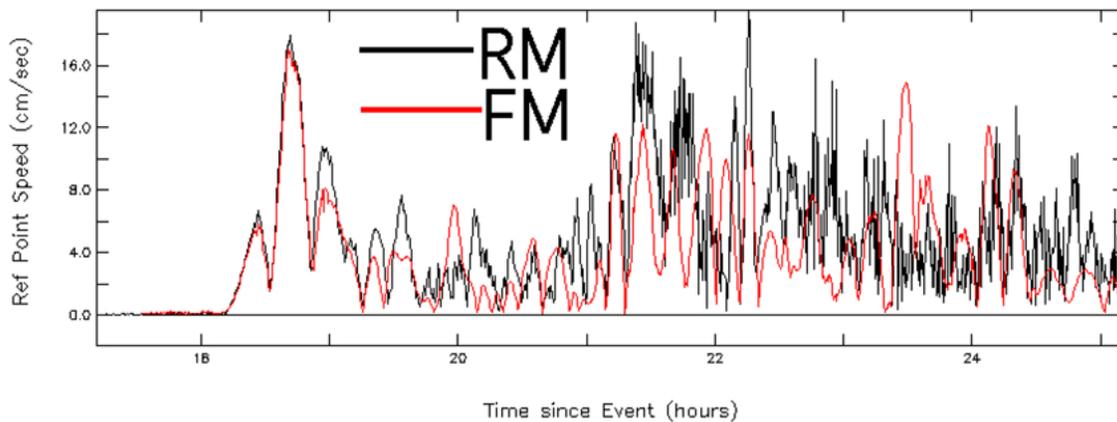
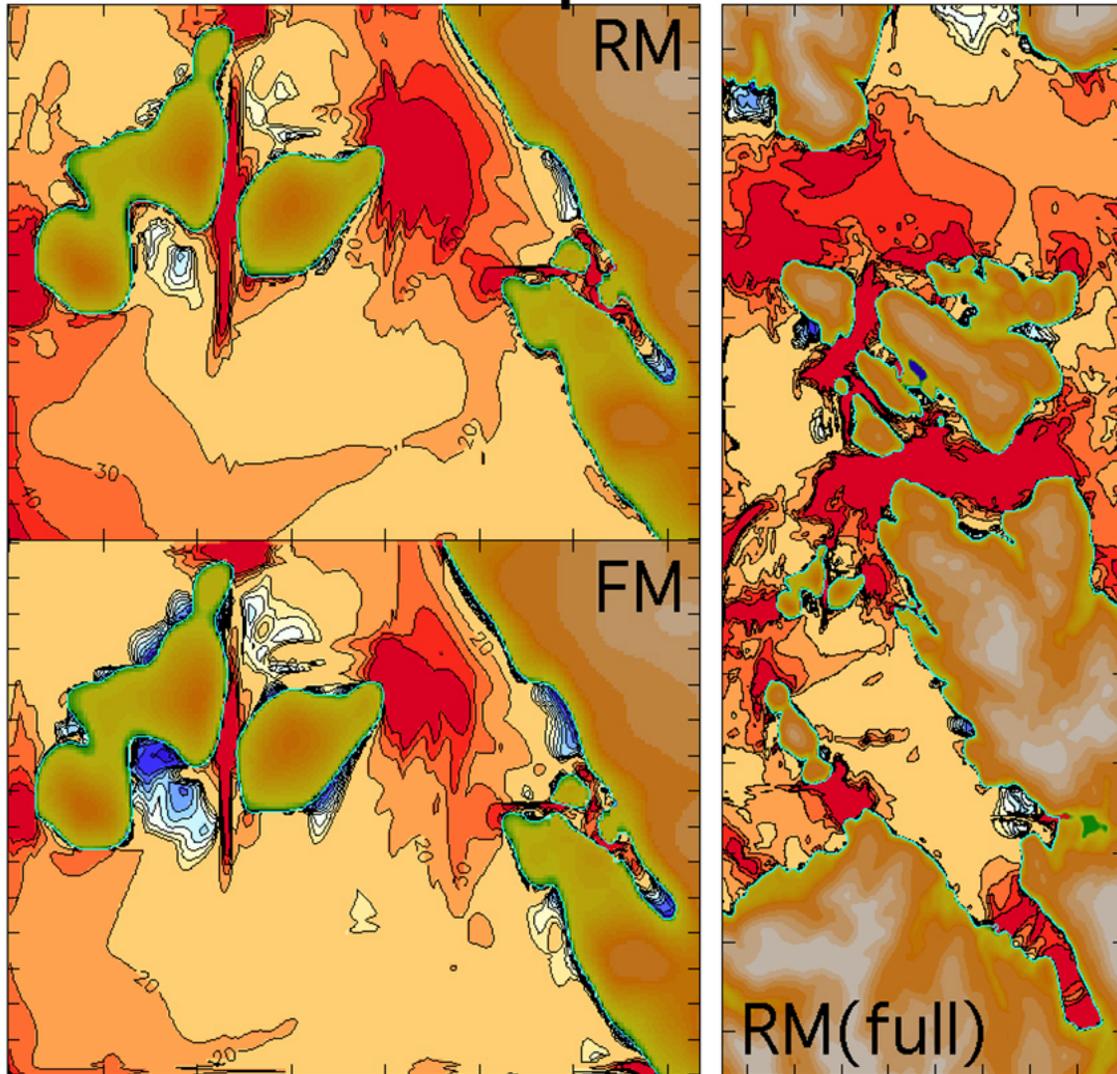


Figure 23 continued. As for Figures 15 and 20 but for a hindcast of the Chile-1960 historic event .
b) distribution of maximum speed.

Chile 1960 U,V

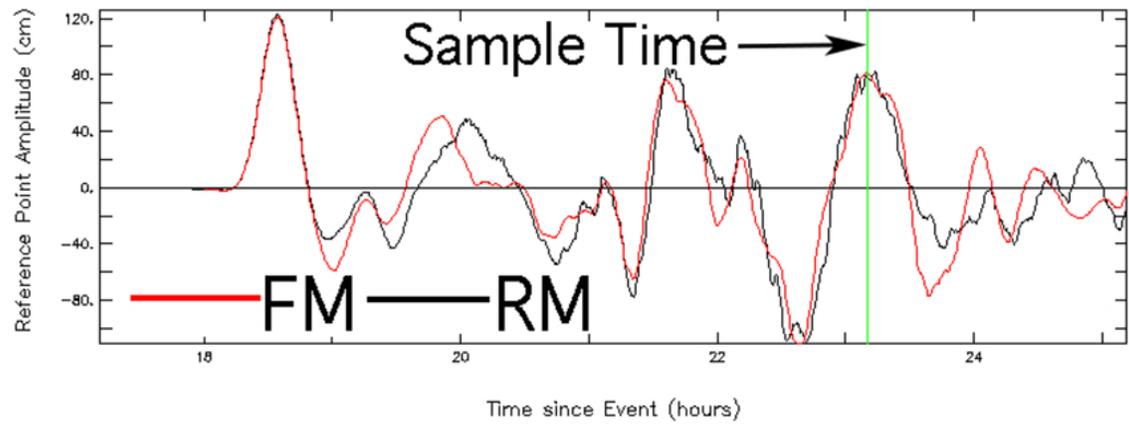
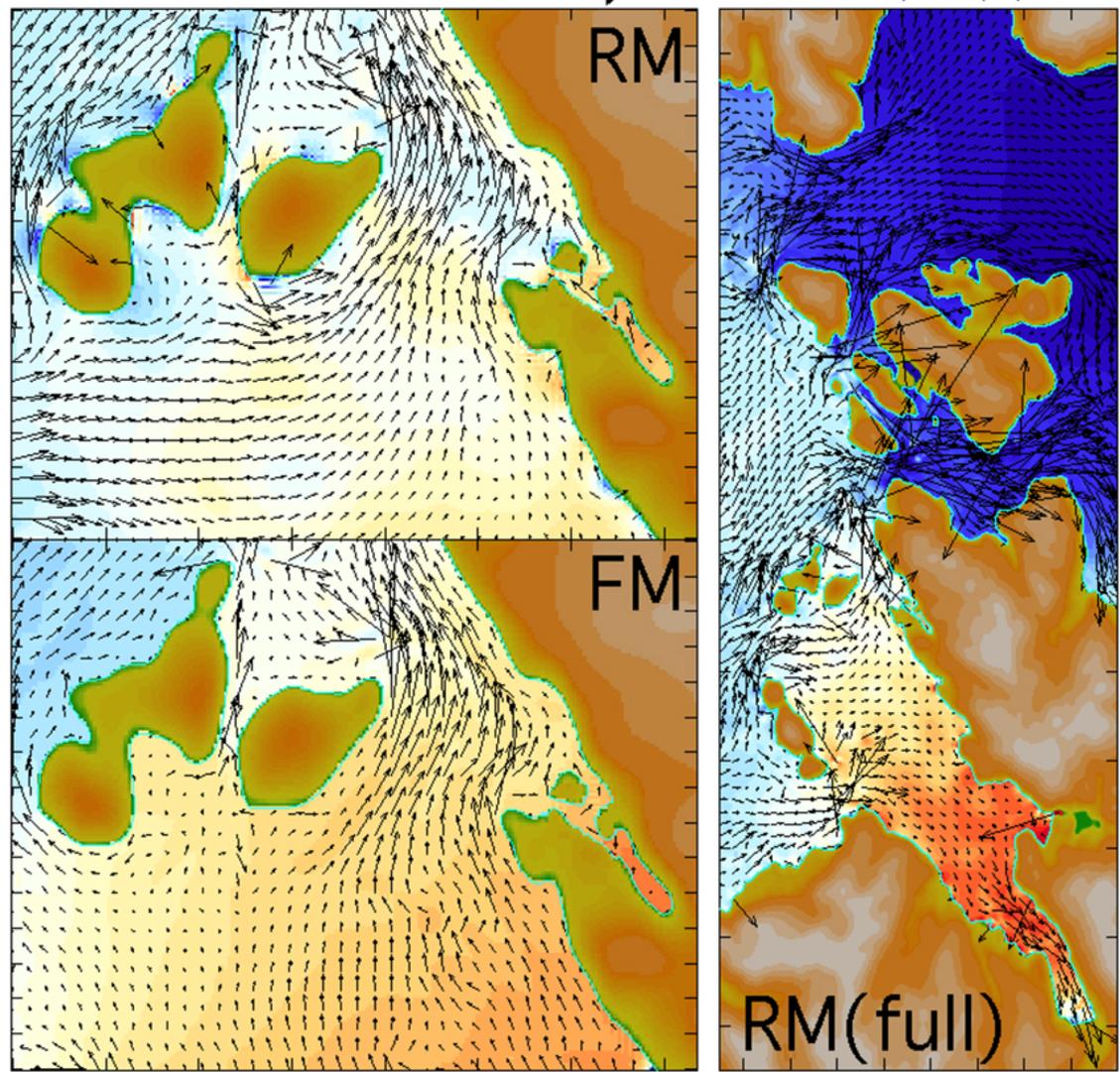
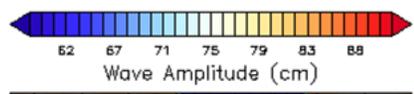


Figure 23 continued. As for Figures 15 and 20 but for a hindcast of the Chile-1960 historic event. c) a snapshot of the current field at the time indicated by the green line in the lower panel.

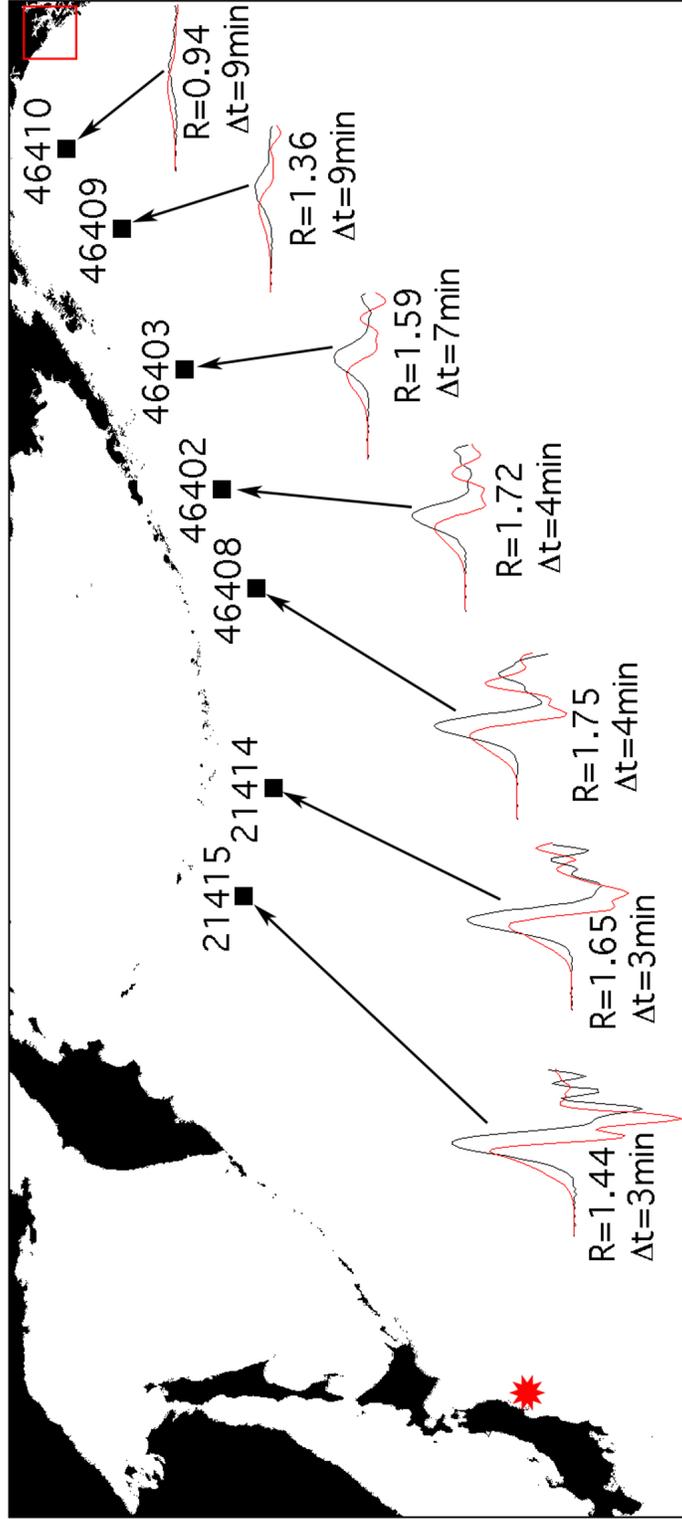


Figure 24. Propagation of the Honshu-2011 tsunami across the North Pacific from its epicenter (red star) to the Gulf of Alaska. DART® observations and model results from MOST use a common vertical and horizontal scale at all locations. The ratio of observed to model amplitude is denoted by R; Δt is the time lead of the model.

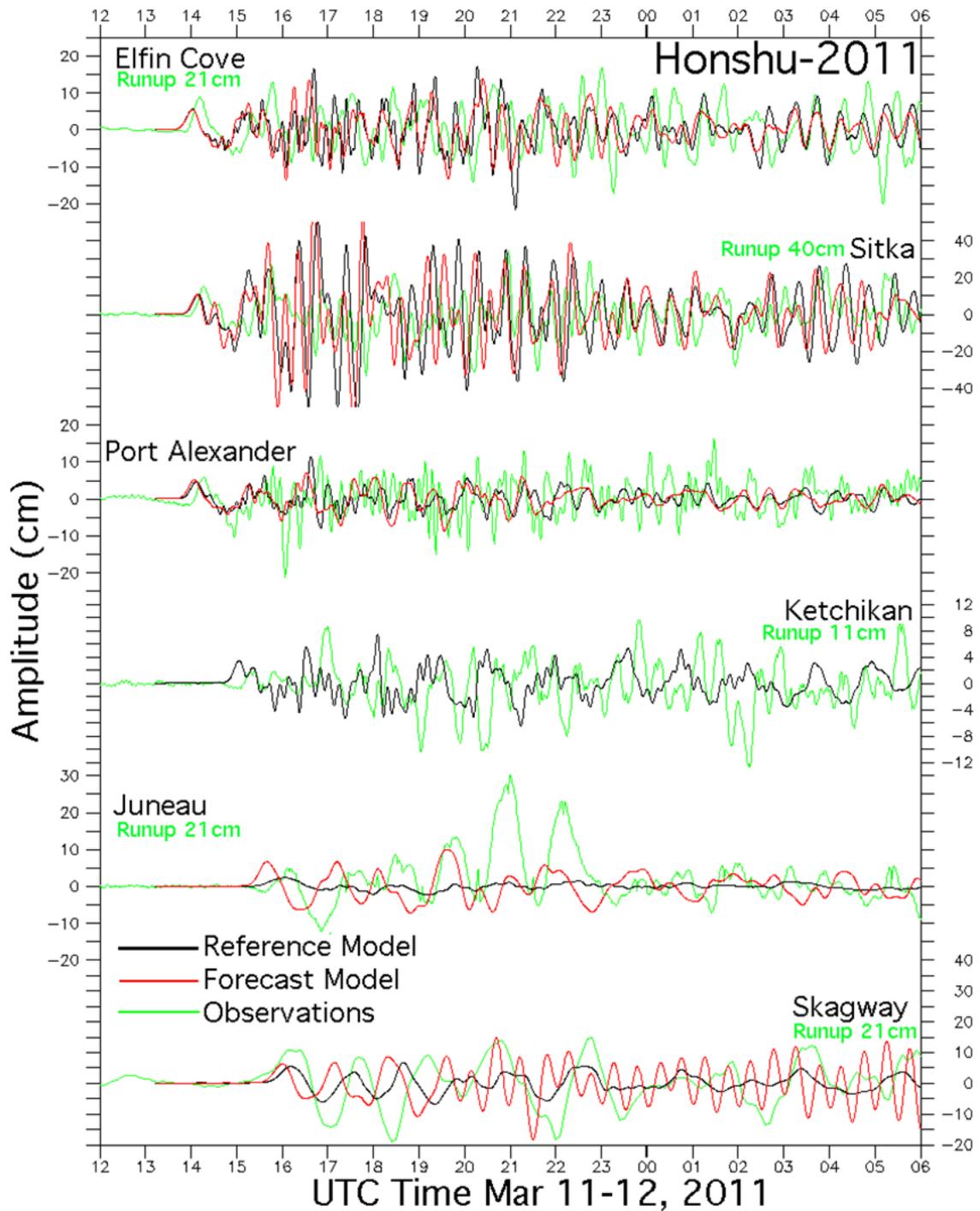


Figure 25. Model validation based on detided and low-passed observations (green) of the Honshu-2011 tsunami at locations within the Elfin Cove model grids. The Reference (RM) and Forecast Model (FM) hindcasts are shown in black and red respectively. Model time series lead the observations, as is common for tele-tsunami events. Agreement is best for Elfin Cove, in the model C-grid, Sitka, and Ketchikan (which is outside the FM grids.) The Port Alexander validation is unclear due to noise in the observations. At Juneau and Skagway, whose grid representation has low resolution, only an approximate match is found.

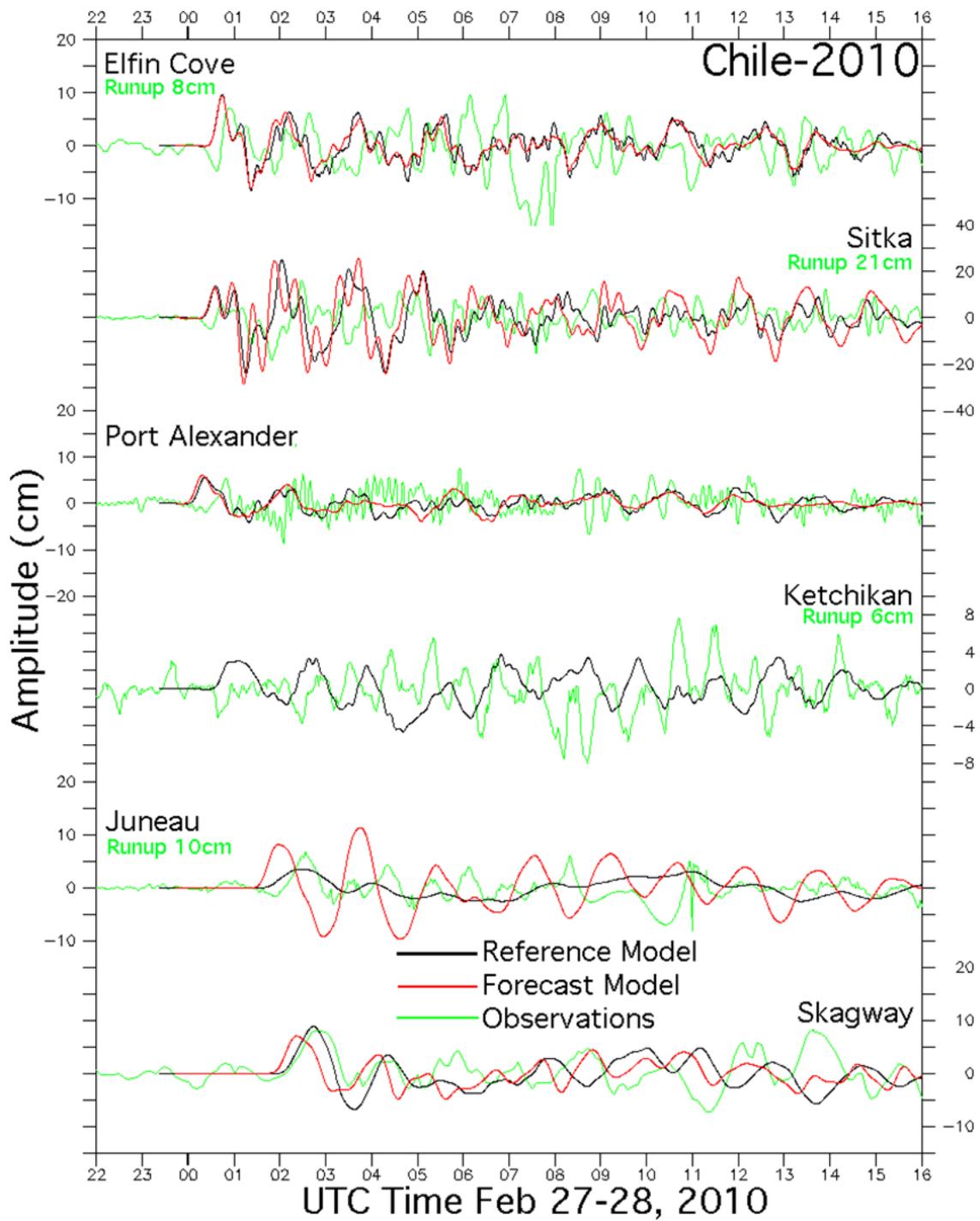


Figure 26. As in Figure 25 but for the Chile-2010 historic tsunami. The model results at the various sites are consistent for the upper three panels in overestimating the observed signal. For Juneau and Skagway the better resolution of the RM A-grid results in improved agreement with the data.

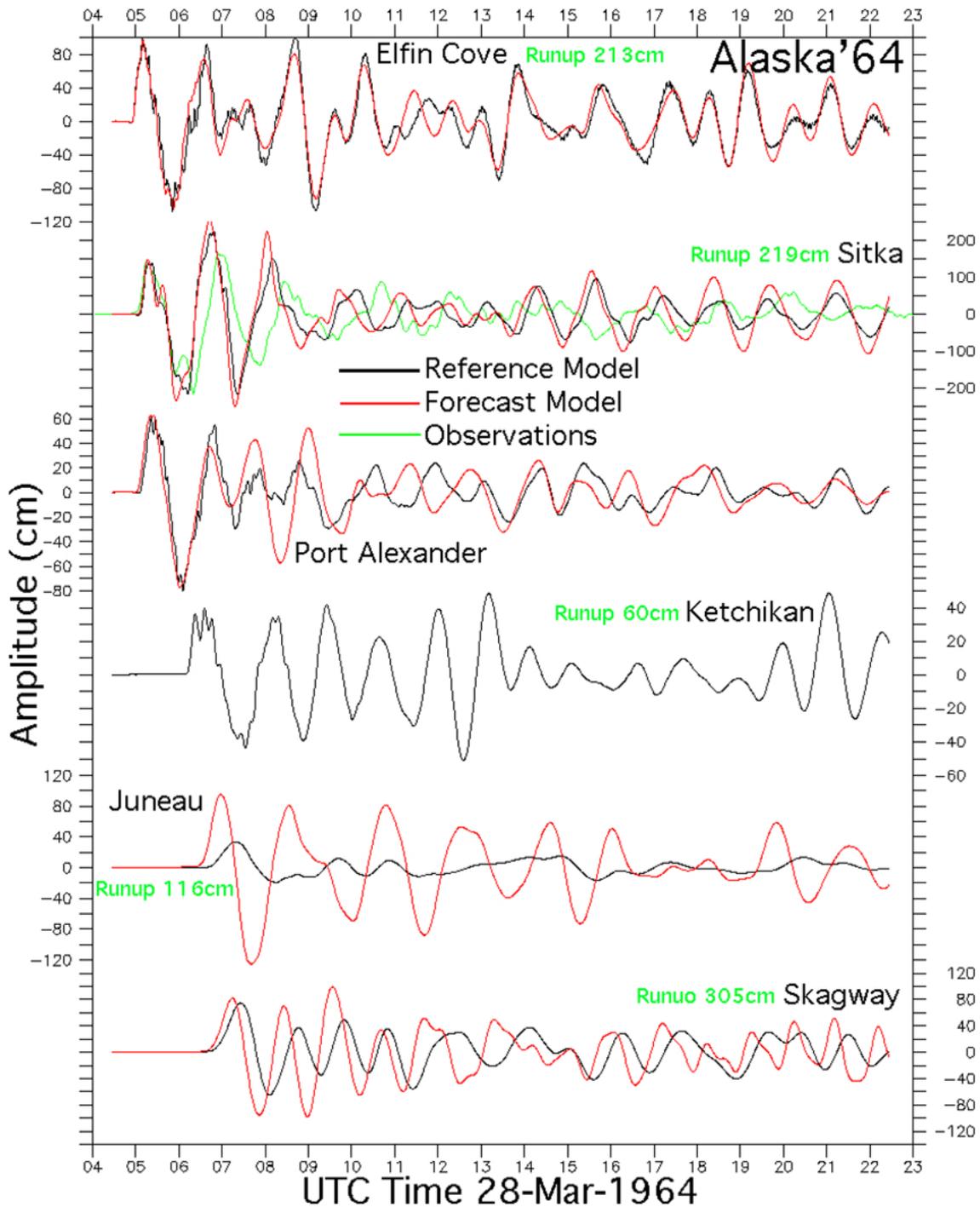


Figure 27. Model validation based on the Alaska-1964 historic tsunami. An observed time series is only available for Sitka, based on a digitized marigram in the WCATWC archives. At Elfin Cove, Port Alexander, and Skagway the agreement between the Reference (RM) and Forecast Model (FM) hindcasts is good, throughout the event. Juneau is less satisfactory but, consistent with the Honshu-2011 and Chile-2010 results, FM exceeds RM.

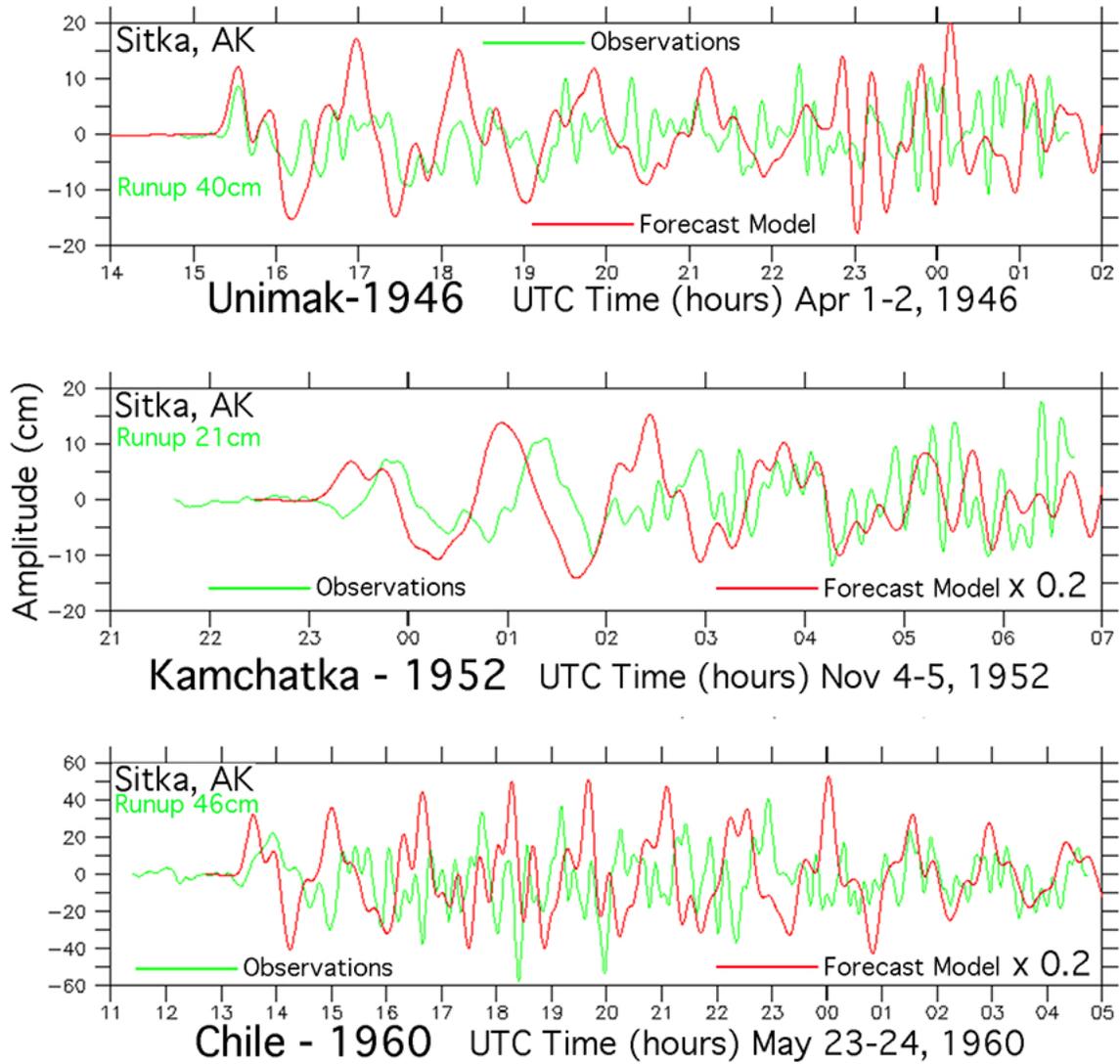


Figure 28. Attempted model validation based on digitized marigrams for Sitka associated with the Unimak-1946, Kamchatka-1952 and Chile-1960 tsunamis.

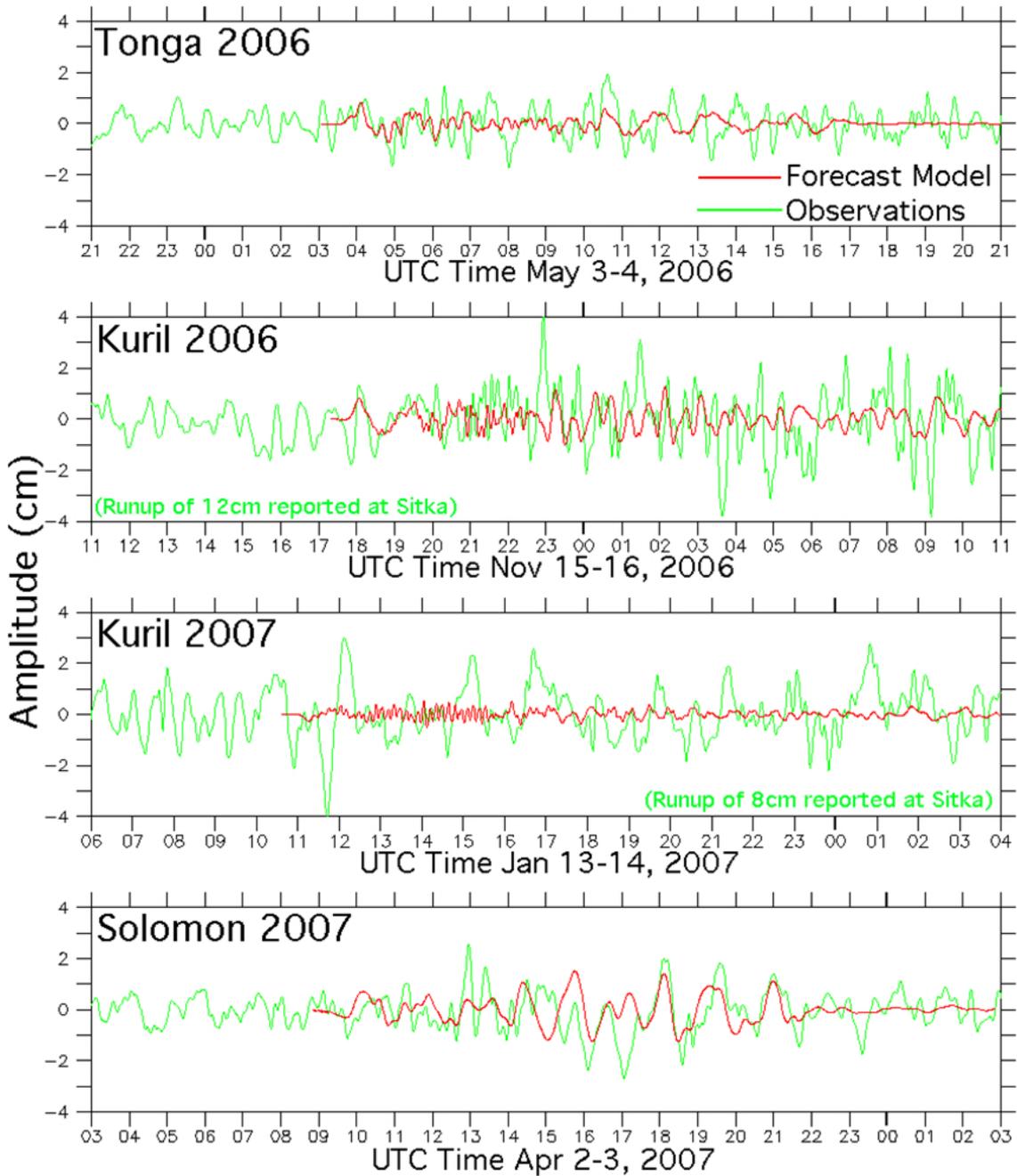


Figure 29. Comparison of Forecast Model (FM) hindcasts at the Elfin Cove tide gage with observations for selection of historic events since one-minute data became available. Owing to the weak response of the Gulf of Alaska region, and poor signal to noise ratios, none of these events were of use in model validation.

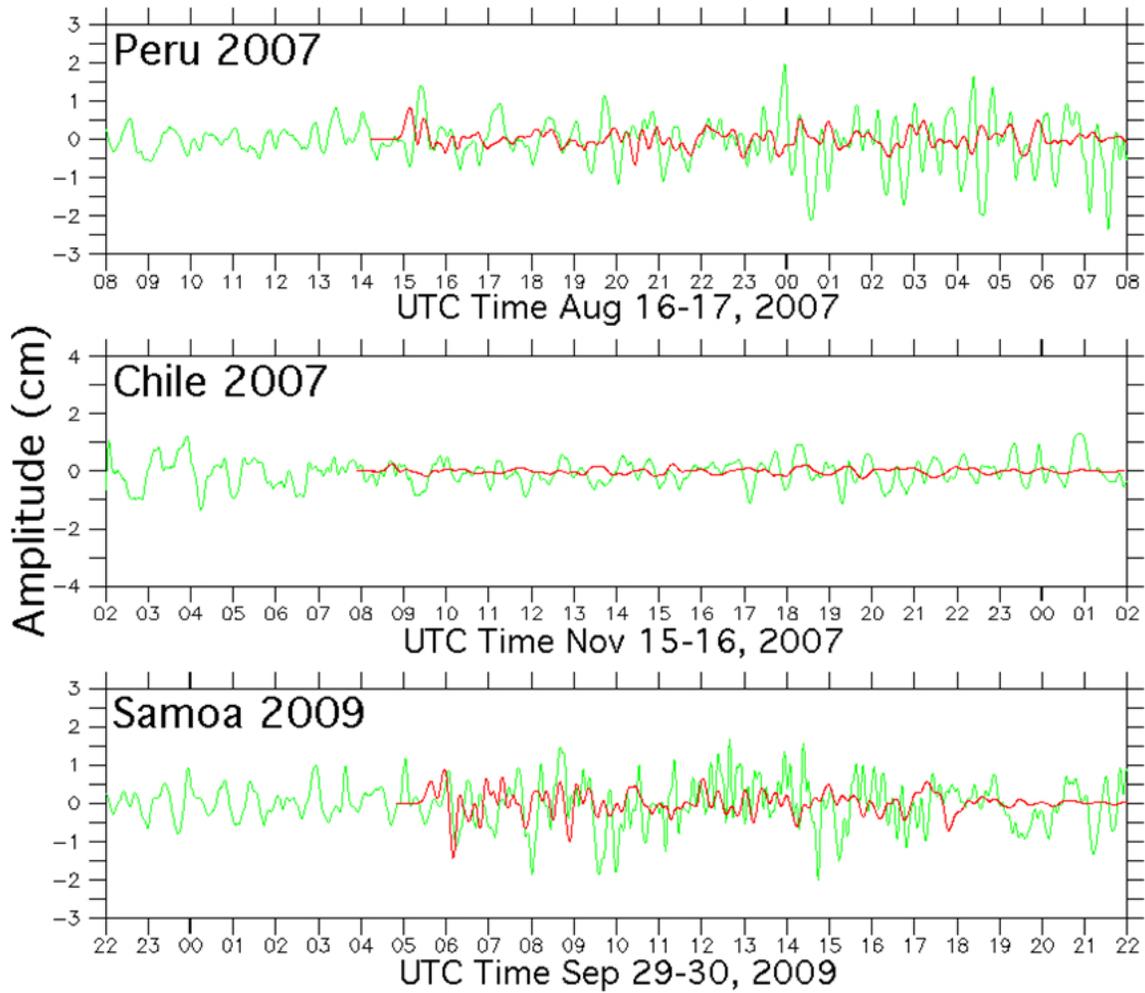


Figure 29 continued. Comparison of Forecast Model (FM) hindcasts at the Elfin Cove tide gage with observations for selection of historic events since one-minute data became available.

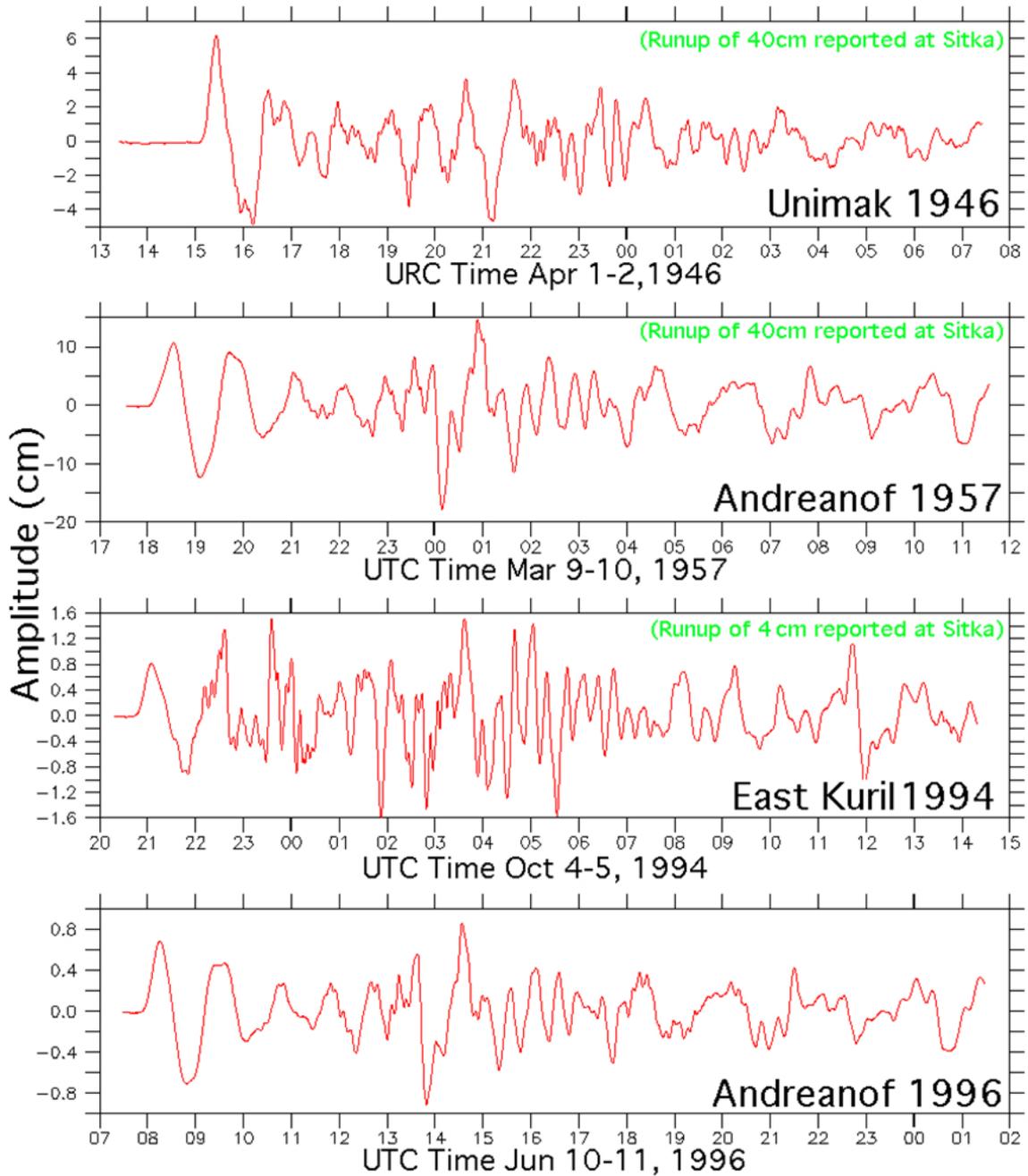


Figure 30. Forecast Model hindcasts for Elfin Cove during various earlier tsunamis for which tide gage records are unavailable. Some Sitka runup reports are indicated.

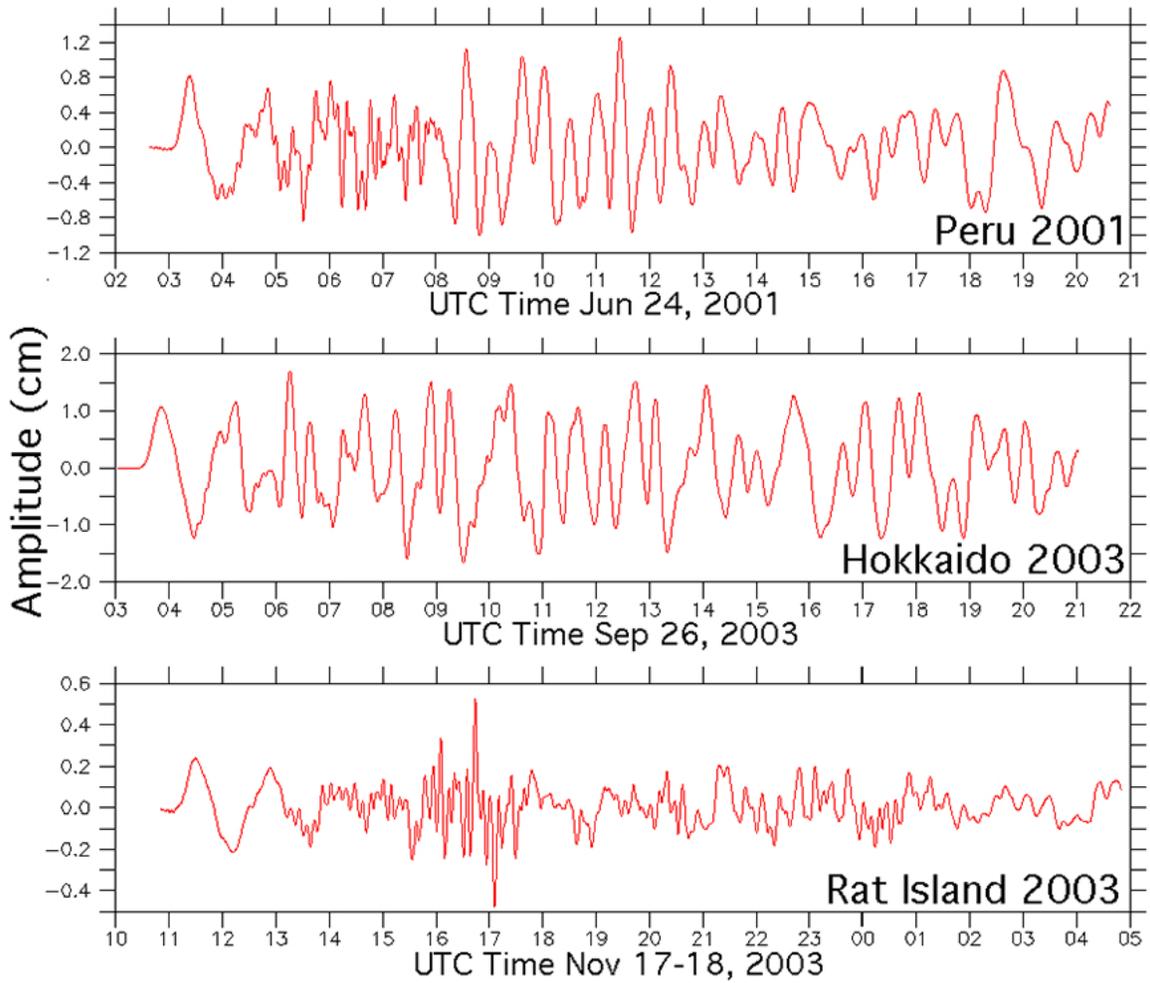


Figure 30 continued. Forecast Model hindcasts for Elfin Cove during various earlier tsunamis for which tide gage records are unavailable. Some Sitka runup reports are indicated.

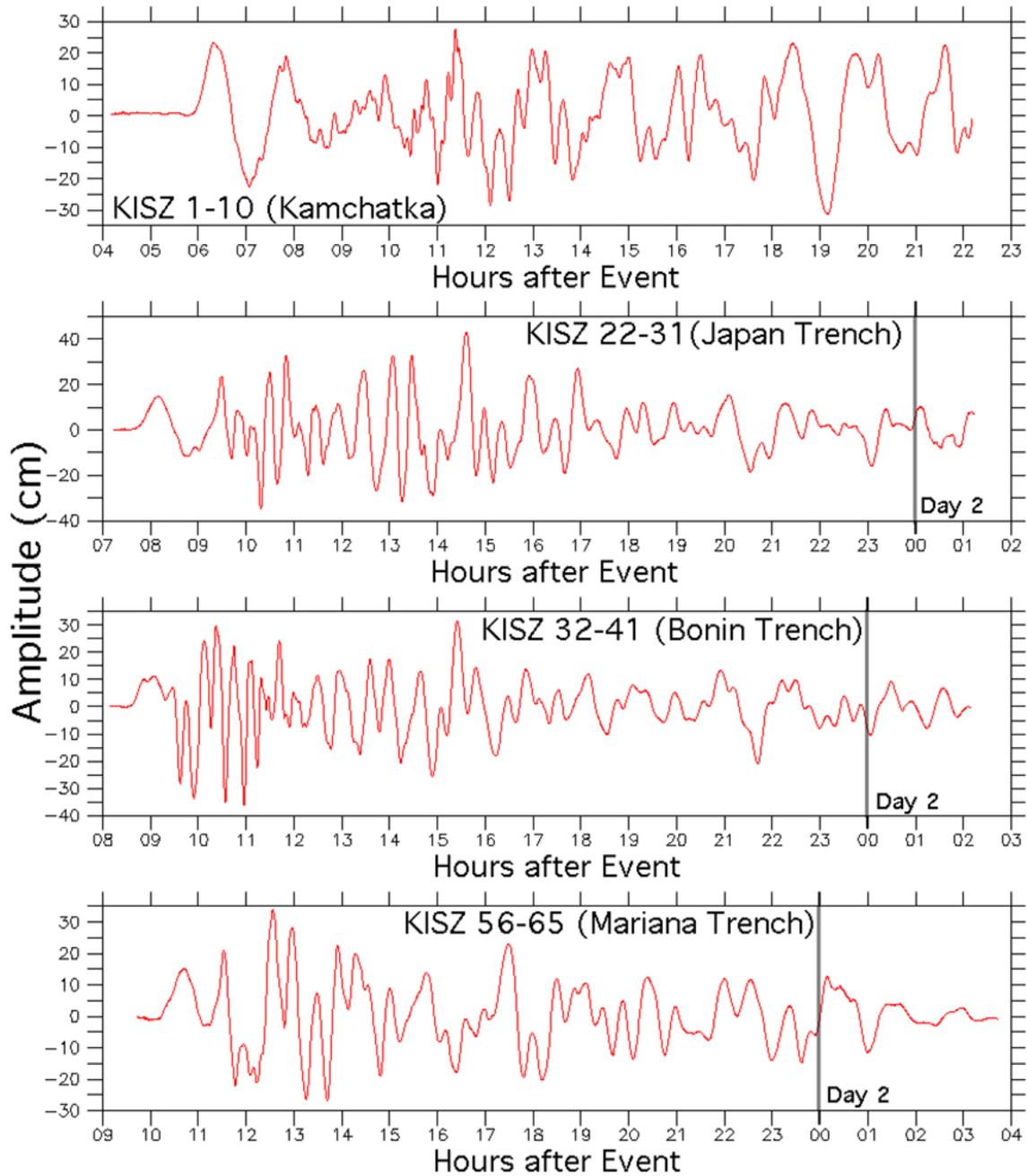


Figure 32. Complete time series of Forecast Model predictions at the Elfin Cove tide gage site for each of the mega-tsunami scenarios. Time is in hours from the event and, although each simulation is limited to 18 hours after the wave enters the model domain, some events extend into a second day after the event.

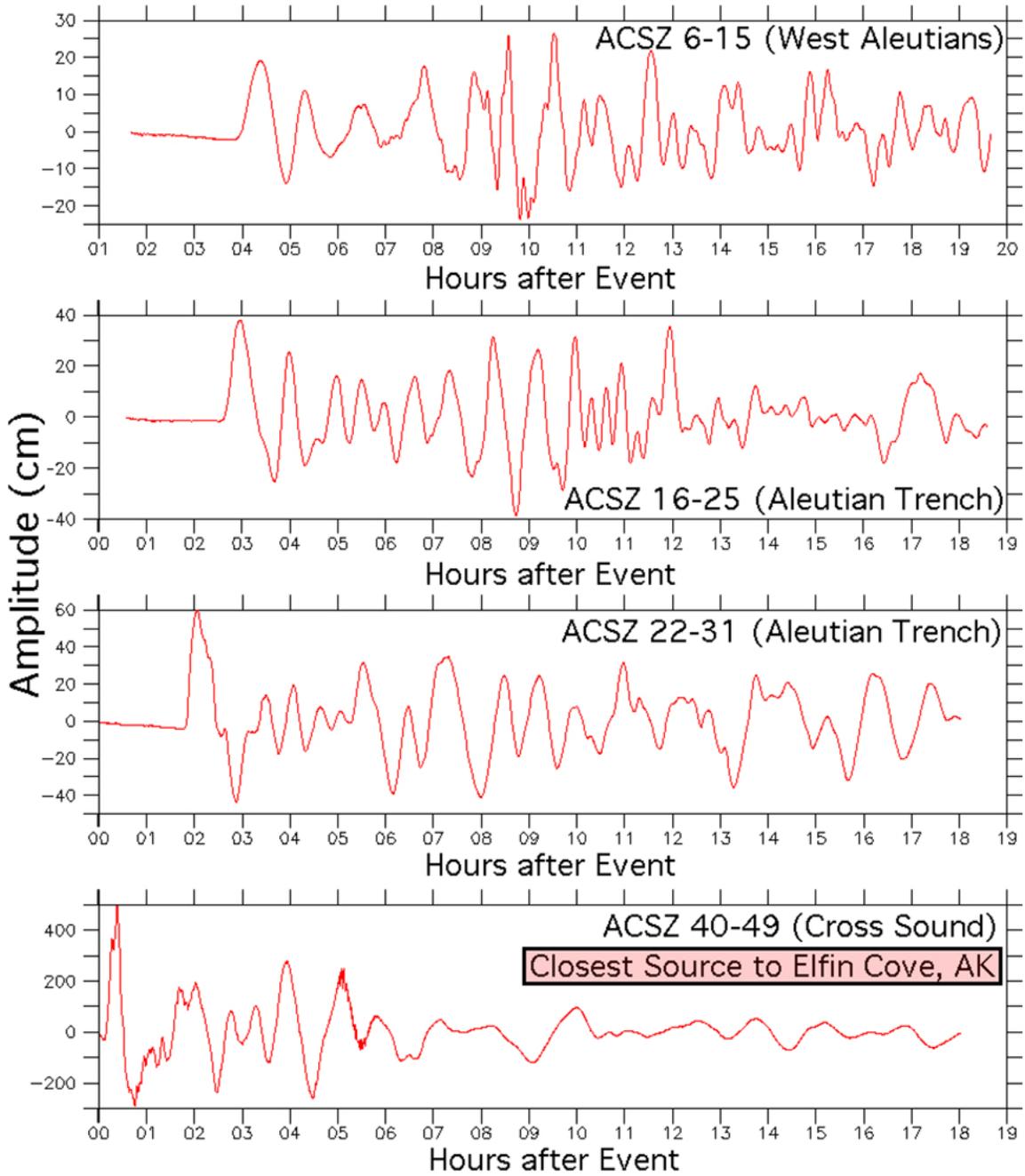


Figure 32 continued. Complete time series of Forecast Model predictions at the Elfin Cove tide gage site for each of the mega-tsunami scenarios.

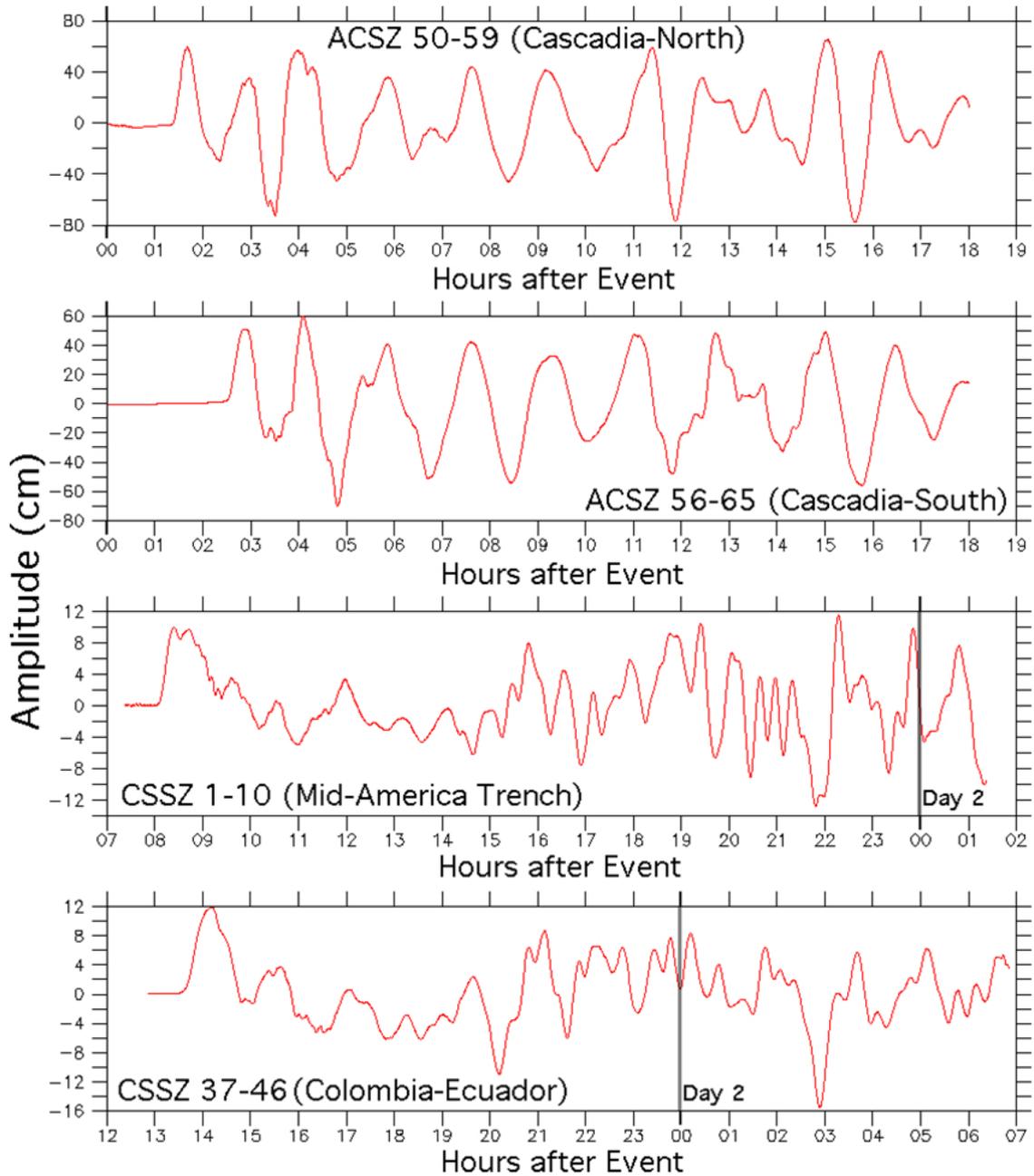


Figure 32 continued. Complete time series of Forecast Model predictions at the Elfin Cove tide gage site for each of the mega-tsunami scenarios.

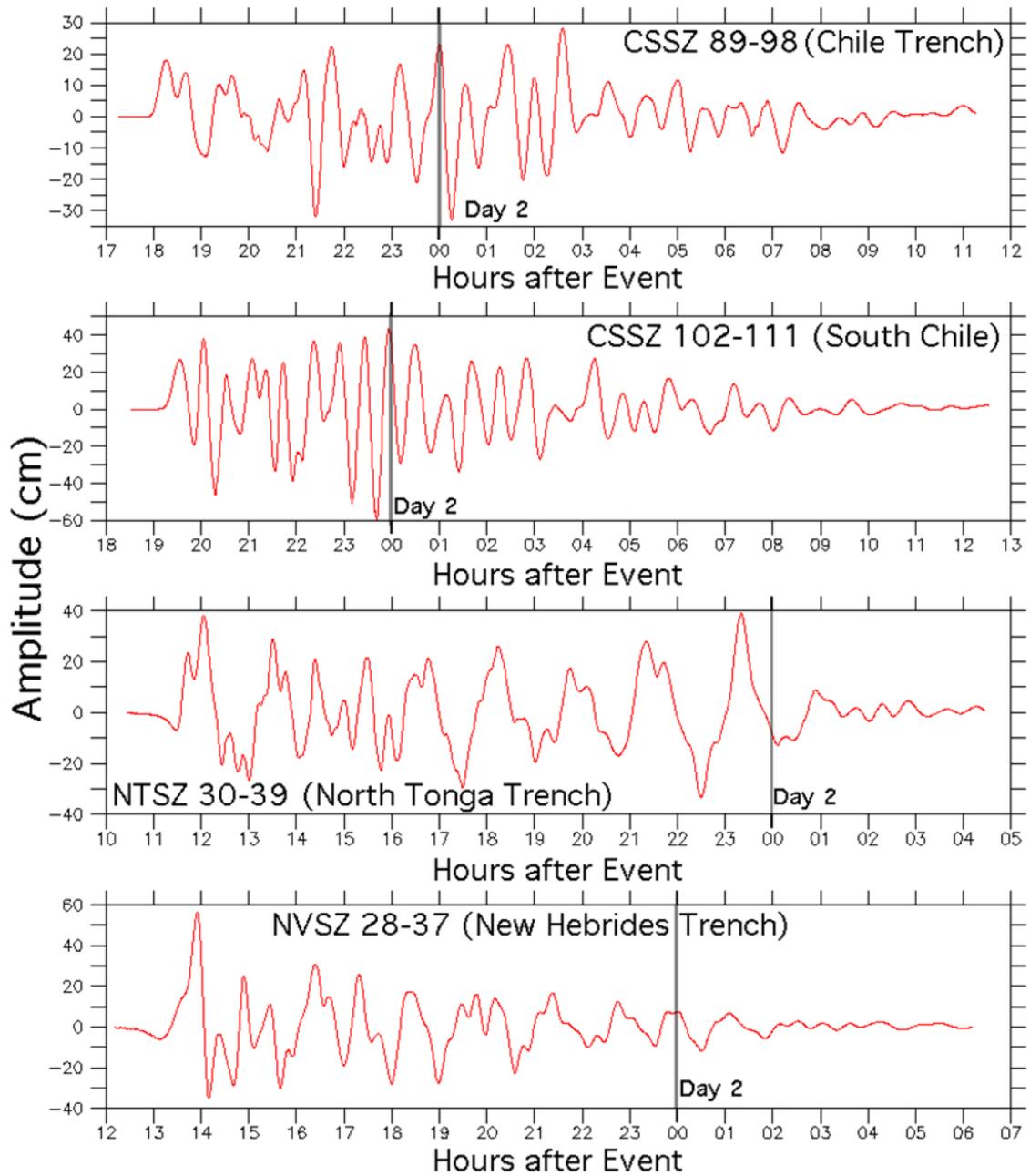


Figure 32 continued. Complete time series of Forecast Model predictions at the Elfin Cove tide gage site for each of the mega-tsunami scenarios.

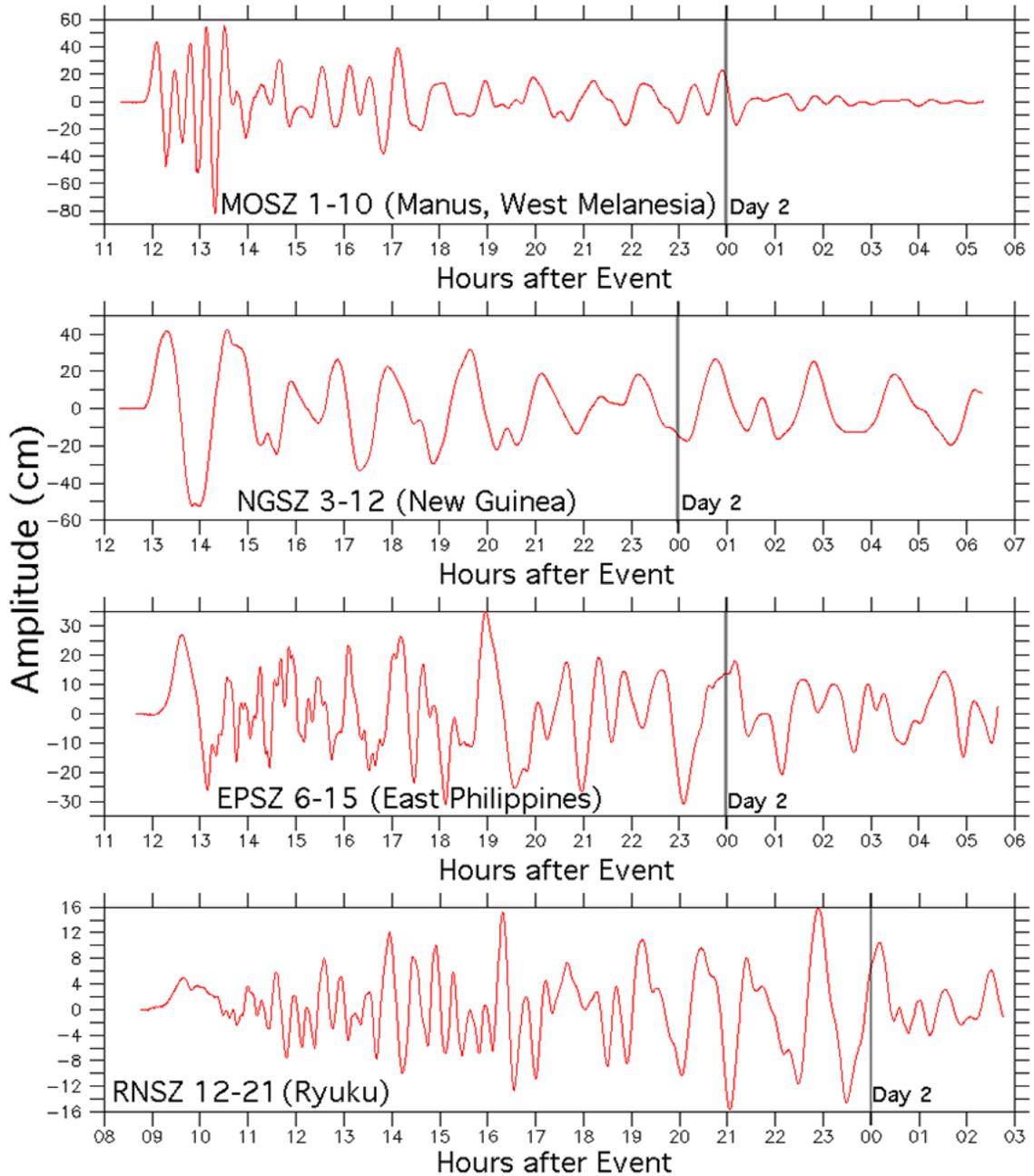


Figure 32 continued. Complete time series of Forecast Model predictions at the Elfin Cove tide gage site for each of the mega-tsunami scenarios.

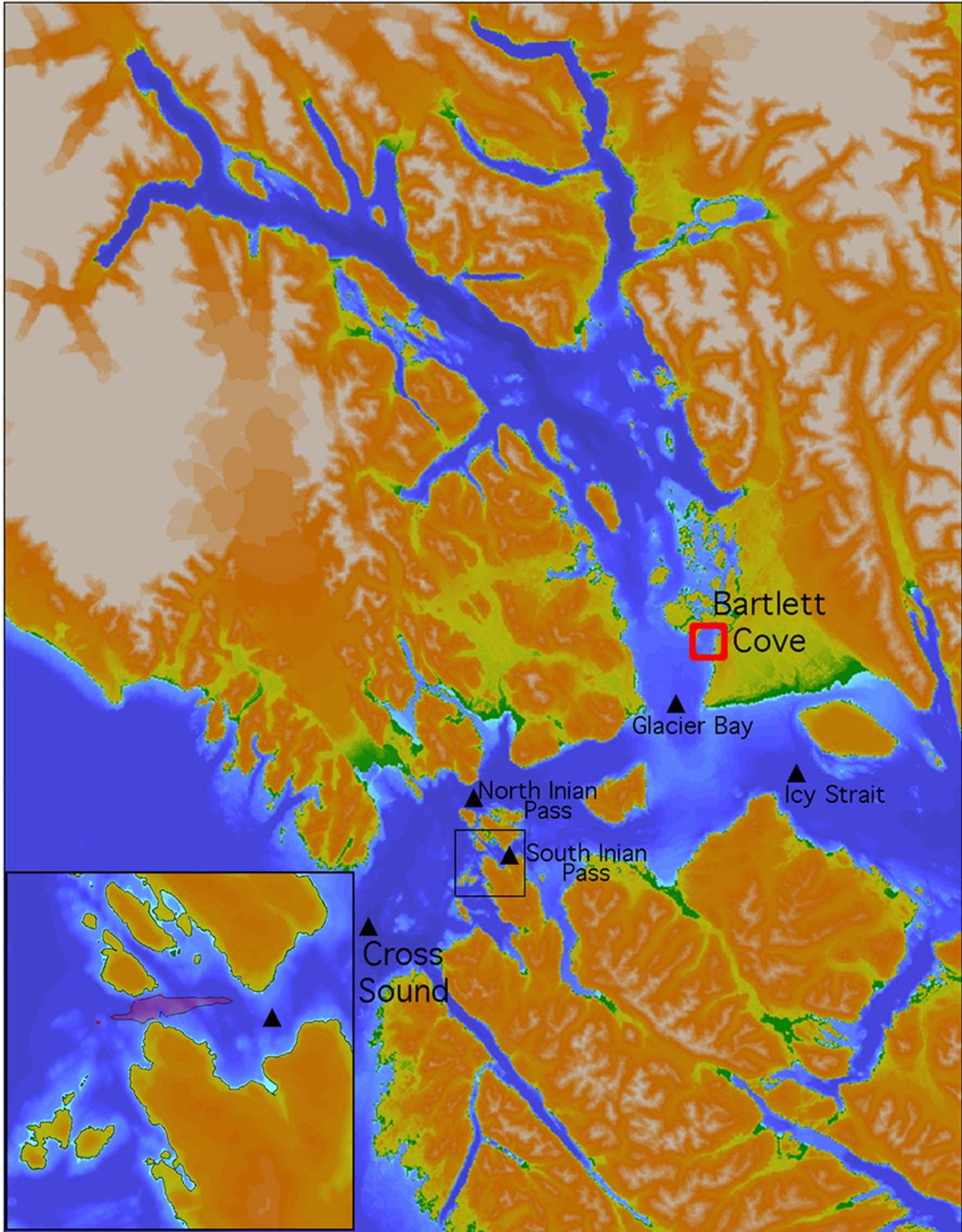


Figure 33. Current meter sites instrumented by NOAA's EcoFOCI Program (Stabeno, personal communication) for which mega-event speed maxima from the Elfin Cove model were extracted and listed in Table 10. The inset panel shows the 10 knot contour for the local (ACSZ 40-49) scenario which produces the strongest currents.

Appendix A

A1. Reference Model Input (*.in) File for Elfin Cove, AK

The following table contains the parameter and file choices used in the input file for the SIFT implementation (most3_facts_nc.in) of the reference model (RM) for Elfin Cove, AK. When run on an Intel® Xeon® E5670 2.93GHz processor the Elfin Cove, AK reference model simulates four hours in 6.77 CPU hours.

Parameter/File*	Purpose
0.0010	Minimum amp. of input offshore wave (m)
2.5	Minimum depth of offshore (m)
0.1	Dry land depth of inundation (m)
0.0009	Friction coefficient (n^{**2})
1	Let A-Grid and B-Grid run up
900.0	Max eta before blow-up (m)
0.25	Time step (sec)
115200	Total number of time steps in run
12	Time steps between A-Grid computations
4	Time steps between B-Grid computations
120	Time steps between output steps
0	Time steps before saving first output step
1	Save output every n-th grid point
ElfinCoveAK_RM_A.most	A-grid bathymetry file
ElfinCoveAK_RM_B.most	B-grid bathymetry file
ElfinCoveAK_RM_C.most	C-grid bathymetry file
./	Directory of source files
./	Directory for output files

* The column headings are not part of most3_facts_nc.in

A2. Forecast Model Input (*.in) File for Elfin Cove, AK

The following table contains the parameter and file choices used in the input file for the SIFT implementation (most3_facts_nc.in) of the optimized forecast model (FM) for Elfin Cove, AK. When run on an Intel® Xeon® E5670 2.93GHz processor the Elfin Cove, AK forecast model simulates four hours in 13.57 minutes.

Parameter/File*	Purpose
0.0010	Minimum amp. of input offshore wave (m)
2.5	Minimum depth of offshore (m)
0.1	Dry land depth of inundation (m)
0.0009	Friction coefficient (n^*2)
1	Let A-Grid and B-Grid run up
900.0	Max eta before blow-up (m)
0.4166666667	Time step (sec)
69120	Total number of time steps in run
12	Time steps between A-Grid computations
4	Time steps between B-Grid computations
72	Time steps between output steps
0	Time steps before saving first output step
1	Save output every n-th grid point
ElfinCoveAK_FM_A.most	A-grid bathymetry file
ElfinCoveAK_FM_B.most	B-grid bathymetry file
ElfinCoveAK_FM_C.most	C-grid bathymetry file
./	Directory of source files
./	Directory for output files

* The column headings are not part of most3_facts_nc.in

Appendix B Propagation Database: Pacific Ocean Unit Sources

DRAFT

Appendix B

Propagation Database: Pacific Ocean Unit Sources

Table B.1: Earthquake parameters for Aleutian–Alaska–Cascadia Subduction Zone unit sources.

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
acsz-1a	Aleutian–Alaska–Cascadia	164.7994	55.9606	299	17	19.61
acsz-1b	Aleutian–Alaska–Cascadia	164.4310	55.5849	299	17	5
acsz-2a	Aleutian–Alaska–Cascadia	166.3418	55.4016	310.2	17	19.61
acsz-2b	Aleutian–Alaska–Cascadia	165.8578	55.0734	310.2	17	5
acsz-3a	Aleutian–Alaska–Cascadia	167.2939	54.8919	300.2	23.36	24.82
acsz-3b	Aleutian–Alaska–Cascadia	166.9362	54.5356	300.2	23.36	5
acsz-4a	Aleutian–Alaska–Cascadia	168.7131	54.2852	310.2	38.51	25.33
acsz-4b	Aleutian–Alaska–Cascadia	168.3269	54.0168	310.2	24	5
acsz-5a	Aleutian–Alaska–Cascadia	169.7447	53.7808	302.8	37.02	23.54
acsz-5b	Aleutian–Alaska–Cascadia	169.4185	53.4793	302.8	21.77	5
acsz-6a	Aleutian–Alaska–Cascadia	171.0144	53.3054	303.2	35.31	22.92
acsz-6b	Aleutian–Alaska–Cascadia	170.6813	52.9986	303.2	21	5
acsz-7a	Aleutian–Alaska–Cascadia	172.1500	52.8528	298.2	35.56	20.16
acsz-7b	Aleutian–Alaska–Cascadia	171.8665	52.5307	298.2	17.65	5
acsz-8a	Aleutian–Alaska–Cascadia	173.2726	52.4579	290.8	37.92	20.35
acsz-8b	Aleutian–Alaska–Cascadia	173.0681	52.1266	290.8	17.88	5
acsz-9a	Aleutian–Alaska–Cascadia	174.5866	52.1434	289	39.09	21.05
acsz-9b	Aleutian–Alaska–Cascadia	174.4027	51.8138	289	18.73	5
acsz-10a	Aleutian–Alaska–Cascadia	175.8784	51.8526	286.1	40.51	20.87
acsz-10b	Aleutian–Alaska–Cascadia	175.7265	51.5245	286.1	18.51	5
acsz-11a	Aleutian–Alaska–Cascadia	177.1140	51.6488	280	15	17.94
acsz-11b	Aleutian–Alaska–Cascadia	176.9937	51.2215	280	15	5
acsz-12a	Aleutian–Alaska–Cascadia	178.4500	51.5690	273	15	17.94
acsz-12b	Aleutian–Alaska–Cascadia	178.4130	51.1200	273	15	5
acsz-13a	Aleutian–Alaska–Cascadia	179.8550	51.5340	271	15	17.94
acsz-13b	Aleutian–Alaska–Cascadia	179.8420	51.0850	271	15	5
acsz-14a	Aleutian–Alaska–Cascadia	181.2340	51.5780	267	15	17.94
acsz-14b	Aleutian–Alaska–Cascadia	181.2720	51.1290	267	15	5
acsz-15a	Aleutian–Alaska–Cascadia	182.6380	51.6470	265	15	17.94
acsz-15b	Aleutian–Alaska–Cascadia	182.7000	51.2000	265	15	5
acsz-16a	Aleutian–Alaska–Cascadia	184.0550	51.7250	264	15	17.94
acsz-16b	Aleutian–Alaska–Cascadia	184.1280	51.2780	264	15	5
acsz-17a	Aleutian–Alaska–Cascadia	185.4560	51.8170	262	15	17.94
acsz-17b	Aleutian–Alaska–Cascadia	185.5560	51.3720	262	15	5
acsz-18a	Aleutian–Alaska–Cascadia	186.8680	51.9410	261	15	17.94
acsz-18b	Aleutian–Alaska–Cascadia	186.9810	51.4970	261	15	5
acsz-19a	Aleutian–Alaska–Cascadia	188.2430	52.1280	257	15	17.94
acsz-19b	Aleutian–Alaska–Cascadia	188.4060	51.6900	257	15	5
acsz-20a	Aleutian–Alaska–Cascadia	189.5810	52.3550	251	15	17.94
acsz-20b	Aleutian–Alaska–Cascadia	189.8180	51.9300	251	15	5
acsz-21a	Aleutian–Alaska–Cascadia	190.9570	52.6470	251	15	17.94
acsz-21b	Aleutian–Alaska–Cascadia	191.1960	52.2220	251	15	5
acsz-21z	Aleutian–Alaska–Cascadia	190.7399	53.0443	250.8	15	30.88
acsz-22a	Aleutian–Alaska–Cascadia	192.2940	52.9430	247	15	17.94
acsz-22b	Aleutian–Alaska–Cascadia	192.5820	52.5300	247	15	5
acsz-22z	Aleutian–Alaska–Cascadia	192.0074	53.3347	247.8	15	30.88
acsz-23a	Aleutian–Alaska–Cascadia	193.6270	53.3070	245	15	17.94
acsz-23b	Aleutian–Alaska–Cascadia	193.9410	52.9000	245	15	5
acsz-23z	Aleutian–Alaska–Cascadia	193.2991	53.6768	244.6	15	30.88
acsz-24a	Aleutian–Alaska–Cascadia	194.9740	53.6870	245	15	17.94
acsz-24b	Aleutian–Alaska–Cascadia	195.2910	53.2800	245	15	5
acsz-24y	Aleutian–Alaska–Cascadia	194.3645	54.4604	244.4	15	43.82
acsz-24z	Aleutian–Alaska–Cascadia	194.6793	54.0674	244.6	15	30.88

Continued on next page

Table B.1 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
acsz-25a	Aleutian-Alaska-Cascadia	196.4340	54.0760	250	15	17.94
acsz-25b	Aleutian-Alaska-Cascadia	196.6930	53.6543	250	15	5
acsz-25y	Aleutian-Alaska-Cascadia	195.9009	54.8572	247.9	15	43.82
acsz-25z	Aleutian-Alaska-Cascadia	196.1761	54.4536	248.1	15	30.88
acsz-26a	Aleutian-Alaska-Cascadia	197.8970	54.3600	253	15	17.94
acsz-26b	Aleutian-Alaska-Cascadia	198.1200	53.9300	253	15	5
acsz-26y	Aleutian-Alaska-Cascadia	197.5498	55.1934	253.1	15	43.82
acsz-26z	Aleutian-Alaska-Cascadia	197.7620	54.7770	253.3	15	30.88
acsz-27a	Aleutian-Alaska-Cascadia	199.4340	54.5960	256	15	17.94
acsz-27b	Aleutian-Alaska-Cascadia	199.6200	54.1600	256	15	5
acsz-27x	Aleutian-Alaska-Cascadia	198.9736	55.8631	256.5	15	56.24
acsz-27y	Aleutian-Alaska-Cascadia	199.1454	55.4401	256.6	15	43.82
acsz-27z	Aleutian-Alaska-Cascadia	199.3135	55.0170	256.8	15	30.88
acsz-28a	Aleutian-Alaska-Cascadia	200.8820	54.8300	253	15	17.94
acsz-28b	Aleutian-Alaska-Cascadia	201.1080	54.4000	253	15	5
acsz-28x	Aleutian-Alaska-Cascadia	200.1929	56.0559	252.5	15	56.24
acsz-28y	Aleutian-Alaska-Cascadia	200.4167	55.6406	252.7	15	43.82
acsz-28z	Aleutian-Alaska-Cascadia	200.6360	55.2249	252.9	15	30.88
acsz-29a	Aleutian-Alaska-Cascadia	202.2610	55.1330	247	15	17.94
acsz-29b	Aleutian-Alaska-Cascadia	202.5650	54.7200	247	15	5
acsz-29x	Aleutian-Alaska-Cascadia	201.2606	56.2861	245.7	15	56.24
acsz-29y	Aleutian-Alaska-Cascadia	201.5733	55.8888	246	15	43.82
acsz-29z	Aleutian-Alaska-Cascadia	201.8797	55.4908	246.2	15	30.88
acsz-30a	Aleutian-Alaska-Cascadia	203.6040	55.5090	240	15	17.94
acsz-30b	Aleutian-Alaska-Cascadia	203.9970	55.1200	240	15	5
acsz-30w	Aleutian-Alaska-Cascadia	201.9901	56.9855	239.5	15	69.12
acsz-30x	Aleutian-Alaska-Cascadia	202.3851	56.6094	239.8	15	56.24
acsz-30y	Aleutian-Alaska-Cascadia	202.7724	56.2320	240.2	15	43.82
acsz-30z	Aleutian-Alaska-Cascadia	203.1521	55.8534	240.5	15	30.88
acsz-31a	Aleutian-Alaska-Cascadia	204.8950	55.9700	236	15	17.94
acsz-31b	Aleutian-Alaska-Cascadia	205.3400	55.5980	236	15	5
acsz-31w	Aleutian-Alaska-Cascadia	203.0825	57.3740	234.5	15	69.12
acsz-31x	Aleutian-Alaska-Cascadia	203.5408	57.0182	234.9	15	56.24
acsz-31y	Aleutian-Alaska-Cascadia	203.9904	56.6607	235.3	15	43.82
acsz-31z	Aleutian-Alaska-Cascadia	204.4315	56.3016	235.7	15	30.88
acsz-32a	Aleutian-Alaska-Cascadia	206.2080	56.4730	236	15	17.94
acsz-32b	Aleutian-Alaska-Cascadia	206.6580	56.1000	236	15	5
acsz-32w	Aleutian-Alaska-Cascadia	204.4129	57.8908	234.3	15	69.12
acsz-32x	Aleutian-Alaska-Cascadia	204.8802	57.5358	234.7	15	56.24
acsz-32y	Aleutian-Alaska-Cascadia	205.3385	57.1792	235.1	15	43.82
acsz-32z	Aleutian-Alaska-Cascadia	205.7880	56.8210	235.5	15	30.88
acsz-33a	Aleutian-Alaska-Cascadia	207.5370	56.9750	236	15	17.94
acsz-33b	Aleutian-Alaska-Cascadia	207.9930	56.6030	236	15	5
acsz-33w	Aleutian-Alaska-Cascadia	205.7126	58.3917	234.2	15	69.12
acsz-33x	Aleutian-Alaska-Cascadia	206.1873	58.0371	234.6	15	56.24
acsz-33y	Aleutian-Alaska-Cascadia	206.6527	57.6808	235	15	43.82
acsz-33z	Aleutian-Alaska-Cascadia	207.1091	57.3227	235.4	15	30.88
acsz-34a	Aleutian-Alaska-Cascadia	208.9371	57.5124	236	15	17.94
acsz-34b	Aleutian-Alaska-Cascadia	209.4000	57.1400	236	15	5
acsz-34w	Aleutian-Alaska-Cascadia	206.9772	58.8804	233.5	15	69.12
acsz-34x	Aleutian-Alaska-Cascadia	207.4677	58.5291	233.9	15	56.24
acsz-34y	Aleutian-Alaska-Cascadia	207.9485	58.1760	234.3	15	43.82
acsz-34z	Aleutian-Alaska-Cascadia	208.4198	57.8213	234.7	15	30.88
acsz-35a	Aleutian-Alaska-Cascadia	210.2597	58.0441	230	15	17.94
acsz-35b	Aleutian-Alaska-Cascadia	210.8000	57.7000	230	15	5

Continued on next page

Table B.1 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
acsz-35w	Aleutian-Alaska-Cascadia	208.0204	59.3199	228.8	15	69.12
acsz-35x	Aleutian-Alaska-Cascadia	208.5715	58.9906	229.3	15	56.24
acsz-35y	Aleutian-Alaska-Cascadia	209.1122	58.6590	229.7	15	43.82
acsz-35z	Aleutian-Alaska-Cascadia	209.6425	58.3252	230.2	15	30.88
acsz-36a	Aleutian-Alaska-Cascadia	211.3249	58.6565	218	15	17.94
acsz-36b	Aleutian-Alaska-Cascadia	212.0000	58.3800	218	15	5
acsz-36w	Aleutian-Alaska-Cascadia	208.5003	59.5894	215.6	15	69.12
acsz-36x	Aleutian-Alaska-Cascadia	209.1909	59.3342	216.2	15	56.24
acsz-36y	Aleutian-Alaska-Cascadia	209.8711	59.0753	216.8	15	43.82
acsz-36z	Aleutian-Alaska-Cascadia	210.5412	58.8129	217.3	15	30.88
acsz-37a	Aleutian-Alaska-Cascadia	212.2505	59.2720	213.7	15	17.94
acsz-37b	Aleutian-Alaska-Cascadia	212.9519	59.0312	213.7	15	5
acsz-37x	Aleutian-Alaska-Cascadia	210.1726	60.0644	213	15	56.24
acsz-37y	Aleutian-Alaska-Cascadia	210.8955	59.8251	213.7	15	43.82
acsz-37z	Aleutian-Alaska-Cascadia	211.6079	59.5820	214.3	15	30.88
acsz-38a	Aleutian-Alaska-Cascadia	214.6555	60.1351	260.1	0	15
acsz-38b	Aleutian-Alaska-Cascadia	214.8088	59.6927	260.1	0	15
acsz-38y	Aleutian-Alaska-Cascadia	214.3737	60.9838	259	0	15
acsz-38z	Aleutian-Alaska-Cascadia	214.5362	60.5429	259	0	15
acsz-39a	Aleutian-Alaska-Cascadia	216.5607	60.2480	267	0	15
acsz-39b	Aleutian-Alaska-Cascadia	216.6068	59.7994	267	0	15
acsz-40a	Aleutian-Alaska-Cascadia	219.3069	59.7574	310.9	0	15
acsz-40b	Aleutian-Alaska-Cascadia	218.7288	59.4180	310.9	0	15
acsz-41a	Aleutian-Alaska-Cascadia	220.4832	59.3390	300.7	0	15
acsz-41b	Aleutian-Alaska-Cascadia	220.0382	58.9529	300.7	0	15
acsz-42a	Aleutian-Alaska-Cascadia	221.8835	58.9310	298.9	0	15
acsz-42b	Aleutian-Alaska-Cascadia	221.4671	58.5379	298.9	0	15
acsz-43a	Aleutian-Alaska-Cascadia	222.9711	58.6934	282.3	0	15
acsz-43b	Aleutian-Alaska-Cascadia	222.7887	58.2546	282.3	0	15
acsz-44a	Aleutian-Alaska-Cascadia	224.9379	57.9054	340.9	12	11.09
acsz-44b	Aleutian-Alaska-Cascadia	224.1596	57.7617	340.9	7	5
acsz-45a	Aleutian-Alaska-Cascadia	225.4994	57.1634	334.1	12	11.09
acsz-45b	Aleutian-Alaska-Cascadia	224.7740	56.9718	334.1	7	5
acsz-46a	Aleutian-Alaska-Cascadia	226.1459	56.3552	334.1	12	11.09
acsz-46b	Aleutian-Alaska-Cascadia	225.4358	56.1636	334.1	7	5
acsz-47a	Aleutian-Alaska-Cascadia	226.7731	55.5830	332.3	12	11.09
acsz-47b	Aleutian-Alaska-Cascadia	226.0887	55.3785	332.3	7	5
acsz-48a	Aleutian-Alaska-Cascadia	227.4799	54.6763	339.4	12	11.09
acsz-48b	Aleutian-Alaska-Cascadia	226.7713	54.5217	339.4	7	5
acsz-49a	Aleutian-Alaska-Cascadia	227.9482	53.8155	341.2	12	11.09
acsz-49b	Aleutian-Alaska-Cascadia	227.2462	53.6737	341.2	7	5
acsz-50a	Aleutian-Alaska-Cascadia	228.3970	53.2509	324.5	12	11.09
acsz-50b	Aleutian-Alaska-Cascadia	227.8027	52.9958	324.5	7	5
acsz-51a	Aleutian-Alaska-Cascadia	229.1844	52.6297	318.4	12	11.09
acsz-51b	Aleutian-Alaska-Cascadia	228.6470	52.3378	318.4	7	5
acsz-52a	Aleutian-Alaska-Cascadia	230.0306	52.0768	310.9	12	11.09
acsz-52b	Aleutian-Alaska-Cascadia	229.5665	51.7445	310.9	7	5
acsz-53a	Aleutian-Alaska-Cascadia	231.1735	51.5258	310.9	12	11.09
acsz-53b	Aleutian-Alaska-Cascadia	230.7150	51.1935	310.9	7	5
acsz-54a	Aleutian-Alaska-Cascadia	232.2453	50.8809	314.1	12	11.09
acsz-54b	Aleutian-Alaska-Cascadia	231.7639	50.5655	314.1	7	5
acsz-55a	Aleutian-Alaska-Cascadia	233.3066	49.9032	333.7	12	11.09
acsz-55b	Aleutian-Alaska-Cascadia	232.6975	49.7086	333.7	7	5
acsz-56a	Aleutian-Alaska-Cascadia	234.0588	49.1702	315	11	12.82
acsz-56b	Aleutian-Alaska-Cascadia	233.5849	48.8584	315	9	5

Continued on next page

Table B.1 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
acsz-57a	Aleutian-Alaska-Cascadia	234.9041	48.2596	341	11	12.82
acsz-57b	Aleutian-Alaska-Cascadia	234.2797	48.1161	341	9	5
acsz-58a	Aleutian-Alaska-Cascadia	235.3021	47.3812	344	11	12.82
acsz-58b	Aleutian-Alaska-Cascadia	234.6776	47.2597	344	9	5
acsz-59a	Aleutian-Alaska-Cascadia	235.6432	46.5082	345	11	12.82
acsz-59b	Aleutian-Alaska-Cascadia	235.0257	46.3941	345	9	5
acsz-60a	Aleutian-Alaska-Cascadia	235.8640	45.5429	356	11	12.82
acsz-60b	Aleutian-Alaska-Cascadia	235.2363	45.5121	356	9	5
acsz-61a	Aleutian-Alaska-Cascadia	235.9106	44.6227	359	11	12.82
acsz-61b	Aleutian-Alaska-Cascadia	235.2913	44.6150	359	9	5
acsz-62a	Aleutian-Alaska-Cascadia	235.9229	43.7245	359	11	12.82
acsz-62b	Aleutian-Alaska-Cascadia	235.3130	43.7168	359	9	5
acsz-63a	Aleutian-Alaska-Cascadia	236.0220	42.9020	350	11	12.82
acsz-63b	Aleutian-Alaska-Cascadia	235.4300	42.8254	350	9	5
acsz-64a	Aleutian-Alaska-Cascadia	235.9638	41.9818	345	11	12.82
acsz-64b	Aleutian-Alaska-Cascadia	235.3919	41.8677	345	9	5
acsz-65a	Aleutian-Alaska-Cascadia	236.2643	41.1141	345	11	12.82
acsz-65b	Aleutian-Alaska-Cascadia	235.7000	41.0000	345	9	5
acsz-238a	Aleutian-Alaska-Cascadia	213.2878	59.8406	236.8	15	17.94
acsz-238y	Aleutian-Alaska-Cascadia	212.3424	60.5664	236.8	15	43.82
acsz-238z	Aleutian-Alaska-Cascadia	212.8119	60.2035	236.8	15	30.88

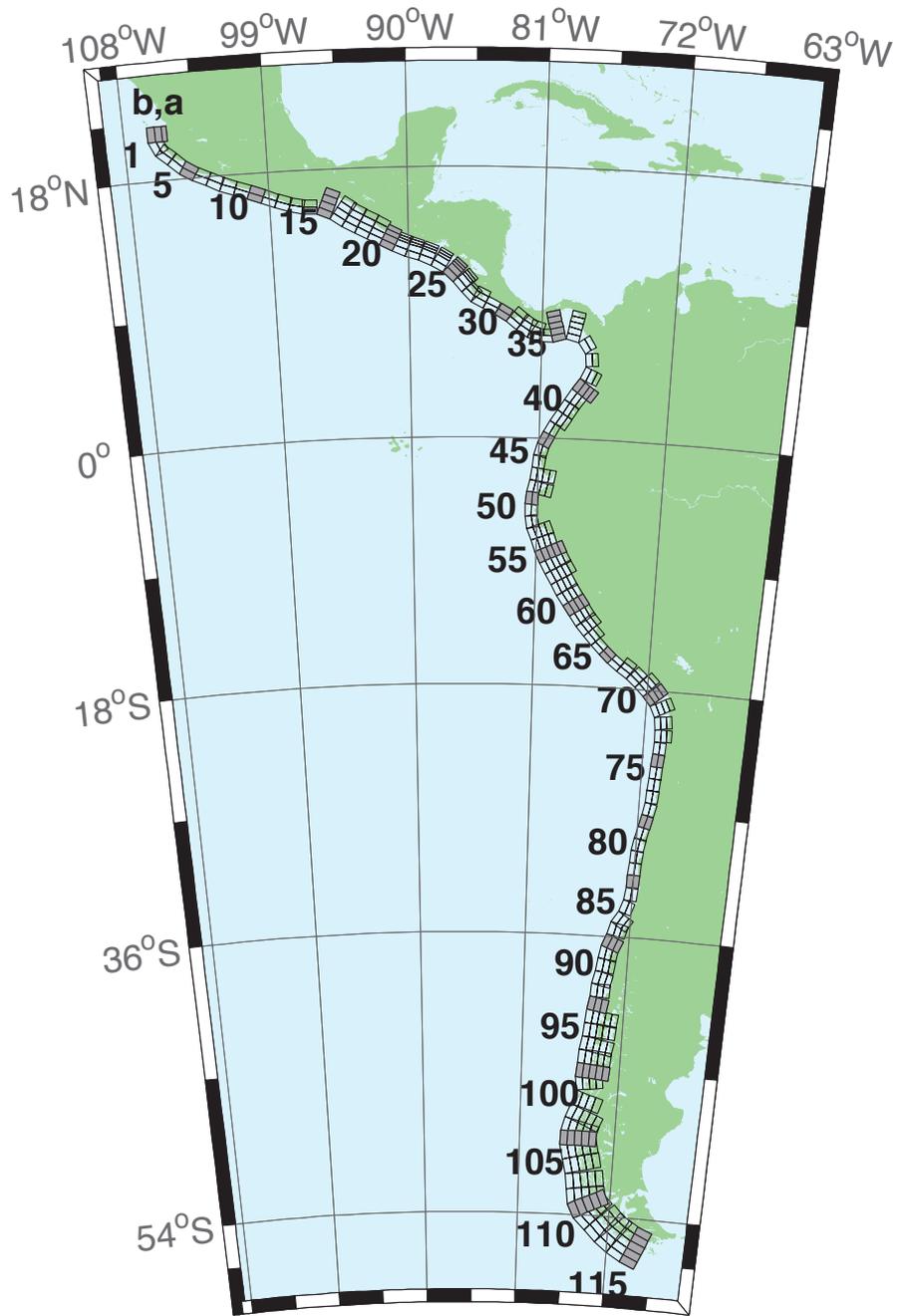


Figure B.2: Central and South America Subduction Zone unit sources.

Table B.2: Earthquake parameters for Central and South America Subduction
Zone unit sources.

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
cssz-1a	Central and South America	254.4573	20.8170	359	19	15.4
cssz-1b	Central and South America	254.0035	20.8094	359	12	5
cssz-1z	Central and South America	254.7664	20.8222	359	50	31.67
cssz-2a	Central and South America	254.5765	20.2806	336.8	19	15.4
cssz-2b	Central and South America	254.1607	20.1130	336.8	12	5
cssz-3a	Central and South America	254.8789	19.8923	310.6	18.31	15.27
cssz-3b	Central and South America	254.5841	19.5685	310.6	11.85	5
cssz-4a	Central and South America	255.6167	19.2649	313.4	17.62	15.12
cssz-4b	Central and South America	255.3056	18.9537	313.4	11.68	5
cssz-5a	Central and South America	256.2240	18.8148	302.7	16.92	15
cssz-5b	Central and South America	255.9790	18.4532	302.7	11.54	5
cssz-6a	Central and South America	256.9425	18.4383	295.1	16.23	14.87
cssz-6b	Central and South America	256.7495	18.0479	295.1	11.38	5
cssz-7a	Central and South America	257.8137	18.0339	296.9	15.54	14.74
cssz-7b	Central and South America	257.6079	17.6480	296.9	11.23	5
cssz-8a	Central and South America	258.5779	17.7151	290.4	14.85	14.61
cssz-8b	Central and South America	258.4191	17.3082	290.4	11.08	5
cssz-9a	Central and South America	259.4578	17.4024	290.5	14.15	14.47
cssz-9b	Central and South America	259.2983	16.9944	290.5	10.92	5
cssz-10a	Central and South America	260.3385	17.0861	290.8	13.46	14.34
cssz-10b	Central and South America	260.1768	16.6776	290.8	10.77	5
cssz-11a	Central and South America	261.2255	16.7554	291.8	12.77	14.21
cssz-11b	Central and South America	261.0556	16.3487	291.8	10.62	5
cssz-12a	Central and South America	262.0561	16.4603	288.9	12.08	14.08
cssz-12b	Central and South America	261.9082	16.0447	288.9	10.46	5
cssz-13a	Central and South America	262.8638	16.2381	283.2	11.38	13.95
cssz-13b	Central and South America	262.7593	15.8094	283.2	10.31	5
cssz-14a	Central and South America	263.6066	16.1435	272.1	10.69	13.81
cssz-14b	Central and South America	263.5901	15.7024	272.1	10.15	5
cssz-15a	Central and South America	264.8259	15.8829	293	10	13.68
cssz-15b	Central and South America	264.6462	15.4758	293	10	5
cssz-15y	Central and South America	265.1865	16.6971	293	10	31.05
cssz-15z	Central and South America	265.0060	16.2900	293	10	22.36
cssz-16a	Central and South America	265.7928	15.3507	304.9	15	15.82
cssz-16b	Central and South America	265.5353	14.9951	304.9	12.5	5
cssz-16y	Central and South America	266.3092	16.0619	304.9	15	41.7
cssz-16z	Central and South America	266.0508	15.7063	304.9	15	28.76
cssz-17a	Central and South America	266.4947	14.9019	299.5	20	17.94
cssz-17b	Central and South America	266.2797	14.5346	299.5	15	5
cssz-17y	Central and South America	266.9259	15.6365	299.5	20	52.14
cssz-17z	Central and South America	266.7101	15.2692	299.5	20	35.04
cssz-18a	Central and South America	267.2827	14.4768	298	21.5	17.94
cssz-18b	Central and South America	267.0802	14.1078	298	15	5
cssz-18y	Central and South America	267.6888	15.2148	298	21.5	54.59
cssz-18z	Central and South America	267.4856	14.8458	298	21.5	36.27
cssz-19a	Central and South America	268.0919	14.0560	297.6	23	17.94
cssz-19b	Central and South America	267.8943	13.6897	297.6	15	5
cssz-19y	Central and South America	268.4880	14.7886	297.6	23	57.01
cssz-19z	Central and South America	268.2898	14.4223	297.6	23	37.48
cssz-20a	Central and South America	268.8929	13.6558	296.2	24	17.94
cssz-20b	Central and South America	268.7064	13.2877	296.2	15	5
cssz-20y	Central and South America	269.1796	14.2206	296.2	45.5	73.94
cssz-20z	Central and South America	269.0362	13.9382	296.2	45.5	38.28

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Table B.2 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
cssz-21a	Central and South America	269.6797	13.3031	292.6	25	17.94
cssz-21b	Central and South America	269.5187	12.9274	292.6	15	5
cssz-21x	Central and South America	269.8797	13.7690	292.6	68	131.8
cssz-21y	Central and South America	269.8130	13.6137	292.6	68	85.43
cssz-21z	Central and South America	269.7463	13.4584	292.6	68	39.07
cssz-22a	Central and South America	270.4823	13.0079	288.6	25	17.94
cssz-22b	Central and South America	270.3492	12.6221	288.6	15	5
cssz-22x	Central and South America	270.6476	13.4864	288.6	68	131.8
cssz-22y	Central and South America	270.5925	13.3269	288.6	68	85.43
cssz-22z	Central and South America	270.5374	13.1674	288.6	68	39.07
cssz-23a	Central and South America	271.3961	12.6734	292.4	25	17.94
cssz-23b	Central and South America	271.2369	12.2972	292.4	15	5
cssz-23x	Central and South America	271.5938	13.1399	292.4	68	131.8
cssz-23y	Central and South America	271.5279	12.9844	292.4	68	85.43
cssz-23z	Central and South America	271.4620	12.8289	292.4	68	39.07
cssz-24a	Central and South America	272.3203	12.2251	300.2	25	17.94
cssz-24b	Central and South America	272.1107	11.8734	300.2	15	5
cssz-24x	Central and South America	272.5917	12.6799	300.2	67	131.1
cssz-24y	Central and South America	272.5012	12.5283	300.2	67	85.1
cssz-24z	Central and South America	272.4107	12.3767	300.2	67	39.07
cssz-25a	Central and South America	273.2075	11.5684	313.8	25	17.94
cssz-25b	Central and South America	272.9200	11.2746	313.8	15	5
cssz-25x	Central and South America	273.5950	11.9641	313.8	66	130.4
cssz-25y	Central and South America	273.4658	11.8322	313.8	66	84.75
cssz-25z	Central and South America	273.3366	11.7003	313.8	66	39.07
cssz-26a	Central and South America	273.8943	10.8402	320.4	25	17.94
cssz-26b	Central and South America	273.5750	10.5808	320.4	15	5
cssz-26x	Central and South America	274.3246	11.1894	320.4	66	130.4
cssz-26y	Central and South America	274.1811	11.0730	320.4	66	84.75
cssz-26z	Central and South America	274.0377	10.9566	320.4	66	39.07
cssz-27a	Central and South America	274.4569	10.2177	316.1	25	17.94
cssz-27b	Central and South America	274.1590	9.9354	316.1	15	5
cssz-27z	Central and South America	274.5907	10.3444	316.1	66	39.07
cssz-28a	Central and South America	274.9586	9.8695	297.1	22	14.54
cssz-28b	Central and South America	274.7661	9.4988	297.1	11	5
cssz-28z	Central and South America	275.1118	10.1643	297.1	42.5	33.27
cssz-29a	Central and South America	275.7686	9.4789	296.6	19	11.09
cssz-29b	Central and South America	275.5759	9.0992	296.6	7	5
cssz-30a	Central and South America	276.6346	8.9973	302.2	19	9.36
cssz-30b	Central and South America	276.4053	8.6381	302.2	5	5
cssz-31a	Central and South America	277.4554	8.4152	309.1	19	7.62
cssz-31b	Central and South America	277.1851	8.0854	309.1	3	5
cssz-31z	Central and South America	277.7260	8.7450	309.1	19	23.9
cssz-32a	Central and South America	278.1112	7.9425	303	18.67	8.49
cssz-32b	Central and South America	277.8775	7.5855	303	4	5
cssz-32z	Central and South America	278.3407	8.2927	303	21.67	24.49
cssz-33a	Central and South America	278.7082	7.6620	287.6	18.33	10.23
cssz-33b	Central and South America	278.5785	7.2555	287.6	6	5
cssz-33z	Central and South America	278.8328	8.0522	287.6	24.33	25.95
cssz-34a	Central and South America	279.3184	7.5592	269.5	18	17.94
cssz-34b	Central and South America	279.3223	7.1320	269.5	15	5
cssz-35a	Central and South America	280.0039	7.6543	255.9	17.67	14.54
cssz-35b	Central and South America	280.1090	7.2392	255.9	11	5
cssz-35x	Central and South America	279.7156	8.7898	255.9	29.67	79.22
cssz-35y	Central and South America	279.8118	8.4113	255.9	29.67	54.47

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Table B.2 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
cssz-35z	Central and South America	279.9079	8.0328	255.9	29.67	29.72
cssz-36a	Central and South America	281.2882	7.6778	282.5	17.33	11.09
cssz-36b	Central and South America	281.1948	7.2592	282.5	7	5
cssz-36x	Central and South America	281.5368	8.7896	282.5	32.33	79.47
cssz-36y	Central and South America	281.4539	8.4190	282.5	32.33	52.73
cssz-36z	Central and South America	281.3710	8.0484	282.5	32.33	25.99
cssz-37a	Central and South America	282.5252	6.8289	326.9	17	10.23
cssz-37b	Central and South America	282.1629	6.5944	326.9	6	5
cssz-38a	Central and South America	282.9469	5.5973	355.4	17	10.23
cssz-38b	Central and South America	282.5167	5.5626	355.4	6	5
cssz-39a	Central and South America	282.7236	4.3108	24.13	17	10.23
cssz-39b	Central and South America	282.3305	4.4864	24.13	6	5
cssz-39z	Central and South America	283.0603	4.1604	24.13	35	24.85
cssz-40a	Central and South America	282.1940	3.3863	35.28	17	10.23
cssz-40b	Central and South America	281.8427	3.6344	35.28	6	5
cssz-40y	Central and South America	282.7956	2.9613	35.28	35	53.52
cssz-40z	Central and South America	282.4948	3.1738	35.28	35	24.85
cssz-41a	Central and South America	281.6890	2.6611	34.27	17	10.23
cssz-41b	Central and South America	281.3336	2.9030	34.27	6	5
cssz-41z	Central and South America	281.9933	2.4539	34.27	35	24.85
cssz-42a	Central and South America	281.2266	1.9444	31.29	17	10.23
cssz-42b	Central and South America	280.8593	2.1675	31.29	6	5
cssz-42z	Central and South America	281.5411	1.7533	31.29	35	24.85
cssz-43a	Central and South America	280.7297	1.1593	33.3	17	10.23
cssz-43b	Central and South America	280.3706	1.3951	33.3	6	5
cssz-43z	Central and South America	281.0373	0.9573	33.3	35	24.85
cssz-44a	Central and South America	280.3018	0.4491	28.8	17	10.23
cssz-44b	Central and South America	279.9254	0.6560	28.8	6	5
cssz-45a	Central and South America	279.9083	-0.3259	26.91	10	8.49
cssz-45b	Central and South America	279.5139	-0.1257	26.91	4	5
cssz-46a	Central and South America	279.6461	-0.9975	15.76	10	8.49
cssz-46b	Central and South America	279.2203	-0.8774	15.76	4	5
cssz-47a	Central and South America	279.4972	-1.7407	6.9	10	8.49
cssz-47b	Central and South America	279.0579	-1.6876	6.9	4	5
cssz-48a	Central and South America	279.3695	-2.6622	8.96	10	8.49
cssz-48b	Central and South America	278.9321	-2.5933	8.96	4	5
cssz-48y	Central and South America	280.2444	-2.8000	8.96	10	25.85
cssz-48z	Central and South America	279.8070	-2.7311	8.96	10	17.17
cssz-49a	Central and South America	279.1852	-3.6070	13.15	10	8.49
cssz-49b	Central and South America	278.7536	-3.5064	13.15	4	5
cssz-49y	Central and South America	280.0486	-3.8082	13.15	10	25.85
cssz-49z	Central and South America	279.6169	-3.7076	13.15	10	17.17
cssz-50a	Central and South America	279.0652	-4.3635	4.78	10.33	9.64
cssz-50b	Central and South America	278.6235	-4.3267	4.78	5.33	5
cssz-51a	Central and South America	279.0349	-5.1773	359.4	10.67	10.81
cssz-51b	Central and South America	278.5915	-5.1817	359.4	6.67	5
cssz-52a	Central and South America	279.1047	-5.9196	349.8	11	11.96
cssz-52b	Central and South America	278.6685	-5.9981	349.8	8	5
cssz-53a	Central and South America	279.3044	-6.6242	339.2	10.25	11.74
cssz-53b	Central and South America	278.8884	-6.7811	339.2	7.75	5
cssz-53y	Central and South America	280.1024	-6.3232	339.2	19.25	37.12
cssz-53z	Central and South America	279.7035	-6.4737	339.2	19.25	20.64
cssz-54a	Central and South America	279.6256	-7.4907	340.8	9.5	11.53
cssz-54b	Central and South America	279.2036	-7.6365	340.8	7.5	5
cssz-54y	Central and South America	280.4267	-7.2137	340.8	20.5	37.29

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Table B.2 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
cssz-54z	Central and South America	280.0262	-7.3522	340.8	20.5	19.78
cssz-55a	Central and South America	279.9348	-8.2452	335.4	8.75	11.74
cssz-55b	Central and South America	279.5269	-8.4301	335.4	7.75	5
cssz-55x	Central and South America	281.0837	-7.7238	335.4	21.75	56.4
cssz-55y	Central and South America	280.7009	-7.8976	335.4	21.75	37.88
cssz-55z	Central and South America	280.3180	-8.0714	335.4	21.75	19.35
cssz-56a	Central and South America	280.3172	-8.9958	331.6	8	11.09
cssz-56b	Central and South America	279.9209	-9.2072	331.6	7	5
cssz-56x	Central and South America	281.4212	-8.4063	331.6	23	57.13
cssz-56y	Central and South America	281.0534	-8.6028	331.6	23	37.59
cssz-56z	Central and South America	280.6854	-8.7993	331.6	23	18.05
cssz-57a	Central and South America	280.7492	-9.7356	328.7	8.6	10.75
cssz-57b	Central and South America	280.3640	-9.9663	328.7	6.6	5
cssz-57x	Central and South America	281.8205	-9.0933	328.7	23.4	57.94
cssz-57y	Central and South America	281.4636	-9.3074	328.7	23.4	38.08
cssz-57z	Central and South America	281.1065	-9.5215	328.7	23.4	18.22
cssz-58a	Central and South America	281.2275	-10.5350	330.5	9.2	10.4
cssz-58b	Central and South America	280.8348	-10.7532	330.5	6.2	5
cssz-58y	Central and South America	281.9548	-10.1306	330.5	23.8	38.57
cssz-58z	Central and South America	281.5913	-10.3328	330.5	23.8	18.39
cssz-59a	Central and South America	281.6735	-11.2430	326.2	9.8	10.05
cssz-59b	Central and South America	281.2982	-11.4890	326.2	5.8	5
cssz-59y	Central and South America	282.3675	-10.7876	326.2	24.2	39.06
cssz-59z	Central and South America	282.0206	-11.0153	326.2	24.2	18.56
cssz-60a	Central and South America	282.1864	-11.9946	326.5	10.4	9.71
cssz-60b	Central and South America	281.8096	-12.2384	326.5	5.4	5
cssz-60y	Central and South America	282.8821	-11.5438	326.5	24.6	39.55
cssz-60z	Central and South America	282.5344	-11.7692	326.5	24.6	18.73
cssz-61a	Central and South America	282.6944	-12.7263	325.5	11	9.36
cssz-61b	Central and South America	282.3218	-12.9762	325.5	5	5
cssz-61y	Central and South America	283.3814	-12.2649	325.5	25	40.03
cssz-61z	Central and South America	283.0381	-12.4956	325.5	25	18.9
cssz-62a	Central and South America	283.1980	-13.3556	319	11	9.79
cssz-62b	Central and South America	282.8560	-13.6451	319	5.5	5
cssz-62y	Central and South America	283.8178	-12.8300	319	27	42.03
cssz-62z	Central and South America	283.5081	-13.0928	319	27	19.33
cssz-63a	Central and South America	283.8032	-14.0147	317.9	11	10.23
cssz-63b	Central and South America	283.4661	-14.3106	317.9	6	5
cssz-63z	Central and South America	284.1032	-13.7511	317.9	29	19.77
cssz-64a	Central and South America	284.4144	-14.6482	315.7	13	11.96
cssz-64b	Central and South America	284.0905	-14.9540	315.7	8	5
cssz-65a	Central and South America	285.0493	-15.2554	313.2	15	13.68
cssz-65b	Central and South America	284.7411	-15.5715	313.2	10	5
cssz-66a	Central and South America	285.6954	-15.7816	307.7	14.5	13.68
cssz-66b	Central and South America	285.4190	-16.1258	307.7	10	5
cssz-67a	Central and South America	286.4127	-16.2781	304.3	14	13.68
cssz-67b	Central and South America	286.1566	-16.6381	304.3	10	5
cssz-67z	Central and South America	286.6552	-15.9365	304.3	23	25.78
cssz-68a	Central and South America	287.2481	-16.9016	311.8	14	13.68
cssz-68b	Central and South America	286.9442	-17.2264	311.8	10	5
cssz-68z	Central and South America	287.5291	-16.6007	311.8	26	25.78
cssz-69a	Central and South America	287.9724	-17.5502	314.9	14	13.68
cssz-69b	Central and South America	287.6496	-17.8590	314.9	10	5
cssz-69y	Central and South America	288.5530	-16.9934	314.9	29	50.02
cssz-69z	Central and South America	288.2629	-17.2718	314.9	29	25.78

Continued on next page

Table B.2 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
cssz-70a	Central and South America	288.6731	-18.2747	320.4	14	13.25
cssz-70b	Central and South America	288.3193	-18.5527	320.4	9.5	5
cssz-70y	Central and South America	289.3032	-17.7785	320.4	30	50.35
cssz-70z	Central and South America	288.9884	-18.0266	320.4	30	25.35
cssz-71a	Central and South America	289.3089	-19.1854	333.2	14	12.82
cssz-71b	Central and South America	288.8968	-19.3820	333.2	9	5
cssz-71y	Central and South America	290.0357	-18.8382	333.2	31	50.67
cssz-71z	Central and South America	289.6725	-19.0118	333.2	31	24.92
cssz-72a	Central and South America	289.6857	-20.3117	352.4	14	12.54
cssz-72b	Central and South America	289.2250	-20.3694	352.4	8.67	5
cssz-72z	Central and South America	290.0882	-20.2613	352.4	32	24.63
cssz-73a	Central and South America	289.7731	-21.3061	358.9	14	12.24
cssz-73b	Central and South America	289.3053	-21.3142	358.9	8.33	5
cssz-73z	Central and South America	290.1768	-21.2991	358.9	33	24.34
cssz-74a	Central and South America	289.7610	-22.2671	3.06	14	11.96
cssz-74b	Central and South America	289.2909	-22.2438	3.06	8	5
cssz-75a	Central and South America	289.6982	-23.1903	4.83	14.09	11.96
cssz-75b	Central and South America	289.2261	-23.1536	4.83	8	5
cssz-76a	Central and South America	289.6237	-24.0831	4.67	14.18	11.96
cssz-76b	Central and South America	289.1484	-24.0476	4.67	8	5
cssz-77a	Central and South America	289.5538	-24.9729	4.3	14.27	11.96
cssz-77b	Central and South America	289.0750	-24.9403	4.3	8	5
cssz-78a	Central and South America	289.4904	-25.8621	3.86	14.36	11.96
cssz-78b	Central and South America	289.0081	-25.8328	3.86	8	5
cssz-79a	Central and South America	289.3491	-26.8644	11.34	14.45	11.96
cssz-79b	Central and South America	288.8712	-26.7789	11.34	8	5
cssz-80a	Central and South America	289.1231	-27.7826	14.16	14.54	11.96
cssz-80b	Central and South America	288.6469	-27.6762	14.16	8	5
cssz-81a	Central and South America	288.8943	-28.6409	13.19	14.63	11.96
cssz-81b	Central and South America	288.4124	-28.5417	13.19	8	5
cssz-82a	Central and South America	288.7113	-29.4680	9.68	14.72	11.96
cssz-82b	Central and South America	288.2196	-29.3950	9.68	8	5
cssz-83a	Central and South America	288.5944	-30.2923	5.36	14.81	11.96
cssz-83b	Central and South America	288.0938	-30.2517	5.36	8	5
cssz-84a	Central and South America	288.5223	-31.1639	3.8	14.9	11.96
cssz-84b	Central and South America	288.0163	-31.1351	3.8	8	5
cssz-85a	Central and South America	288.4748	-32.0416	2.55	15	11.96
cssz-85b	Central and South America	287.9635	-32.0223	2.55	8	5
cssz-86a	Central and South America	288.3901	-33.0041	7.01	15	11.96
cssz-86b	Central and South America	287.8768	-32.9512	7.01	8	5
cssz-87a	Central and South America	288.1050	-34.0583	19.4	15	11.96
cssz-87b	Central and South America	287.6115	-33.9142	19.4	8	5
cssz-88a	Central and South America	287.5309	-35.0437	32.81	15	11.96
cssz-88b	Central and South America	287.0862	-34.8086	32.81	8	5
cssz-88z	Central and South America	287.9308	-35.2545	32.81	30	24.9
cssz-89a	Central and South America	287.2380	-35.5993	14.52	16.67	11.96
cssz-89b	Central and South America	286.7261	-35.4914	14.52	8	5
cssz-89z	Central and South America	287.7014	-35.6968	14.52	30	26.3
cssz-90a	Central and South America	286.8442	-36.5645	22.64	18.33	11.96
cssz-90b	Central and South America	286.3548	-36.4004	22.64	8	5
cssz-90z	Central and South America	287.2916	-36.7142	22.64	30	27.68
cssz-91a	Central and South America	286.5925	-37.2488	10.9	20	11.96
cssz-91b	Central and South America	286.0721	-37.1690	10.9	8	5
cssz-91z	Central and South America	287.0726	-37.3224	10.9	30	29.06
cssz-92a	Central and South America	286.4254	-38.0945	8.23	20	11.96

Continued on next page

Table B.2 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
cssz-92b	Central and South America	285.8948	-38.0341	8.23	8	5
cssz-92z	Central and South America	286.9303	-38.1520	8.23	26.67	29.06
cssz-93a	Central and South America	286.2047	-39.0535	13.46	20	11.96
cssz-93b	Central and South America	285.6765	-38.9553	13.46	8	5
cssz-93z	Central and South America	286.7216	-39.1495	13.46	23.33	29.06
cssz-94a	Central and South America	286.0772	-39.7883	3.4	20	11.96
cssz-94b	Central and South America	285.5290	-39.7633	3.4	8	5
cssz-94z	Central and South America	286.6255	-39.8133	3.4	20	29.06
cssz-95a	Central and South America	285.9426	-40.7760	9.84	20	11.96
cssz-95b	Central and South America	285.3937	-40.7039	9.84	8	5
cssz-95z	Central and South America	286.4921	-40.8481	9.84	20	29.06
cssz-96a	Central and South America	285.7839	-41.6303	7.6	20	11.96
cssz-96b	Central and South America	285.2245	-41.5745	7.6	8	5
cssz-96x	Central and South America	287.4652	-41.7977	7.6	20	63.26
cssz-96y	Central and South America	286.9043	-41.7419	7.6	20	46.16
cssz-96z	Central and South America	286.3439	-41.6861	7.6	20	29.06
cssz-97a	Central and South America	285.6695	-42.4882	5.3	20	11.96
cssz-97b	Central and South America	285.0998	-42.4492	5.3	8	5
cssz-97x	Central and South America	287.3809	-42.6052	5.3	20	63.26
cssz-97y	Central and South America	286.8101	-42.5662	5.3	20	46.16
cssz-97z	Central and South America	286.2396	-42.5272	5.3	20	29.06
cssz-98a	Central and South America	285.5035	-43.4553	10.53	20	11.96
cssz-98b	Central and South America	284.9322	-43.3782	10.53	8	5
cssz-98x	Central and South America	287.2218	-43.6866	10.53	20	63.26
cssz-98y	Central and South America	286.6483	-43.6095	10.53	20	46.16
cssz-98z	Central and South America	286.0755	-43.5324	10.53	20	29.06
cssz-99a	Central and South America	285.3700	-44.2595	4.86	20	11.96
cssz-99b	Central and South America	284.7830	-44.2237	4.86	8	5
cssz-99x	Central and South America	287.1332	-44.3669	4.86	20	63.26
cssz-99y	Central and South America	286.5451	-44.3311	4.86	20	46.16
cssz-99z	Central and South America	285.9574	-44.2953	4.86	20	29.06
cssz-100a	Central and South America	285.2713	-45.1664	5.68	20	11.96
cssz-100b	Central and South America	284.6758	-45.1246	5.68	8	5
cssz-100x	Central and South America	287.0603	-45.2918	5.68	20	63.26
cssz-100y	Central and South America	286.4635	-45.2500	5.68	20	46.16
cssz-100z	Central and South America	285.8672	-45.2082	5.68	20	29.06
cssz-101a	Central and South America	285.3080	-45.8607	352.6	20	9.36
cssz-101b	Central and South America	284.7067	-45.9152	352.6	5	5
cssz-101y	Central and South America	286.5089	-45.7517	352.6	20	43.56
cssz-101z	Central and South America	285.9088	-45.8062	352.6	20	26.46
cssz-102a	Central and South America	285.2028	-47.1185	17.72	5	9.36
cssz-102b	Central and South America	284.5772	-46.9823	17.72	5	5
cssz-102y	Central and South America	286.4588	-47.3909	17.72	5	18.07
cssz-102z	Central and South America	285.8300	-47.2547	17.72	5	13.72
cssz-103a	Central and South America	284.7075	-48.0396	23.37	7.5	11.53
cssz-103b	Central and South America	284.0972	-47.8630	23.37	7.5	5
cssz-103x	Central and South America	286.5511	-48.5694	23.37	7.5	31.11
cssz-103y	Central and South America	285.9344	-48.3928	23.37	7.5	24.58
cssz-103z	Central and South America	285.3199	-48.2162	23.37	7.5	18.05
cssz-104a	Central and South America	284.3440	-48.7597	14.87	10	13.68
cssz-104b	Central and South America	283.6962	-48.6462	14.87	10	5
cssz-104x	Central and South America	286.2962	-49.1002	14.87	10	39.73
cssz-104y	Central and South America	285.6440	-48.9867	14.87	10	31.05
cssz-104z	Central and South America	284.9933	-48.8732	14.87	10	22.36
cssz-105a	Central and South America	284.2312	-49.4198	0.25	9.67	13.4

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Table B.2 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
cssz-105b	Central and South America	283.5518	-49.4179	0.25	9.67	5
cssz-105x	Central and South America	286.2718	-49.4255	0.25	9.67	38.59
cssz-105y	Central and South America	285.5908	-49.4236	0.25	9.67	30.2
cssz-105z	Central and South America	284.9114	-49.4217	0.25	9.67	21.8
cssz-106a	Central and South America	284.3730	-50.1117	347.5	9.25	13.04
cssz-106b	Central and South America	283.6974	-50.2077	347.5	9.25	5
cssz-106x	Central and South America	286.3916	-49.8238	347.5	9.25	37.15
cssz-106y	Central and South America	285.7201	-49.9198	347.5	9.25	29.11
cssz-106z	Central and South America	285.0472	-50.0157	347.5	9.25	21.07
cssz-107a	Central and South America	284.7130	-50.9714	346.5	9	12.82
cssz-107b	Central and South America	284.0273	-51.0751	346.5	9	5
cssz-107x	Central and South America	286.7611	-50.6603	346.5	9	36.29
cssz-107y	Central and South America	286.0799	-50.7640	346.5	9	28.47
cssz-107z	Central and South America	285.3972	-50.8677	346.5	9	20.64
cssz-108a	Central and South America	285.0378	-51.9370	352	8.67	12.54
cssz-108b	Central and South America	284.3241	-51.9987	352	8.67	5
cssz-108x	Central and South America	287.1729	-51.7519	352	8.67	35.15
cssz-108y	Central and South America	286.4622	-51.8136	352	8.67	27.61
cssz-108z	Central and South America	285.7505	-51.8753	352	8.67	20.07
cssz-109a	Central and South America	285.2635	-52.8439	353.1	8.33	12.24
cssz-109b	Central and South America	284.5326	-52.8974	353.1	8.33	5
cssz-109x	Central and South America	287.4508	-52.6834	353.1	8.33	33.97
cssz-109y	Central and South America	286.7226	-52.7369	353.1	8.33	26.73
cssz-109z	Central and South America	285.9935	-52.7904	353.1	8.33	19.49
cssz-110a	Central and South America	285.5705	-53.4139	334.2	8	11.96
cssz-110b	Central and South America	284.8972	-53.6076	334.2	8	5
cssz-110x	Central and South America	287.5724	-52.8328	334.2	8	32.83
cssz-110y	Central and South America	286.9081	-53.0265	334.2	8	25.88
cssz-110z	Central and South America	286.2408	-53.2202	334.2	8	18.92
cssz-111a	Central and South America	286.1627	-53.8749	313.8	8	11.96
cssz-111b	Central and South America	285.6382	-54.1958	313.8	8	5
cssz-111x	Central and South America	287.7124	-52.9122	313.8	8	32.83
cssz-111y	Central and South America	287.1997	-53.2331	313.8	8	25.88
cssz-111z	Central and South America	286.6832	-53.5540	313.8	8	18.92
cssz-112a	Central and South America	287.3287	-54.5394	316.4	8	11.96
cssz-112b	Central and South America	286.7715	-54.8462	316.4	8	5
cssz-112x	Central and South America	288.9756	-53.6190	316.4	8	32.83
cssz-112y	Central and South America	288.4307	-53.9258	316.4	8	25.88
cssz-112z	Central and South America	287.8817	-54.2326	316.4	8	18.92
cssz-113a	Central and South America	288.3409	-55.0480	307.6	8	11.96
cssz-113b	Central and South America	287.8647	-55.4002	307.6	8	5
cssz-113x	Central and South America	289.7450	-53.9914	307.6	8	32.83
cssz-113y	Central and South America	289.2810	-54.3436	307.6	8	25.88
cssz-113z	Central and South America	288.8130	-54.6958	307.6	8	18.92
cssz-114a	Central and South America	289.5342	-55.5026	301.5	8	11.96
cssz-114b	Central and South America	289.1221	-55.8819	301.5	8	5
cssz-114x	Central and South America	290.7472	-54.3647	301.5	8	32.83
cssz-114y	Central and South America	290.3467	-54.7440	301.5	8	25.88
cssz-114z	Central and South America	289.9424	-55.1233	301.5	8	18.92
cssz-115a	Central and South America	290.7682	-55.8485	292.7	8	11.96
cssz-115b	Central and South America	290.4608	-56.2588	292.7	8	5
cssz-115x	Central and South America	291.6714	-54.6176	292.7	8	32.83
cssz-115y	Central and South America	291.3734	-55.0279	292.7	8	25.88
cssz-115z	Central and South America	291.0724	-55.4382	292.7	8	18.92

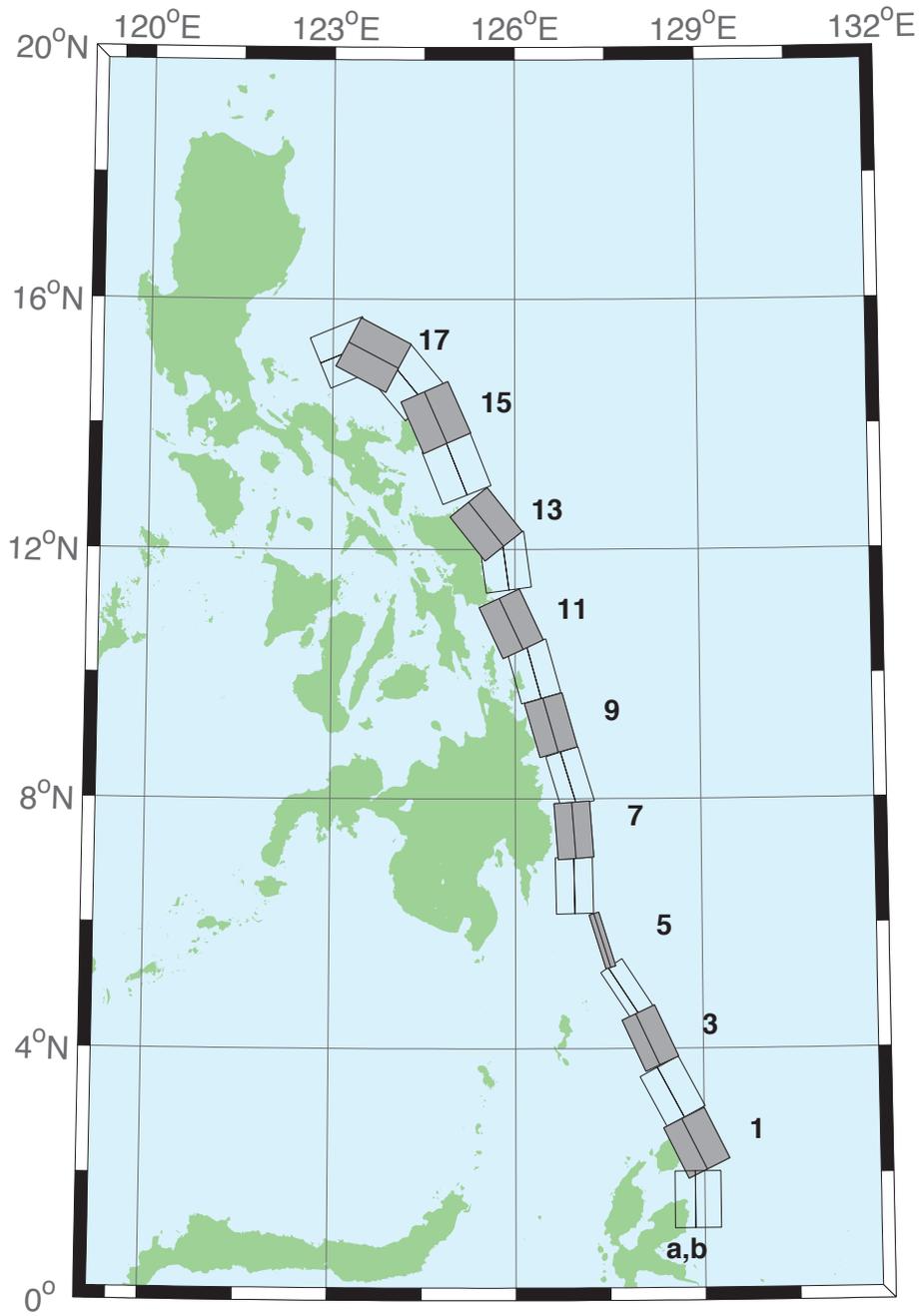


Figure B.3: Eastern Philippines Subduction Zone unit sources.

Table B.3: Earthquake parameters for Eastern Philippines Subduction Zone unit sources.

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
epsz-1a	Eastern Philippines	128.5521	2.3289	153.6	44.2	27.62
epsz-1b	Eastern Philippines	128.8408	2.4720	153.6	26.9	5
epsz-2a	Eastern Philippines	128.1943	3.1508	151.9	45.9	32.44
epsz-2b	Eastern Philippines	128.4706	3.2979	151.9	32.8	5.35
epsz-3a	Eastern Philippines	127.8899	4.0428	155.2	57.3	40.22
epsz-3b	Eastern Philippines	128.1108	4.1445	155.2	42.7	6.31
epsz-4a	Eastern Philippines	127.6120	4.8371	146.8	71.4	48.25
epsz-4b	Eastern Philippines	127.7324	4.9155	146.8	54.8	7.39
epsz-5a	Eastern Philippines	127.3173	5.7040	162.9	79.9	57.4
epsz-5b	Eastern Philippines	127.3930	5.7272	162.9	79.4	8.25
epsz-6a	Eastern Philippines	126.6488	6.6027	178.9	48.6	45.09
epsz-6b	Eastern Philippines	126.9478	6.6085	178.9	48.6	7.58
epsz-7a	Eastern Philippines	126.6578	7.4711	175.8	50.7	45.52
epsz-7b	Eastern Philippines	126.9439	7.4921	175.8	50.7	6.83
epsz-8a	Eastern Philippines	126.6227	8.2456	163.3	56.7	45.6
epsz-8b	Eastern Philippines	126.8614	8.3164	163.3	48.9	7.92
epsz-9a	Eastern Philippines	126.2751	9.0961	164.1	47	43.59
epsz-9b	Eastern Philippines	126.5735	9.1801	164.1	44.9	8.3
epsz-10a	Eastern Philippines	125.9798	9.9559	164.5	43.1	42.25
epsz-10b	Eastern Philippines	126.3007	10.0438	164.5	43.1	8.09
epsz-11a	Eastern Philippines	125.6079	10.6557	155	37.8	38.29
epsz-11b	Eastern Philippines	125.9353	10.8059	155	37.8	7.64
epsz-12a	Eastern Philippines	125.4697	11.7452	172.1	36	37.01
epsz-12b	Eastern Philippines	125.8374	11.7949	172.1	36	7.62
epsz-13a	Eastern Philippines	125.2238	12.1670	141.5	32.4	33.87
epsz-13b	Eastern Philippines	125.5278	12.4029	141.5	32.4	7.08
epsz-14a	Eastern Philippines	124.6476	13.1365	158.2	23	25.92
epsz-14b	Eastern Philippines	125.0421	13.2898	158.2	23	6.38
epsz-15a	Eastern Philippines	124.3107	13.9453	156.1	24.1	26.51
epsz-15b	Eastern Philippines	124.6973	14.1113	156.1	24.1	6.09
epsz-16a	Eastern Philippines	123.8998	14.4025	140.3	19.5	21.69
epsz-16b	Eastern Philippines	124.2366	14.6728	140.3	19.5	5
epsz-17a	Eastern Philippines	123.4604	14.7222	117.6	15.3	18.19
epsz-17b	Eastern Philippines	123.6682	15.1062	117.6	15.3	5
epsz-18a	Eastern Philippines	123.3946	14.7462	67.4	15	17.94
epsz-18b	Eastern Philippines	123.2219	15.1467	67.4	15	5
epsz-19a	Eastern Philippines	121.3638	15.7400	189.6	15	17.94
epsz-19b	Eastern Philippines	121.8082	15.6674	189.6	15	5
epsz-20a	Eastern Philippines	121.6833	16.7930	203.3	15	17.94
epsz-20b	Eastern Philippines	122.0994	16.6216	203.3	15	5
epsz-21a	Eastern Philippines	121.8279	17.3742	184.2	15	17.94
epsz-21b	Eastern Philippines	122.2814	17.3425	184.2	15	5

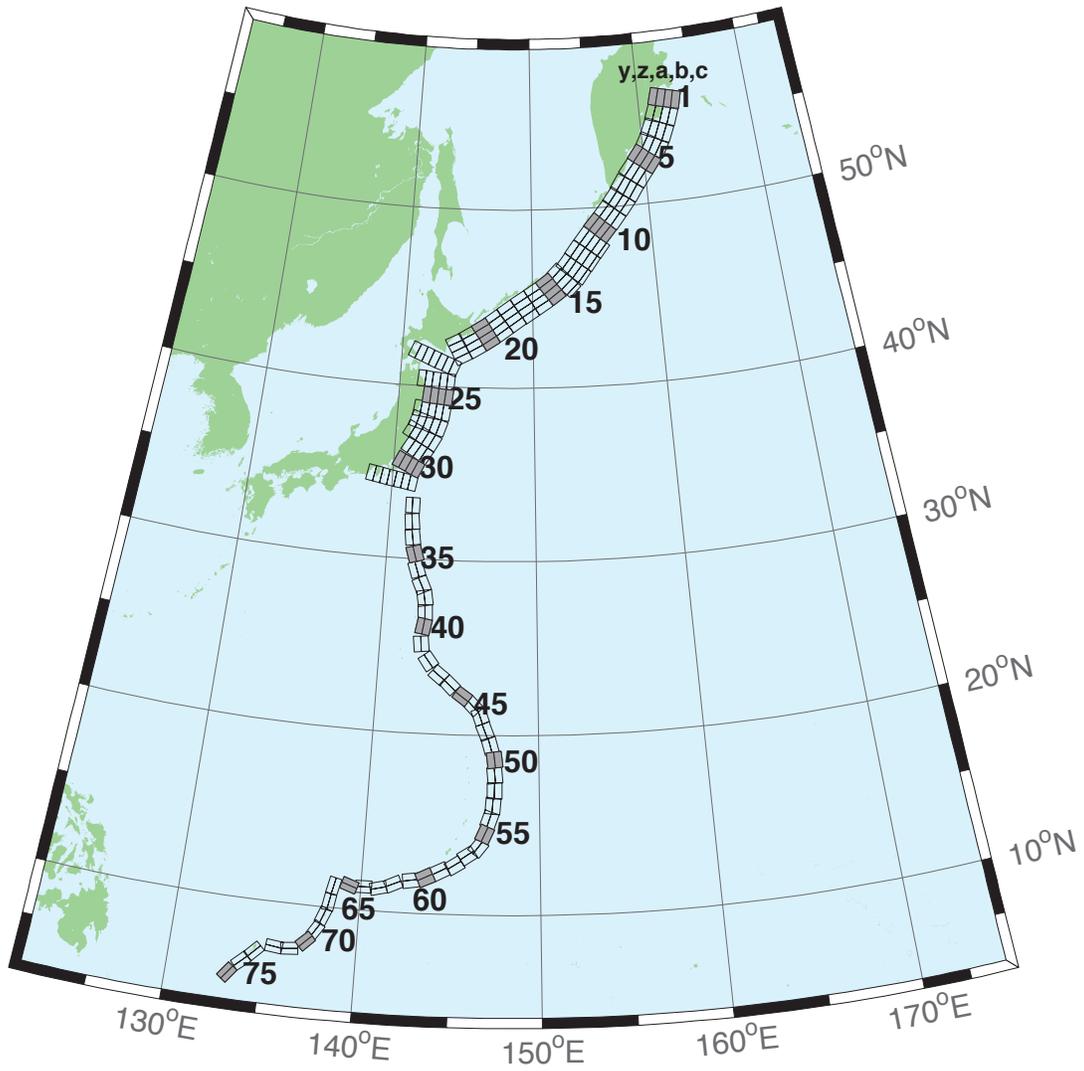


Figure B.4: Kamchatka-Kuril-Japan-Izu-Mariana-Yap Subduction Zone unit sources.

Table B.4: Earthquake parameters for Kamchatka-Kuril-Japan-Izu-Mariana-Yap Subduction Zone unit sources.

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
kisz-1a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	162.4318	55.5017	195	29	26.13
kisz-1b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	163.1000	55.4000	195	25	5
kisz-1y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	161.0884	55.7050	195	29	74.61
kisz-1z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	161.7610	55.6033	195	29	50.37
kisz-2a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	161.9883	54.6784	200	29	26.13
kisz-2b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	162.6247	54.5440	200	25	5
kisz-2y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	160.7072	54.9471	200	29	74.61
kisz-2z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	161.3488	54.8127	200	29	50.37
kisz-3a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	161.4385	53.8714	204	29	26.13
kisz-3b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	162.0449	53.7116	204	25	5
kisz-3y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	160.2164	54.1910	204	29	74.61
kisz-3z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	160.8286	54.0312	204	29	50.37
kisz-4a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	160.7926	53.1087	210	29	26.13
kisz-4b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	161.3568	52.9123	210	25	5
kisz-4y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	159.6539	53.5015	210	29	74.61
kisz-4z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	160.2246	53.3051	210	29	50.37
kisz-5a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	160.0211	52.4113	218	29	26.13
kisz-5b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	160.5258	52.1694	218	25	5
kisz-5y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	159.0005	52.8950	218	29	74.61
kisz-5z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	159.5122	52.6531	218	29	50.37
kisz-6a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	159.1272	51.7034	218	29	26.13
kisz-6b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	159.6241	51.4615	218	25	5
kisz-6y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	158.1228	52.1871	218	29	74.61
kisz-6z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	158.6263	51.9452	218	29	50.37
kisz-7a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	158.2625	50.9549	214	29	26.13
kisz-7b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	158.7771	50.7352	214	25	5
kisz-7y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	157.2236	51.3942	214	29	74.61
kisz-7z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	157.7443	51.1745	214	29	50.37
kisz-8a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	157.4712	50.2459	218	31	27.7
kisz-8b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	157.9433	50.0089	218	27	5
kisz-8y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	156.5176	50.7199	218	31	79.2
kisz-8z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	156.9956	50.4829	218	31	53.45
kisz-9a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	156.6114	49.5583	220	31	27.7
kisz-9b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	157.0638	49.3109	220	27	5
kisz-9y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	155.6974	50.0533	220	31	79.2
kisz-9z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	156.1556	49.8058	220	31	53.45
kisz-10a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	155.7294	48.8804	221	31	27.7
kisz-10b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	156.1690	48.6278	221	27	5
kisz-10y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	154.8413	49.3856	221	31	79.2
kisz-10z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	155.2865	49.1330	221	31	53.45
kisz-11a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	154.8489	48.1821	219	31	27.7
kisz-11b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	155.2955	47.9398	219	27	5
kisz-11y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	153.9472	48.6667	219	31	79.2
kisz-11z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	154.3991	48.4244	219	31	53.45
kisz-11c	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	156.0358	47.5374	39	57.89	4.602
kisz-12a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	153.9994	47.4729	217	31	27.7
kisz-12b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	154.4701	47.2320	217	27	5
kisz-12y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	153.0856	47.9363	217	31	79.2
kisz-12z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	153.5435	47.7046	217	31	53.45
kisz-12c	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	155.2208	46.8473	37	57.89	4.602
kisz-13a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	153.2239	46.7564	218	31	27.7
kisz-13b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	153.6648	46.5194	218	27	5

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Table B.4 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
kisz-13y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	152.3343	47.2304	218	31	79.2
kisz-13z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	152.7801	46.9934	218	31	53.45
kisz-13c	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	154.3957	46.1257	38	57.89	4.602
kisz-14a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	152.3657	46.1514	225	23	24.54
kisz-14b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	152.7855	45.8591	225	23	5
kisz-14y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	151.5172	46.7362	225	23	63.62
kisz-14z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	151.9426	46.4438	225	23	44.08
kisz-14c	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	153.4468	45.3976	45	57.89	4.602
kisz-15a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	151.4663	45.5963	233	25	23.73
kisz-15b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	151.8144	45.2712	233	22	5
kisz-15y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	150.7619	46.2465	233	25	65.99
kisz-15z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	151.1151	45.9214	233	25	44.86
kisz-16a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	150.4572	45.0977	237	25	23.73
kisz-16b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	150.7694	44.7563	237	22	5
kisz-16y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	149.8253	45.7804	237	25	65.99
kisz-16z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	150.1422	45.4390	237	25	44.86
kisz-17a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	149.3989	44.6084	237	25	23.73
kisz-17b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	149.7085	44.2670	237	22	5
kisz-17y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	148.7723	45.2912	237	25	65.99
kisz-17z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	149.0865	44.9498	237	25	44.86
kisz-18a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	148.3454	44.0982	235	25	23.73
kisz-18b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	148.6687	43.7647	235	22	5
kisz-18y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	147.6915	44.7651	235	25	65.99
kisz-18z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	148.0194	44.4316	235	25	44.86
kisz-19a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	147.3262	43.5619	233	25	23.73
kisz-19b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	147.6625	43.2368	233	22	5
kisz-19y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	146.6463	44.2121	233	25	65.99
kisz-19z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	146.9872	43.8870	233	25	44.86
kisz-20a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	146.3513	43.0633	237	25	23.73
kisz-20b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	146.6531	42.7219	237	22	5
kisz-20y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	145.7410	43.7461	237	25	65.99
kisz-20z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	146.0470	43.4047	237	25	44.86
kisz-21a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	145.3331	42.5948	239	25	23.73
kisz-21b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	145.6163	42.2459	239	22	5
kisz-21y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	144.7603	43.2927	239	25	65.99
kisz-21z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	145.0475	42.9438	239	25	44.86
kisz-22a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	144.3041	42.1631	242	25	23.73
kisz-22b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	144.5605	41.8037	242	22	5
kisz-22y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	143.7854	42.8819	242	25	65.99
kisz-22z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	144.0455	42.5225	242	25	44.86
kisz-23a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	143.2863	41.3335	202	21	21.28
kisz-23b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	143.8028	41.1764	202	19	5
kisz-23v	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	140.6816	42.1189	202	21	110.9
kisz-23w	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.2050	41.9618	202	21	92.95
kisz-23x	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.7273	41.8047	202	21	75.04
kisz-23y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.2482	41.6476	202	21	57.12
kisz-23z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.7679	41.4905	202	21	39.2
kisz-24a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.9795	40.3490	185	21	21.28
kisz-24b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	143.5273	40.3125	185	19	5
kisz-24x	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.3339	40.4587	185	21	75.04
kisz-24y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.8827	40.4221	185	21	57.12
kisz-24z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.4312	40.3856	185	21	39.2
kisz-25a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.8839	39.4541	185	21	21.28
kisz-25b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	143.4246	39.4176	185	19	5
kisz-25y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.8012	39.5272	185	21	57.12

Continued on next page

Table B.4 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
kisz-25z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.3426	39.4907	185	21	39.2
kisz-26a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.7622	38.5837	188	21	21.28
kisz-26b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	143.2930	38.5254	188	19	5
kisz-26x	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.1667	38.7588	188	21	75.04
kisz-26y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.6990	38.7004	188	21	57.12
kisz-26z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.2308	38.6421	188	21	39.2
kisz-27a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.5320	37.7830	198	21	21.28
kisz-27b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	143.0357	37.6534	198	19	5
kisz-27x	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.0142	38.1717	198	21	75.04
kisz-27y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.5210	38.0421	198	21	57.12
kisz-27z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.0269	37.9126	198	21	39.2
kisz-28a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.1315	37.0265	208	21	21.28
kisz-28b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.5941	36.8297	208	19	5
kisz-28x	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	140.7348	37.6171	208	21	75.04
kisz-28y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.2016	37.4202	208	21	57.12
kisz-28z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.6671	37.2234	208	21	39.2
kisz-29a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.5970	36.2640	211	21	21.28
kisz-29b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.0416	36.0481	211	19	5
kisz-29y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	140.7029	36.6960	211	21	57.12
kisz-29z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.1506	36.4800	211	21	39.2
kisz-30a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.0553	35.4332	205	21	21.28
kisz-30b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.5207	35.2560	205	19	5
kisz-30y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	140.1204	35.7876	205	21	57.12
kisz-30z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	140.5883	35.6104	205	21	39.2
kisz-31a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	140.6956	34.4789	190	22	22.1
kisz-31b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.1927	34.4066	190	20	5
kisz-31v	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	138.2025	34.8405	190	22	115.8
kisz-31w	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	138.7021	34.7682	190	22	97.02
kisz-31x	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	139.2012	34.6958	190	22	78.29
kisz-31y	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	139.6997	34.6235	190	22	59.56
kisz-31z	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	140.1979	34.5512	190	22	40.83
kisz-32a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.0551	33.0921	180	32	23.48
kisz-32b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.5098	33.0921	180	21.69	5
kisz-33a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.0924	32.1047	173.8	27.65	20.67
kisz-33b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.5596	32.1473	173.8	18.27	5
kisz-34a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.1869	31.1851	172.1	25	18.26
kisz-34b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.6585	31.2408	172.1	15.38	5
kisz-35a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.4154	30.1707	163	25	17.12
kisz-35b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.8662	30.2899	163	14.03	5
kisz-36a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.6261	29.2740	161.7	25.73	18.71
kisz-36b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.0670	29.4012	161.7	15.91	5
kisz-37a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.0120	28.3322	154.7	20	14.54
kisz-37b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.4463	28.5124	154.7	11	5
kisz-38a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.2254	27.6946	170.3	20	14.54
kisz-38b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.6955	27.7659	170.3	11	5
kisz-39a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.3085	26.9127	177.2	24.23	17.42
kisz-39b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.7674	26.9325	177.2	14.38	5
kisz-40a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.2673	26.1923	189.4	26.49	22.26
kisz-40b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.7090	26.1264	189.4	20.2	5
kisz-41a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.1595	25.0729	173.7	22.07	19.08
kisz-41b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.6165	25.1184	173.7	16.36	5
kisz-42a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.7641	23.8947	143.5	21.54	18.4
kisz-42b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	143.1321	24.1432	143.5	15.54	5
kisz-43a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	143.5281	23.0423	129.2	23.02	18.77
kisz-43b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	143.8128	23.3626	129.2	15.99	5

Continued on next page

Table B.4 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
kisz-44a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	144.2230	22.5240	134.6	28.24	18.56
kisz-44b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	144.5246	22.8056	134.6	15.74	5
kisz-45a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	145.0895	21.8866	125.8	36.73	22.79
kisz-45b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	145.3171	22.1785	125.8	20.84	5
kisz-46a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	145.6972	21.3783	135.9	30.75	20.63
kisz-46b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	145.9954	21.6469	135.9	18.22	5
kisz-47a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	146.0406	20.9341	160.1	29.87	19.62
kisz-47b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	146.4330	21.0669	160.1	17	5
kisz-48a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	146.3836	20.0690	158	32.75	19.68
kisz-48b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	146.7567	20.2108	158	17.07	5
kisz-49a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	146.6689	19.3123	164.5	25.07	21.41
kisz-49b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	147.0846	19.4212	164.5	19.16	5
kisz-50a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	146.9297	18.5663	172.1	22	22.1
kisz-50b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	147.3650	18.6238	172.1	20	5
kisz-51a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	146.9495	17.7148	175.1	22.06	22.04
kisz-51b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	147.3850	17.7503	175.1	19.93	5
kisz-52a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	146.9447	16.8869	180	25.51	18.61
kisz-52b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	147.3683	16.8869	180	15.79	5
kisz-53a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	146.8626	16.0669	185.2	27.39	18.41
kisz-53b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	147.2758	16.0309	185.2	15.56	5
kisz-54a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	146.7068	15.3883	199.1	28.12	20.91
kisz-54b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	147.0949	15.2590	199.1	18.56	5
kisz-55a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	146.4717	14.6025	204.3	29.6	26.27
kisz-55b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	146.8391	14.4415	204.3	25.18	5
kisz-56a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	146.1678	13.9485	217.4	32.04	26.79
kisz-56b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	146.4789	13.7170	217.4	25.84	5
kisz-57a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	145.6515	13.5576	235.8	37	24.54
kisz-57b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	145.8586	13.2609	235.8	23	5
kisz-58a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	144.9648	12.9990	237.8	37.72	24.54
kisz-58b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	145.1589	12.6984	237.8	23	5
kisz-59a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	144.1799	12.6914	242.9	34.33	22.31
kisz-59b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	144.3531	12.3613	242.9	20.25	5
kisz-60a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	143.3687	12.3280	244.9	30.9	20.62
kisz-60b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	143.5355	11.9788	244.9	18.2	5
kisz-61a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.7051	12.1507	261.8	35.41	25.51
kisz-61b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	142.7582	11.7883	261.8	24.22	5
kisz-62a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.6301	11.8447	245.7	39.86	34.35
kisz-62b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	141.7750	11.5305	245.7	35.94	5
kisz-63a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	140.8923	11.5740	256.2	42	38.46
kisz-63b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	140.9735	11.2498	256.2	42	5
kisz-64a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	140.1387	11.6028	269.6	42.48	38.77
kisz-64b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	140.1410	11.2716	269.6	42.48	5
kisz-65a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	139.4595	11.5883	288.7	44.16	39.83
kisz-65b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	139.3541	11.2831	288.7	44.16	5
kisz-66a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	138.1823	11.2648	193.1	45	40.36
kisz-66b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	138.4977	11.1929	193.1	45	5
kisz-67a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	137.9923	10.3398	189.8	45	40.36
kisz-67b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	138.3104	10.2856	189.8	45	5
kisz-68a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	137.7607	9.6136	201.7	45	40.36
kisz-68b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	138.0599	9.4963	201.7	45	5
kisz-69a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	137.4537	8.8996	213.5	45	40.36
kisz-69b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	137.7215	8.7241	213.5	45	5
kisz-70a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	137.0191	8.2872	226.5	45	40.36
kisz-70b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	137.2400	8.0569	226.5	45	5
kisz-71a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	136.3863	7.9078	263.9	45	40.36

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Table B.4 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
kisz-71b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	136.4202	7.5920	263.9	45	5
kisz-72a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	135.6310	7.9130	276.9	45	40.36
kisz-72b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	135.5926	7.5977	276.9	45	5
kisz-73a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	134.3296	7.4541	224	45	40.36
kisz-73b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	134.5600	7.2335	224	45	5
kisz-74a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	133.7125	6.8621	228.1	45	40.36
kisz-74b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	133.9263	6.6258	228.1	45	5
kisz-75a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	133.0224	6.1221	217.7	45	40.36
kisz-75b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	133.2751	5.9280	217.7	45	5

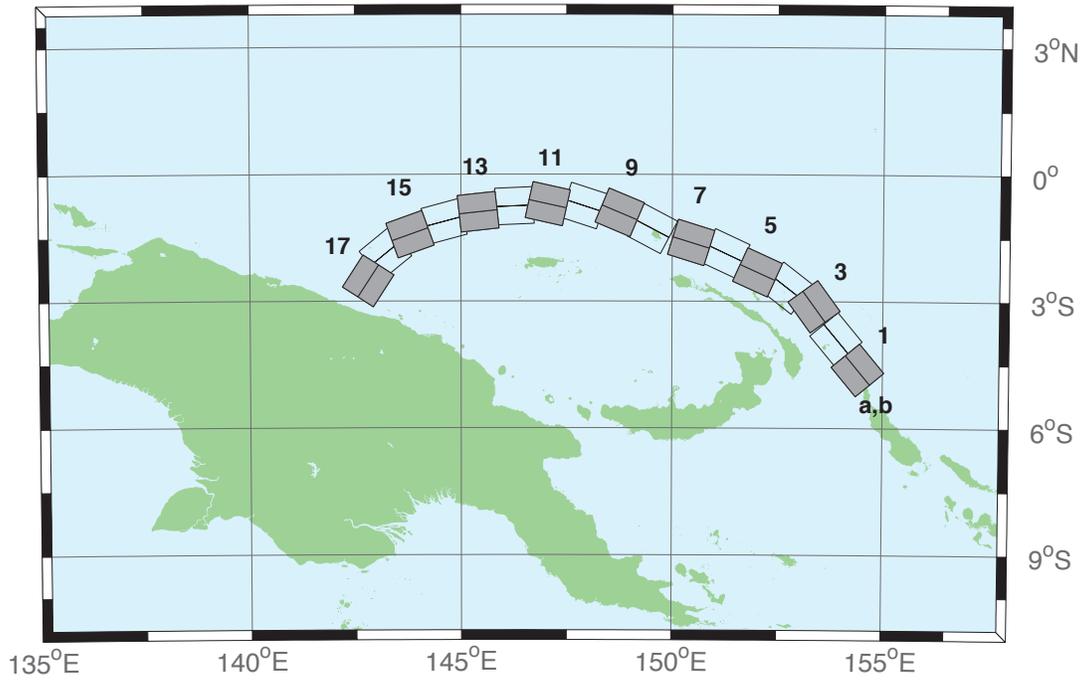


Figure B.5: Manus–Oceanic Convergent Boundary Subduction Zone unit sources.

Table B.5: Earthquake parameters for Manus–Oceanic Convergent Boundary Subduction Zone unit sources.

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
mosz-1a	Manus	154.0737	-4.8960	140.2	15	15.88
mosz-1b	Manus	154.4082	-4.6185	140.2	15	2.94
mosz-2a	Manus	153.5589	-4.1575	140.2	15	15.91
mosz-2b	Manus	153.8931	-3.8800	140.2	15	2.97
mosz-3a	Manus	153.0151	-3.3716	143.9	15	16.64
mosz-3b	Manus	153.3662	-3.1160	143.9	15	3.7
mosz-4a	Manus	152.4667	-3.0241	127.7	15	17.32
mosz-4b	Manus	152.7321	-2.6806	127.7	15	4.38
mosz-5a	Manus	151.8447	-2.7066	114.3	15	17.57
mosz-5b	Manus	152.0235	-2.3112	114.3	15	4.63
mosz-6a	Manus	151.0679	-2.2550	115	15	17.66
mosz-6b	Manus	151.2513	-1.8618	115	15	4.72
mosz-7a	Manus	150.3210	-2.0236	107.2	15	17.73
mosz-7b	Manus	150.4493	-1.6092	107.2	15	4.79
mosz-8a	Manus	149.3226	-1.6666	117.8	15	17.83
mosz-8b	Manus	149.5251	-1.2829	117.8	15	4.89
mosz-9a	Manus	148.5865	-1.3017	112.7	15	17.84
mosz-9b	Manus	148.7540	-0.9015	112.7	15	4.9
mosz-10a	Manus	147.7760	-1.1560	108	15	17.78
mosz-10b	Manus	147.9102	-0.7434	108	15	4.84
mosz-11a	Manus	146.9596	-1.1226	102.5	15	17.54
mosz-11b	Manus	147.0531	-0.6990	102.5	15	4.6
mosz-12a	Manus	146.2858	-1.1820	87.48	15	17.29
mosz-12b	Manus	146.2667	-0.7486	87.48	15	4.35
mosz-13a	Manus	145.4540	-1.3214	83.75	15	17.34
mosz-13b	Manus	145.4068	-0.8901	83.75	15	4.4
mosz-14a	Manus	144.7151	-1.5346	75.09	15	17.21
mosz-14b	Manus	144.6035	-1.1154	75.09	15	4.27
mosz-15a	Manus	143.9394	-1.8278	70.43	15	16.52
mosz-15b	Manus	143.7940	-1.4190	70.43	15	3.58
mosz-16a	Manus	143.4850	-2.2118	50.79	15	15.86
mosz-16b	Manus	143.2106	-1.8756	50.79	15	2.92
mosz-17a	Manus	143.1655	-2.7580	33	15	16.64
mosz-17b	Manus	142.8013	-2.5217	33	15	3.7

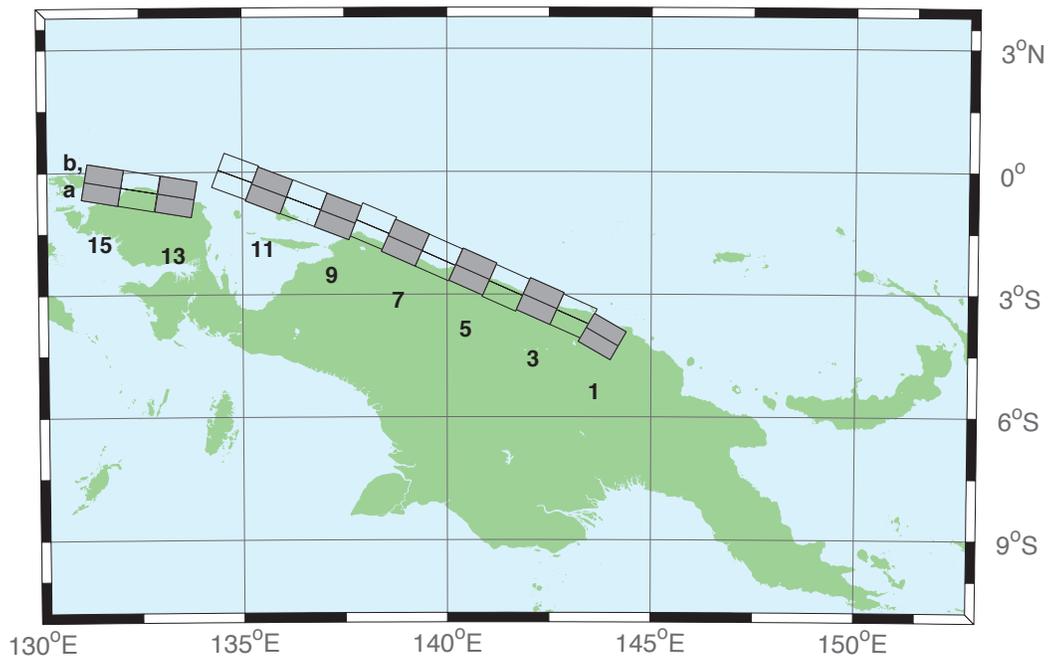


Figure B.6: New Guinea Subduction Zone unit sources.

Table B.6: Earthquake parameters for New Guinea Subduction Zone unit sources.

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
ngsz-1a	New Guinea	143.6063	-4.3804	120	29	25.64
ngsz-1b	New Guinea	143.8032	-4.0402	120	29	1.4
ngsz-2a	New Guinea	142.9310	-3.9263	114	27.63	20.1
ngsz-2b	New Guinea	143.0932	-3.5628	114	21.72	1.6
ngsz-3a	New Guinea	142.1076	-3.5632	114	20.06	18.73
ngsz-3b	New Guinea	142.2795	-3.1778	114	15.94	5
ngsz-4a	New Guinea	141.2681	-3.2376	114	21	17.76
ngsz-4b	New Guinea	141.4389	-2.8545	114	14.79	5
ngsz-5a	New Guinea	140.4592	-2.8429	114	21.26	16.14
ngsz-5b	New Guinea	140.6296	-2.4605	114	12.87	5
ngsz-6a	New Guinea	139.6288	-2.4960	114	22.72	15.4
ngsz-6b	New Guinea	139.7974	-2.1175	114	12	5
ngsz-7a	New Guinea	138.8074	-2.1312	114	21.39	15.4
ngsz-7b	New Guinea	138.9776	-1.7491	114	12	5
ngsz-8a	New Guinea	138.0185	-1.7353	113.1	18.79	15.14
ngsz-8b	New Guinea	138.1853	-1.3441	113.1	11.7	5
ngsz-9a	New Guinea	137.1805	-1.5037	111	15.24	13.23
ngsz-9b	New Guinea	137.3358	-1.0991	111	9.47	5
ngsz-10a	New Guinea	136.3418	-1.1774	111	13.51	11.09
ngsz-10b	New Guinea	136.4983	-0.7697	111	7	5
ngsz-11a	New Guinea	135.4984	-0.8641	111	11.38	12.49
ngsz-11b	New Guinea	135.6562	-0.4530	111	8.62	5
ngsz-12a	New Guinea	134.6759	-0.5216	110.5	10	13.68
ngsz-12b	New Guinea	134.8307	-0.1072	110.5	10	5
ngsz-13a	New Guinea	133.3065	-1.0298	99.5	10	13.68
ngsz-13b	New Guinea	133.3795	-0.5935	99.5	10	5
ngsz-14a	New Guinea	132.4048	-0.8816	99.5	10	13.68
ngsz-14b	New Guinea	132.4778	-0.4453	99.5	10	5
ngsz-15a	New Guinea	131.5141	-0.7353	99.5	10	13.68
ngsz-15b	New Guinea	131.5871	-0.2990	99.5	10	5

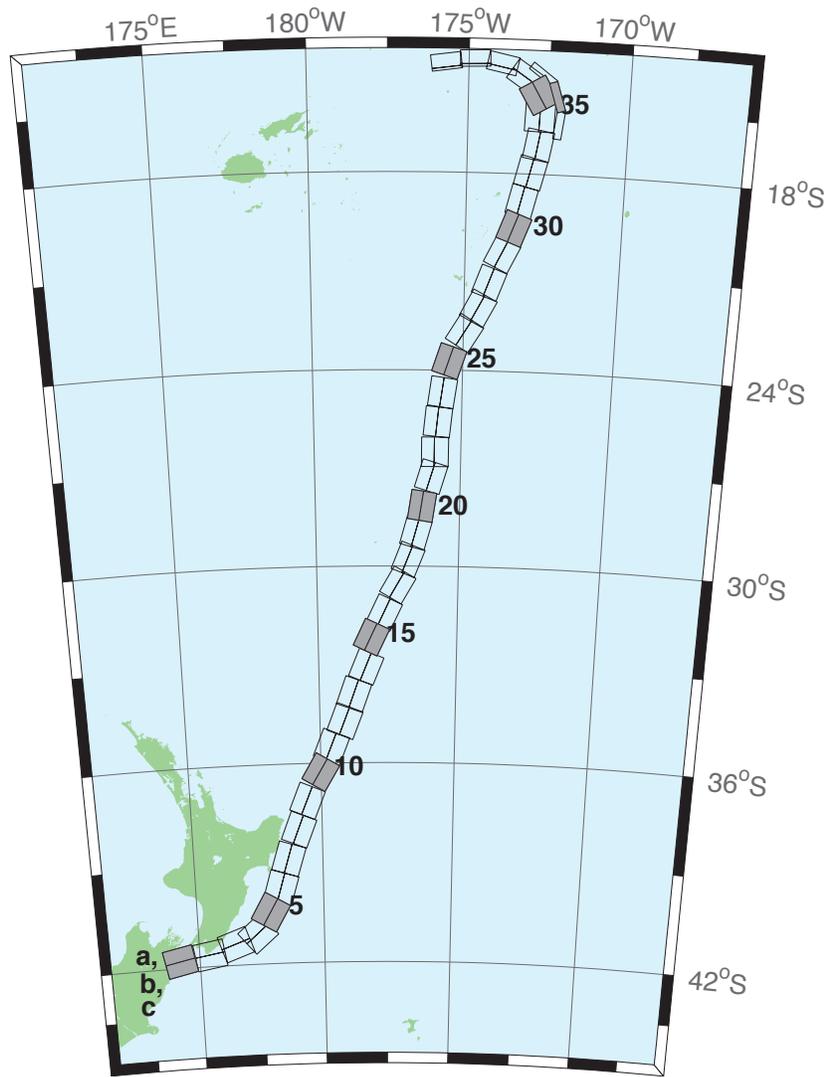


Figure B.7: New Zealand–Kermadec–Tonga Subduction Zone unit sources.

Table B.7: Earthquake parameters for New Zealand–Kermadec–Tonga Subduction Zone unit sources.

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
ntsz-1a	New Zealand–Tonga	174.0985	-41.3951	258.6	24	25.34
ntsz-1b	New Zealand–Tonga	174.2076	-41.7973	258.6	24	5
ntsz-2a	New Zealand–Tonga	175.3289	-41.2592	260.6	29.38	23.17
ntsz-2b	New Zealand–Tonga	175.4142	-41.6454	260.6	21.31	5
ntsz-3a	New Zealand–Tonga	176.2855	-40.9950	250.7	29.54	21.74
ntsz-3b	New Zealand–Tonga	176.4580	-41.3637	250.7	19.56	5
ntsz-4a	New Zealand–Tonga	177.0023	-40.7679	229.4	24.43	18.87
ntsz-4b	New Zealand–Tonga	177.3552	-41.0785	229.4	16.1	5
ntsz-5a	New Zealand–Tonga	177.4114	-40.2396	210	18.8	19.29
ntsz-5b	New Zealand–Tonga	177.8951	-40.4525	210	16.61	5
ntsz-6a	New Zealand–Tonga	177.8036	-39.6085	196.7	18.17	15.8
ntsz-6b	New Zealand–Tonga	178.3352	-39.7310	196.7	12.48	5
ntsz-7a	New Zealand–Tonga	178.1676	-38.7480	197	28.1	17.85
ntsz-7b	New Zealand–Tonga	178.6541	-38.8640	197	14.89	5
ntsz-8a	New Zealand–Tonga	178.6263	-37.8501	201.4	31.47	18.78
ntsz-8b	New Zealand–Tonga	179.0788	-37.9899	201.4	16	5
ntsz-9a	New Zealand–Tonga	178.9833	-36.9770	202.2	29.58	20.02
ntsz-9b	New Zealand–Tonga	179.4369	-37.1245	202.2	17.48	5
ntsz-10a	New Zealand–Tonga	179.5534	-36.0655	210.6	32.1	20.72
ntsz-10b	New Zealand–Tonga	179.9595	-36.2593	210.6	18.32	5
ntsz-11a	New Zealand–Tonga	179.9267	-35.3538	201.7	25	16.09
ntsz-11b	New Zealand–Tonga	180.3915	-35.5040	201.7	12.81	5
ntsz-12a	New Zealand–Tonga	180.4433	-34.5759	201.2	25	15.46
ntsz-12b	New Zealand–Tonga	180.9051	-34.7230	201.2	12.08	5
ntsz-13a	New Zealand–Tonga	180.7990	-33.7707	199.8	25.87	19.06
ntsz-13b	New Zealand–Tonga	181.2573	-33.9073	199.8	16.33	5
ntsz-14a	New Zealand–Tonga	181.2828	-32.9288	202.4	31.28	22.73
ntsz-14b	New Zealand–Tonga	181.7063	-33.0751	202.4	20.77	5
ntsz-15a	New Zealand–Tonga	181.4918	-32.0035	205.4	32.33	22.64
ntsz-15b	New Zealand–Tonga	181.8967	-32.1665	205.4	20.66	5
ntsz-16a	New Zealand–Tonga	181.9781	-31.2535	205.5	34.29	23.59
ntsz-16b	New Zealand–Tonga	182.3706	-31.4131	205.5	21.83	5
ntsz-17a	New Zealand–Tonga	182.4819	-30.3859	210.3	37.6	25.58
ntsz-17b	New Zealand–Tonga	182.8387	-30.5655	210.3	24.3	5
ntsz-18a	New Zealand–Tonga	182.8176	-29.6545	201.6	37.65	26.13
ntsz-18b	New Zealand–Tonga	183.1985	-29.7856	201.6	25	5
ntsz-19a	New Zealand–Tonga	183.0622	-28.8739	195.7	34.41	26.13
ntsz-19b	New Zealand–Tonga	183.4700	-28.9742	195.7	25	5
ntsz-20a	New Zealand–Tonga	183.2724	-28.0967	188.8	38	26.13
ntsz-20b	New Zealand–Tonga	183.6691	-28.1508	188.8	25	5
ntsz-21a	New Zealand–Tonga	183.5747	-27.1402	197.1	32.29	24.83
ntsz-21b	New Zealand–Tonga	183.9829	-27.2518	197.1	23.37	5
ntsz-22a	New Zealand–Tonga	183.6608	-26.4975	180	29.56	18.63
ntsz-22b	New Zealand–Tonga	184.0974	-26.4975	180	15.82	5
ntsz-23a	New Zealand–Tonga	183.7599	-25.5371	185.8	32.42	20.56
ntsz-23b	New Zealand–Tonga	184.1781	-25.5752	185.8	18.13	5
ntsz-24a	New Zealand–Tonga	183.9139	-24.6201	188.2	33.31	23.73
ntsz-24b	New Zealand–Tonga	184.3228	-24.6734	188.2	22	5
ntsz-25a	New Zealand–Tonga	184.1266	-23.5922	198.5	29.34	19.64
ntsz-25b	New Zealand–Tonga	184.5322	-23.7163	198.5	17.03	5
ntsz-26a	New Zealand–Tonga	184.6613	-22.6460	211.7	30.26	19.43
ntsz-26b	New Zealand–Tonga	185.0196	-22.8497	211.7	16.78	5
ntsz-27a	New Zealand–Tonga	185.0879	-21.9139	207.9	31.73	20.67

Continued on next page

Table B.7 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
ntsz-27b	New Zealand–Tonga	185.4522	-22.0928	207.9	18.27	5
ntsz-28a	New Zealand–Tonga	185.4037	-21.1758	200.5	32.44	21.76
ntsz-28b	New Zealand–Tonga	185.7849	-21.3084	200.5	19.58	5
ntsz-29a	New Zealand–Tonga	185.8087	-20.2629	206.4	32.47	20.4
ntsz-29b	New Zealand–Tonga	186.1710	-20.4312	206.4	17.94	5
ntsz-30a	New Zealand–Tonga	186.1499	-19.5087	200.9	32.98	22.46
ntsz-30b	New Zealand–Tonga	186.5236	-19.6432	200.9	20.44	5
ntsz-31a	New Zealand–Tonga	186.3538	-18.7332	193.9	34.41	21.19
ntsz-31b	New Zealand–Tonga	186.7339	-18.8221	193.9	18.89	5
ntsz-32a	New Zealand–Tonga	186.5949	-17.8587	194.1	30	19.12
ntsz-32b	New Zealand–Tonga	186.9914	-17.9536	194.1	16.4	5
ntsz-33a	New Zealand–Tonga	186.8172	-17.0581	190	33.15	23.34
ntsz-33b	New Zealand–Tonga	187.2047	-17.1237	190	21.52	5
ntsz-34a	New Zealand–Tonga	186.7814	-16.2598	182.1	15	13.41
ntsz-34b	New Zealand–Tonga	187.2330	-16.2759	182.1	9.68	5
ntsz-34c	New Zealand–Tonga	187.9697	-16.4956	7.62	57.06	6.571
ntsz-35a	New Zealand–Tonga	186.8000	-15.8563	149.8	15	12.17
ntsz-35b	New Zealand–Tonga	187.1896	-15.6384	149.8	8.24	5
ntsz-35c	New Zealand–Tonga	187.8776	-15.6325	342.4	57.06	6.571
ntsz-36a	New Zealand–Tonga	186.5406	-15.3862	123.9	40.44	36.72
ntsz-36b	New Zealand–Tonga	186.7381	-15.1025	123.9	39.38	5
ntsz-36c	New Zealand–Tonga	187.3791	-14.9234	307	57.06	6.571
ntsz-37a	New Zealand–Tonga	185.9883	-14.9861	102	68.94	30.99
ntsz-37b	New Zealand–Tonga	186.0229	-14.8282	102	31.32	5
ntsz-38a	New Zealand–Tonga	185.2067	-14.8259	88.4	80	26.13
ntsz-38b	New Zealand–Tonga	185.2044	-14.7479	88.4	25	5
ntsz-39a	New Zealand–Tonga	184.3412	-14.9409	82.55	80	26.13
ntsz-39b	New Zealand–Tonga	184.3307	-14.8636	82.55	25	5

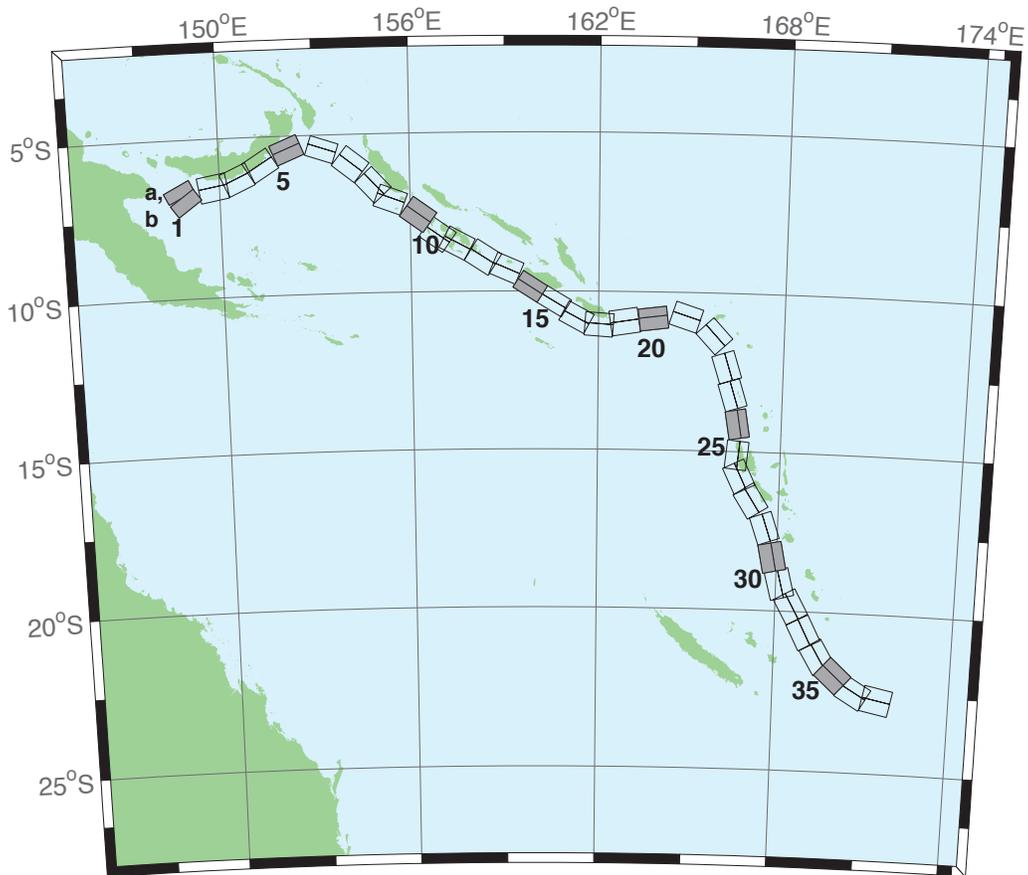


Figure B.8: New Britain–Solomons–Vanuatu Zone unit sources.

Table B.8: Earthquake parameters for New Britain–Solomons–Vanuatu Subduction Zone unit sources.

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
nvsz-1a	New Britain–Vanuatu	148.6217	-6.4616	243.2	32.34	15.69
nvsz-1b	New Britain–Vanuatu	148.7943	-6.8002	234.2	12.34	5
nvsz-2a	New Britain–Vanuatu	149.7218	-6.1459	260.1	35.1	16.36
nvsz-2b	New Britain–Vanuatu	149.7856	-6.5079	260.1	13.13	5
nvsz-3a	New Britain–Vanuatu	150.4075	-5.9659	245.7	42.35	18.59
nvsz-3b	New Britain–Vanuatu	150.5450	-6.2684	245.7	15.77	5
nvsz-4a	New Britain–Vanuatu	151.1095	-5.5820	238.2	42.41	23.63
nvsz-4b	New Britain–Vanuatu	151.2851	-5.8639	238.2	21.88	5
nvsz-5a	New Britain–Vanuatu	152.0205	-5.1305	247.7	49.22	32.39
nvsz-5b	New Britain–Vanuatu	152.1322	-5.4020	247.7	33.22	5
nvsz-6a	New Britain–Vanuatu	153.3450	-5.1558	288.6	53.53	33.59
nvsz-6b	New Britain–Vanuatu	153.2595	-5.4089	288.6	34.87	5
nvsz-7a	New Britain–Vanuatu	154.3814	-5.6308	308.3	39.72	19.18
nvsz-7b	New Britain–Vanuatu	154.1658	-5.9017	308.3	16.48	5
nvsz-8a	New Britain–Vanuatu	155.1097	-6.3511	317.2	45.33	22.92
nvsz-8b	New Britain–Vanuatu	154.8764	-6.5656	317.2	21	5
nvsz-9a	New Britain–Vanuatu	155.5027	-6.7430	290.5	48.75	22.92
nvsz-9b	New Britain–Vanuatu	155.3981	-7.0204	290.5	21	5
nvsz-10a	New Britain–Vanuatu	156.4742	-7.2515	305.9	36.88	27.62
nvsz-10b	New Britain–Vanuatu	156.2619	-7.5427	305.9	26.9	5
nvsz-11a	New Britain–Vanuatu	157.0830	-7.8830	305.4	32.97	29.72
nvsz-11b	New Britain–Vanuatu	156.8627	-8.1903	305.4	29.63	5
nvsz-12a	New Britain–Vanuatu	157.6537	-8.1483	297.9	37.53	28.57
nvsz-12b	New Britain–Vanuatu	157.4850	-8.4630	297.9	28.13	5
nvsz-13a	New Britain–Vanuatu	158.5089	-8.5953	302.7	33.62	23.02
nvsz-13b	New Britain–Vanuatu	158.3042	-8.9099	302.7	21.12	5
nvsz-14a	New Britain–Vanuatu	159.1872	-8.9516	293.3	38.44	34.06
nvsz-14b	New Britain–Vanuatu	159.0461	-9.2747	293.3	35.54	5
nvsz-15a	New Britain–Vanuatu	159.9736	-9.5993	302.8	46.69	41.38
nvsz-15b	New Britain–Vanuatu	159.8044	-9.8584	302.8	46.69	5
nvsz-16a	New Britain–Vanuatu	160.7343	-10.0574	301	46.05	41
nvsz-16b	New Britain–Vanuatu	160.5712	-10.3246	301	46.05	5
nvsz-17a	New Britain–Vanuatu	161.4562	-10.5241	298.4	40.12	37.22
nvsz-17b	New Britain–Vanuatu	161.2900	-10.8263	298.4	40.12	5
nvsz-18a	New Britain–Vanuatu	162.0467	-10.6823	274.1	40.33	29.03
nvsz-18b	New Britain–Vanuatu	162.0219	-11.0238	274.1	28.72	5
nvsz-19a	New Britain–Vanuatu	162.7818	-10.5645	261.3	34.25	24.14
nvsz-19b	New Britain–Vanuatu	162.8392	-10.9315	261.3	22.51	5
nvsz-20a	New Britain–Vanuatu	163.7222	-10.5014	262.9	50.35	26.3
nvsz-20b	New Britain–Vanuatu	163.7581	-10.7858	262.9	25.22	5
nvsz-21a	New Britain–Vanuatu	164.9445	-10.4183	287.9	40.31	23.3
nvsz-21b	New Britain–Vanuatu	164.8374	-10.7442	287.9	21.47	5
nvsz-22a	New Britain–Vanuatu	166.0261	-11.1069	317.1	42.39	20.78
nvsz-22b	New Britain–Vanuatu	165.7783	-11.3328	317.1	18.4	5
nvsz-23a	New Britain–Vanuatu	166.5179	-12.2260	342.4	47.95	22.43
nvsz-23b	New Britain–Vanuatu	166.2244	-12.3171	342.4	20.4	5
nvsz-24a	New Britain–Vanuatu	166.7236	-13.1065	342.6	47.13	28.52
nvsz-24b	New Britain–Vanuatu	166.4241	-13.1979	342.6	28.06	5
nvsz-25a	New Britain–Vanuatu	166.8914	-14.0785	350.3	54.1	31.16
nvsz-25b	New Britain–Vanuatu	166.6237	-14.1230	350.3	31.55	5
nvsz-26a	New Britain–Vanuatu	166.9200	-15.1450	365.6	50.46	29.05
nvsz-26b	New Britain–Vanuatu	166.6252	-15.1170	365.6	28.75	5
nvsz-27a	New Britain–Vanuatu	167.0053	-15.6308	334.2	44.74	25.46

Continued on next page

Table B.8 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
nvsz-27b	New Britain–Vanuatu	166.7068	-15.7695	334.2	24.15	5
nvsz-28a	New Britain–Vanuatu	167.4074	-16.3455	327.5	41.53	22.44
nvsz-28b	New Britain–Vanuatu	167.1117	-16.5264	327.5	20.42	5
nvsz-29a	New Britain–Vanuatu	167.9145	-17.2807	341.2	49.1	24.12
nvsz-29b	New Britain–Vanuatu	167.6229	-17.3757	341.2	22.48	5
nvsz-30a	New Britain–Vanuatu	168.2220	-18.2353	348.6	44.19	23.99
nvsz-30b	New Britain–Vanuatu	167.8895	-18.2991	348.6	22.32	5
nvsz-31a	New Britain–Vanuatu	168.5022	-19.0510	345.6	42.2	22.26
nvsz-31b	New Britain–Vanuatu	168.1611	-19.1338	345.6	20.2	5
nvsz-32a	New Britain–Vanuatu	168.8775	-19.6724	331.1	42.03	21.68
nvsz-32b	New Britain–Vanuatu	168.5671	-19.8338	331.1	19.49	5
nvsz-33a	New Britain–Vanuatu	169.3422	-20.4892	332.9	40.25	22.4
nvsz-33b	New Britain–Vanuatu	169.0161	-20.6453	332.9	20.37	5
nvsz-34a	New Britain–Vanuatu	169.8304	-21.2121	329.1	39	22.73
nvsz-34b	New Britain–Vanuatu	169.5086	-21.3911	329.1	20.77	5
nvsz-35a	New Britain–Vanuatu	170.3119	-21.6945	311.9	39	22.13
nvsz-35b	New Britain–Vanuatu	170.0606	-21.9543	311.9	20.03	5
nvsz-36a	New Britain–Vanuatu	170.9487	-22.1585	300.4	39.42	23.5
nvsz-36b	New Britain–Vanuatu	170.7585	-22.4577	300.4	21.71	5
nvsz-37a	New Britain–Vanuatu	171.6335	-22.3087	281.3	30	22.1
nvsz-37b	New Britain–Vanuatu	171.5512	-22.6902	281.3	20	5

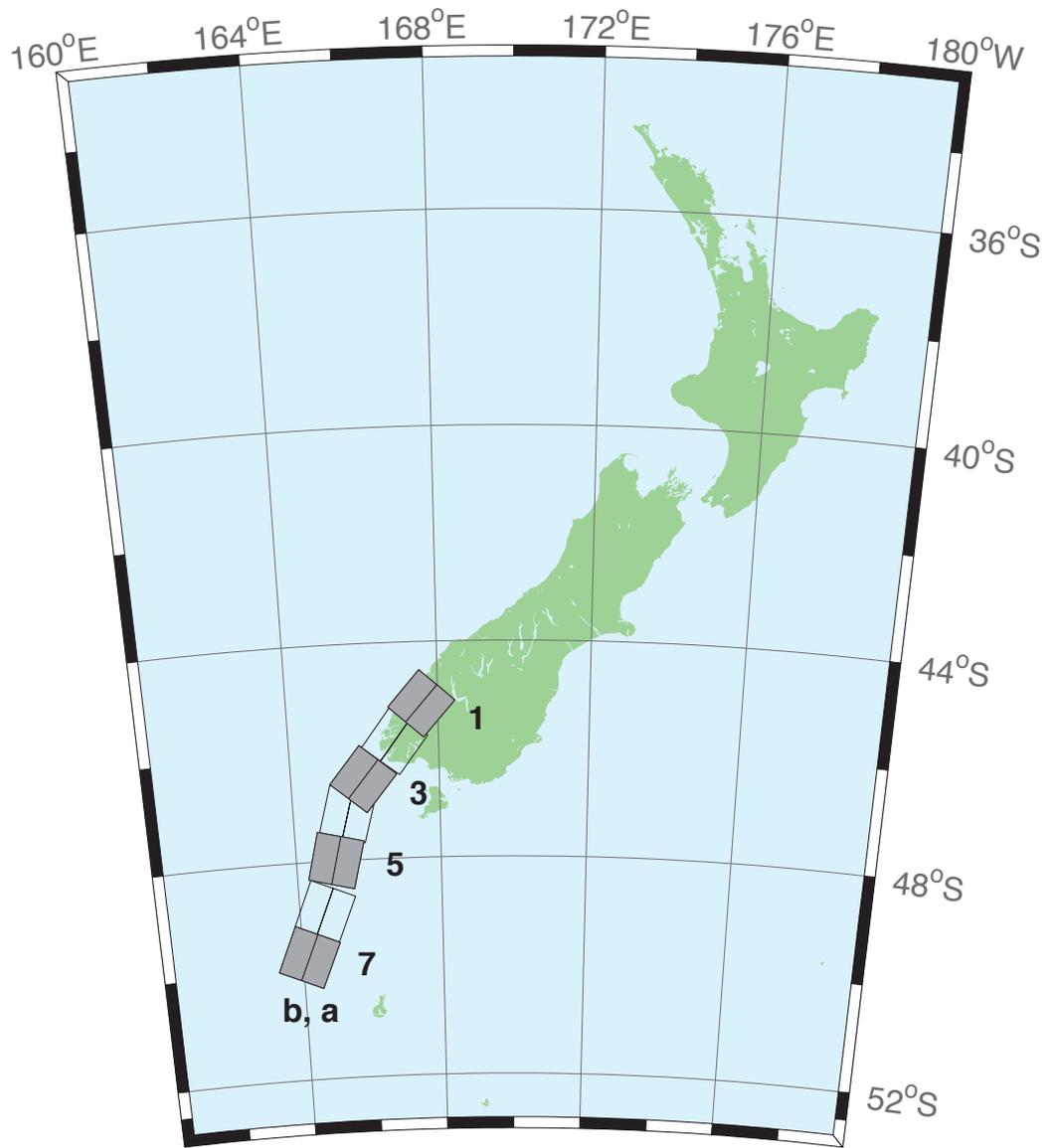


Figure B.9: New Zealand–Puysegur Zone unit sources.

Table B.9: Earthquake parameters for New Zealand–Puysegur Subduction Zone unit sources.

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
nzs-1a	New Zealand–Puysegur	168.0294	-45.4368	41.5	15	17.94
nzs-1b	New Zealand–Puysegur	167.5675	-45.1493	41.5	15	5
nzs-2a	New Zealand–Puysegur	167.3256	-46.0984	37.14	15	17.94
nzs-2b	New Zealand–Puysegur	166.8280	-45.8365	37.14	15	5
nzs-3a	New Zealand–Puysegur	166.4351	-46.7897	39.53	15	17.94
nzs-3b	New Zealand–Puysegur	165.9476	-46.5136	39.53	15	5
nzs-4a	New Zealand–Puysegur	166.0968	-47.2583	15.38	15	17.94
nzs-4b	New Zealand–Puysegur	165.4810	-47.1432	15.38	15	5
nzs-5a	New Zealand–Puysegur	165.7270	-48.0951	13.94	15	17.94
nzs-5b	New Zealand–Puysegur	165.0971	-47.9906	13.94	15	5
nzs-6a	New Zealand–Puysegur	165.3168	-49.0829	22.71	15	17.94
nzs-6b	New Zealand–Puysegur	164.7067	-48.9154	22.71	15	5
nzs-7a	New Zealand–Puysegur	164.8017	-49.9193	23.25	15	17.94
nzs-7b	New Zealand–Puysegur	164.1836	-49.7480	23.25	15	5

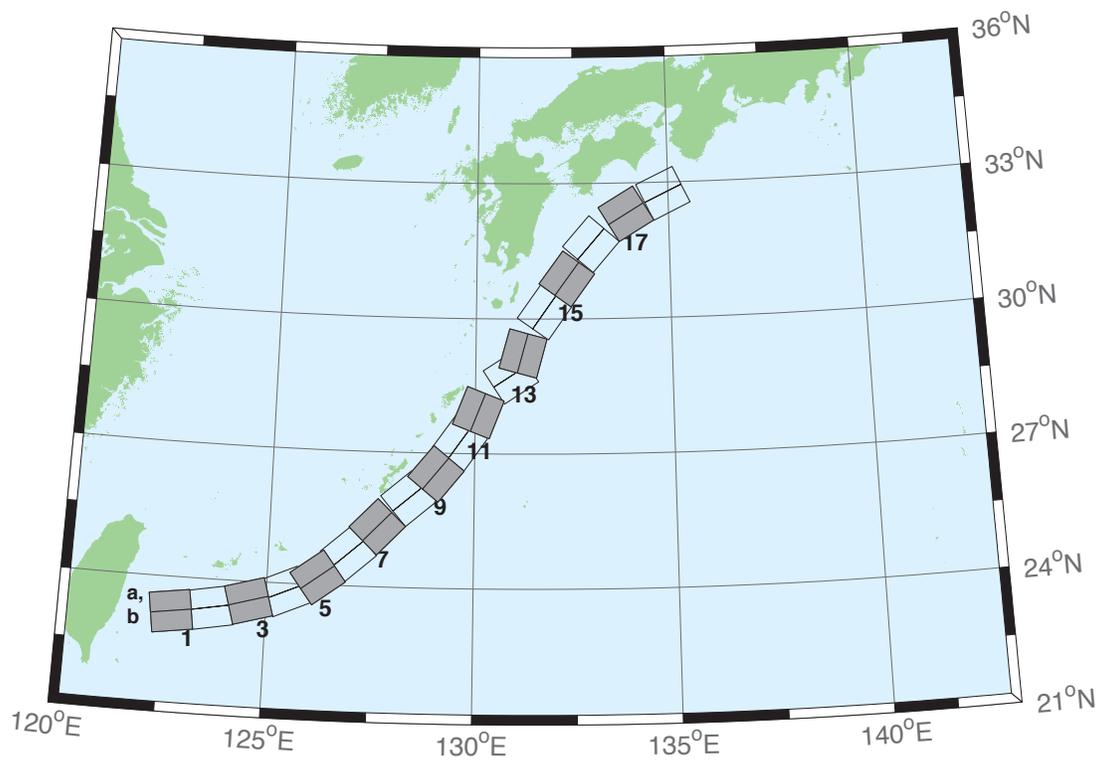


Figure B.10: Ryukyu-Kyushu-Nankai Zone unit sources.

Table B.10: Earthquake parameters for Ryukyu–Kyushu–Nankai Subduction
Zone unit sources.

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
rnsz-1a	Ryukyu–Nankai	122.6672	23.6696	262	14	11.88
rnsz-1b	Ryukyu–Nankai	122.7332	23.2380	262	10	3.2
rnsz-2a	Ryukyu–Nankai	123.5939	23.7929	259.9	18.11	12.28
rnsz-2b	Ryukyu–Nankai	123.6751	23.3725	259.9	10	3.6
rnsz-3a	Ryukyu–Nankai	124.4604	23.9777	254.6	19.27	14.65
rnsz-3b	Ryukyu–Nankai	124.5830	23.5689	254.6	12.18	4.1
rnsz-4a	Ryukyu–Nankai	125.2720	24.2102	246.8	18	20.38
rnsz-4b	Ryukyu–Nankai	125.4563	23.8177	246.8	16	6.6
rnsz-5a	Ryukyu–Nankai	125.9465	24.5085	233.6	18	20.21
rnsz-5b	Ryukyu–Nankai	126.2241	24.1645	233.6	16	6.43
rnsz-6a	Ryukyu–Nankai	126.6349	25.0402	228.7	17.16	19.55
rnsz-6b	Ryukyu–Nankai	126.9465	24.7176	228.7	15.16	6.47
rnsz-7a	Ryukyu–Nankai	127.2867	25.6343	224	15.85	17.98
rnsz-7b	Ryukyu–Nankai	127.6303	25.3339	224	13.56	6.26
rnsz-8a	Ryukyu–Nankai	128.0725	26.3146	229.7	14.55	14.31
rnsz-8b	Ryukyu–Nankai	128.3854	25.9831	229.7	9.64	5.94
rnsz-9a	Ryukyu–Nankai	128.6642	26.8177	219.2	15.4	12.62
rnsz-9b	Ryukyu–Nankai	129.0391	26.5438	219.2	8	5.66
rnsz-10a	Ryukyu–Nankai	129.2286	27.4879	215.2	17	12.55
rnsz-10b	Ryukyu–Nankai	129.6233	27.2402	215.2	8.16	5.45
rnsz-11a	Ryukyu–Nankai	129.6169	28.0741	201.3	17	12.91
rnsz-11b	Ryukyu–Nankai	130.0698	27.9181	201.3	8.8	5.26
rnsz-12a	Ryukyu–Nankai	130.6175	29.0900	236.7	16.42	13.05
rnsz-12b	Ryukyu–Nankai	130.8873	28.7299	236.7	9.57	4.74
rnsz-13a	Ryukyu–Nankai	130.7223	29.3465	195.2	20.25	15.89
rnsz-13b	Ryukyu–Nankai	131.1884	29.2362	195.2	12.98	4.66
rnsz-14a	Ryukyu–Nankai	131.3467	30.3899	215.1	22.16	19.73
rnsz-14b	Ryukyu–Nankai	131.7402	30.1507	215.1	17.48	4.71
rnsz-15a	Ryukyu–Nankai	131.9149	31.1450	216	15.11	16.12
rnsz-15b	Ryukyu–Nankai	132.3235	30.8899	216	13.46	4.48
rnsz-16a	Ryukyu–Nankai	132.5628	31.9468	220.9	10.81	10.88
rnsz-16b	Ryukyu–Nankai	132.9546	31.6579	220.9	7.19	4.62
rnsz-17a	Ryukyu–Nankai	133.6125	32.6956	239	10.14	12.01
rnsz-17b	Ryukyu–Nankai	133.8823	32.3168	239	8.41	4.7
rnsz-18a	Ryukyu–Nankai	134.6416	33.1488	244.7	10.99	14.21
rnsz-18b	Ryukyu–Nankai	134.8656	32.7502	244.5	10.97	4.7
rnsz-19a	Ryukyu–Nankai	135.6450	33.5008	246.5	14.49	14.72
rnsz-19b	Ryukyu–Nankai	135.8523	33.1021	246.5	11.87	4.44
rnsz-20a	Ryukyu–Nankai	136.5962	33.8506	244.8	15	14.38
rnsz-20b	Ryukyu–Nankai	136.8179	33.4581	244.8	12	3.98
rnsz-21a	Ryukyu–Nankai	137.2252	34.3094	231.9	15	15.4
rnsz-21b	Ryukyu–Nankai	137.5480	33.9680	231.9	12	5
rnsz-22a	Ryukyu–Nankai	137.4161	34.5249	192.3	15	15.4
rnsz-22b	Ryukyu–Nankai	137.9301	34.4327	192.3	12	5

Appendix C SIFT Testing Report

Elfin Cove, Alaska

Lindsey Wright
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1.0 PURPOSE

Forecast models are tested with synthetic tsunami events covering a range of tsunami source locations. Testing is also done with selected historical tsunami events when available.

The purpose of forecast model testing is three-fold. The first objective is to assure that the results obtained with NOAA's tsunami forecast system, which has been released to the Tsunami Warning Centers for operational use, are consistent with those obtained by the researcher during the development of the forecast model. The second objective is to test the forecast model for consistency, accuracy, time efficiency, and quality of results over a range of possible tsunami locations and magnitudes. The third objective is to identify bugs and issues in need of resolution by the researcher who developed the Forecast Model or by the forecast software development team before the next version release to NOAA's two Tsunami Warning Centers.

Local hardware and software applications, and tools familiar to the researcher(s), are used to run the Method of Splitting Tsunamis (MOST) model during the forecast model development. The test results presented in this report lend confidence that the model performs as developed and produces the same results when initiated within the forecast application in an operational setting as those produced by the researcher during the forecast model development. The test results assure those who rely on the Elfin Cove tsunami forecast model that consistent results are produced irrespective of system.

2.0 TESTING PROCEDURE

The general procedure for forecast model testing is to run a set of synthetic tsunami scenarios and a selected set of historical tsunami events through the forecast system application and compare the results with those obtained by the researcher during the forecast model development and presented in the Tsunami Forecast Model Report. Specific steps taken to test the model include:

1. Identification of testing scenarios, including the standard set of synthetic events, appropriate historical events, and customized synthetic scenarios that may have been used by the researcher(s) in developing the forecast model.
2. Creation of new events to represent customized synthetic scenarios used by the researcher(s) in developing the forecast model, if any.
3. Submission of test model runs with the forecast system, and export of the results from A, B, and C grids, along with time series.
4. Recording applicable metadata, including the specific version of the forecast system used for testing.
5. Examination of forecast model results from the forecast system for instabilities in both time series and plot results.
6. Comparison of forecast model results obtained through the forecast system with those obtained during the forecast model development.
7. Summarization of results with specific mention of quality, consistency, and time efficiency.
8. Reporting of issues identified to modeler and forecast software development team.
9. Retesting the forecast models in the forecast system when reported issues have been addressed or explained.

Synthetic model runs were tested on a DELL PowerEdge R510 computer equipped with two Xeon E5670 processors at 2.93 Ghz, each with 12 MBytes of cache and 32GB memory. The processors are hex core and support hyperthreading, resulting in the computer performing as a 24 processor core machine. Additionally, the testing computer supports 10 Gigabit Ethernet for fast network connections. This computer configuration is similar or the same as the configurations of the computers installed at the Tsunami Warning Centers so the compute times should only vary slightly.

Results

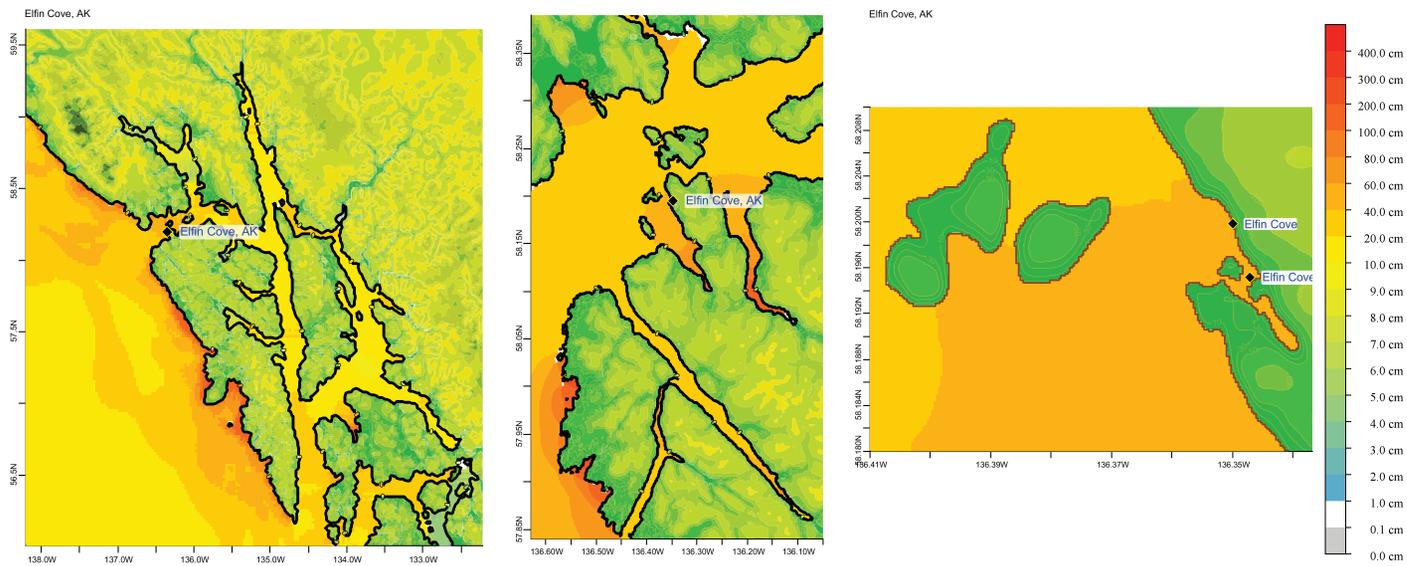
The Elfin Cove forecast model was tested with NOAA's tsunami forecast system version 3.2. The propagation database used during development was dated in 2012.

The Elfin Cove forecast model was tested with four synthetic scenarios and one historical tsunami event. Test results from the forecast system and comparisons with the results obtained during the forecast model development are shown numerically in Table C1 and graphically in Figures C1 to C5. The results show that the forecast model is stable and robust, with consistent and high quality results across geographically distributed tsunami sources and mega-event tsunami magnitudes. The model run time (wall clock time) was under 25.88 minutes for 8 hours of simulation time, and 12.92 minutes for 4 hours. This run time is not within the 10 minute run time for 4 hours of simulation time and does not satisfy time efficiency requirements.

Four synthetic events were run on the Elfin Cove forecast model. The modeled scenarios were stable for all cases tested, with no instabilities or ringing. Results show that the largest modeled height was 60 centimeters (cm) and originated in the Aleutian-Alaska-Cascadia (ACSZ 56-65) source. Amplitudes less than 75 cm were recorded for all of the test sources. The smallest signal of 23 cm was recorded at the far field Central and South America (CSSZ 89-98) source. Direct comparisons of output from the forecast tool with results of both the Tohoku 2011 historical event and available development synthetic events, demonstrated that the wave patterns were similar in shape, pattern and amplitude.

Table C1. Table of maximum and minimum amplitudes (cm) at the Elfin Cove, Alaska warning point for synthetic and historical events tested using SIFT 3.2 and obtained during development.

Scenario Name	Source Zone	Tsunami Source	α [m]	SIFT Max (cm)	Development Max (cm)	SIFT Min (cm)	Development Min (cm)
Mega-tsunami Scenarios							
KISZ 22-31	Kamchatka-Yap-Mariana-Izu-Bonin	A22-A31, B22-B31	25	42.9	42.90	-35.1	-34.99
ACSZ 56-65	Aleutian-Alaska-Cascadia	A56-A65, B56-B65	25	59.9	59.60	-70.3	-70.41
CSSZ 89-98	Central and South America	A89-A98, B89-B98	25	22.9	22.90	-32.9	-32.9
NTSZ 30-39	New Zealand-Kermadec-Tonga	A30-A39, B30-B39	25	38.2	38.15	-29.5	-29.55
Historical Events							
Tohoku 2011	Kamchatka-Yap-Mariana-Izu-Bonin	4.66 b24 + 12.23 b25+26.31 a26+21.27 b26+22.75 a27 +4.98 b27		13.9	13.89	-13.6	-13.59



◆ max @ 14:36 = 42.9 (cm) ◆ min @ 10:18 = -35.1 (cm)

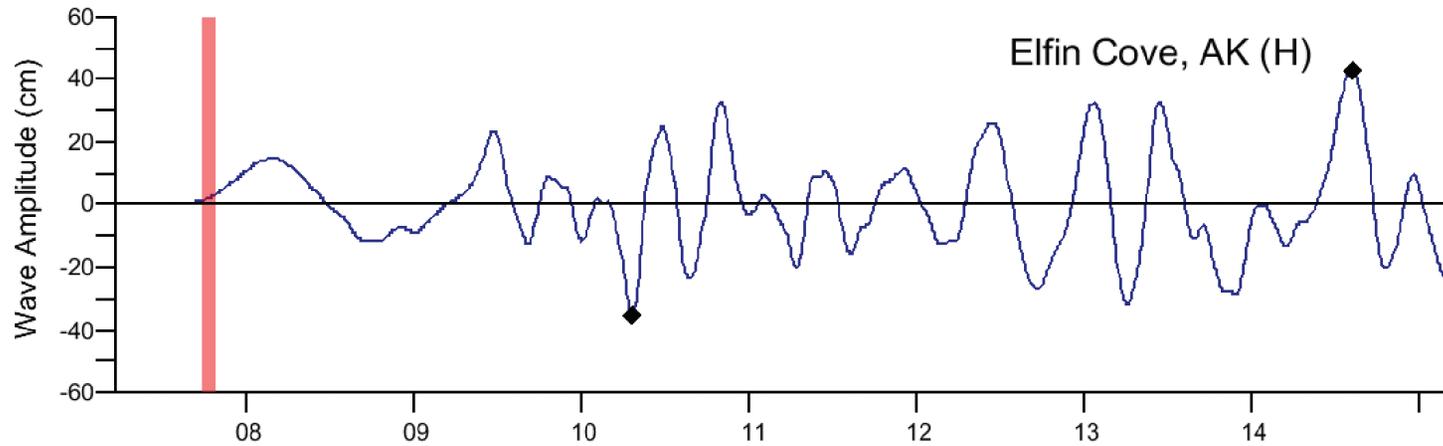


Figure C1: Response of the Elfin Cove forecast model to synthetic scenario KISZ 22-31 ($\alpha=25$). Maximum sea surface elevation for (a) A-grid, b) B-grid, c) C-grid. Sea surface elevation time series at the C-grid warning point (d).

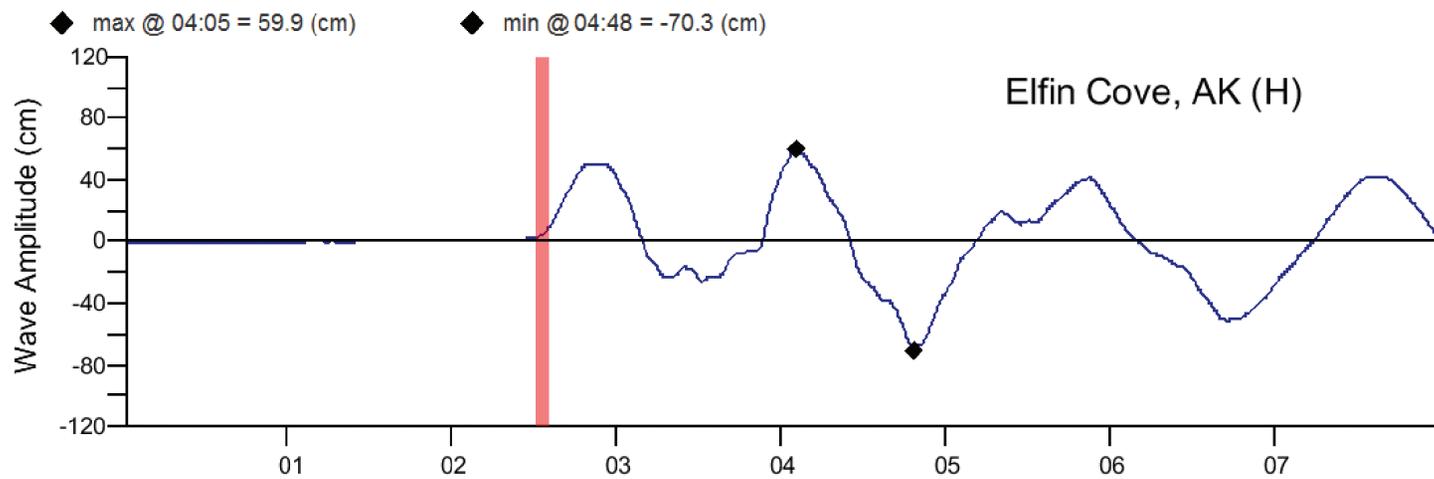
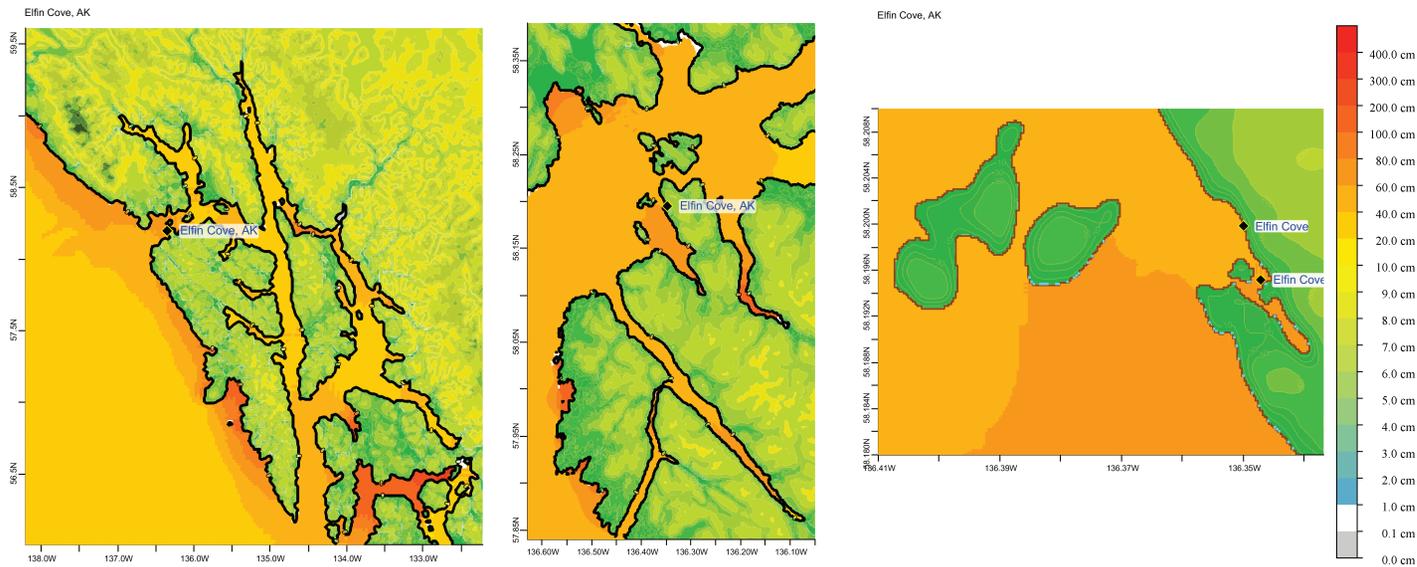
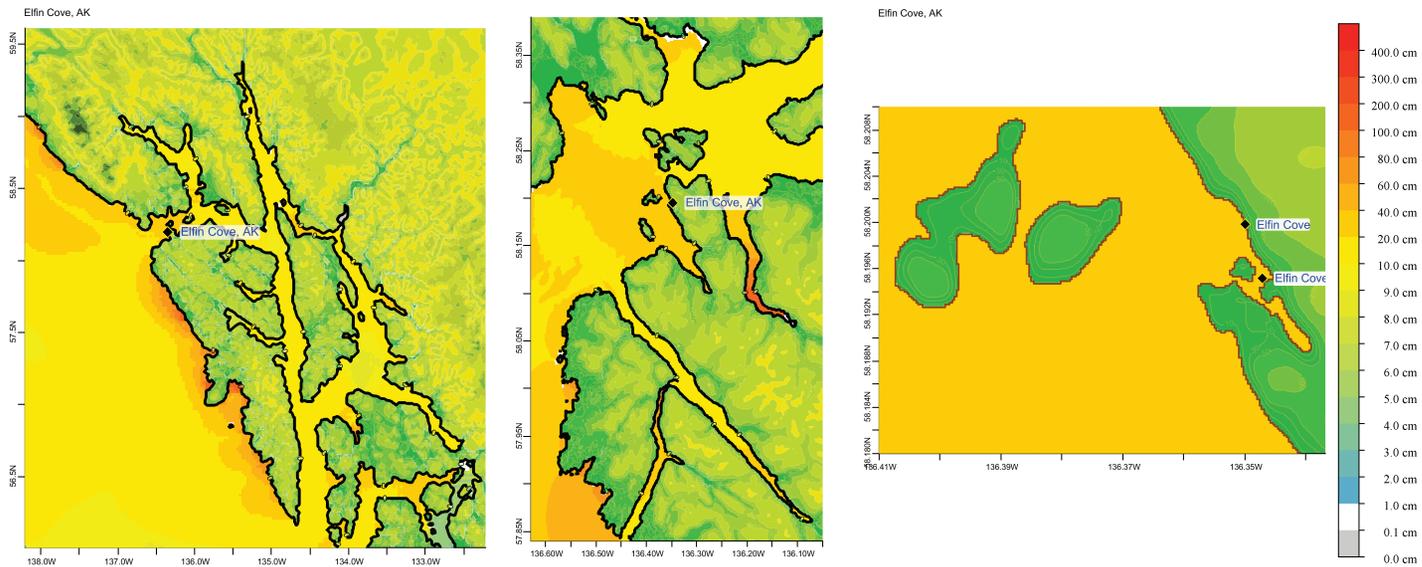


Figure C2: Response of the Elfin Cove forecast model to synthetic scenario ACSZ 56-65 (alpha=25). Maximum sea surface elevation for (a) A-grid, b) B-grid, c) C-grid. Sea surface elevation time series at the C-grid warning point (d).).



◆ max @ 00:00 = 22.9 (cm)

◆ min @ 00:15 = -32.9 (cm)

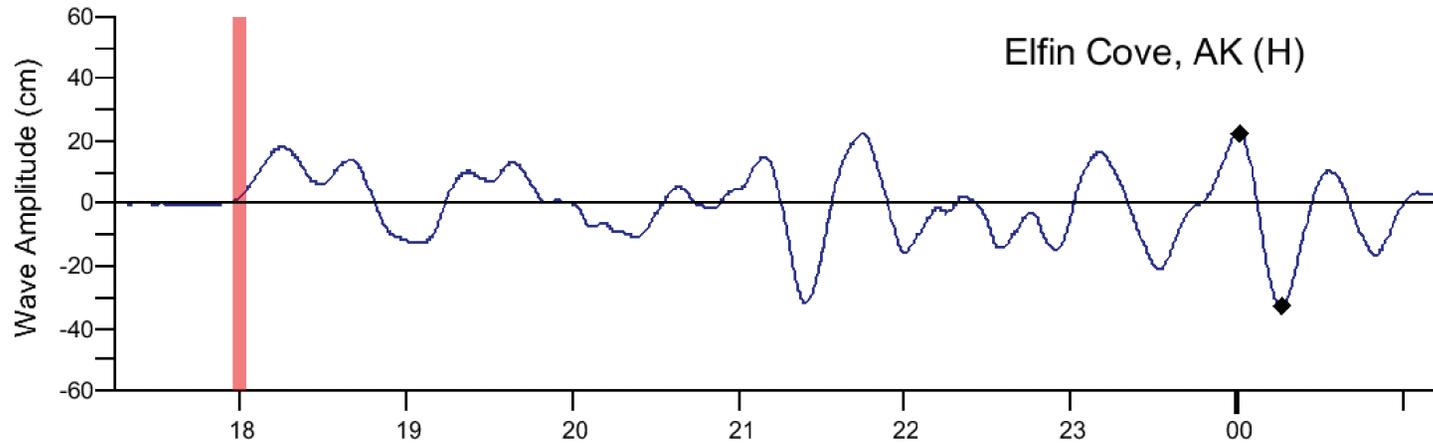
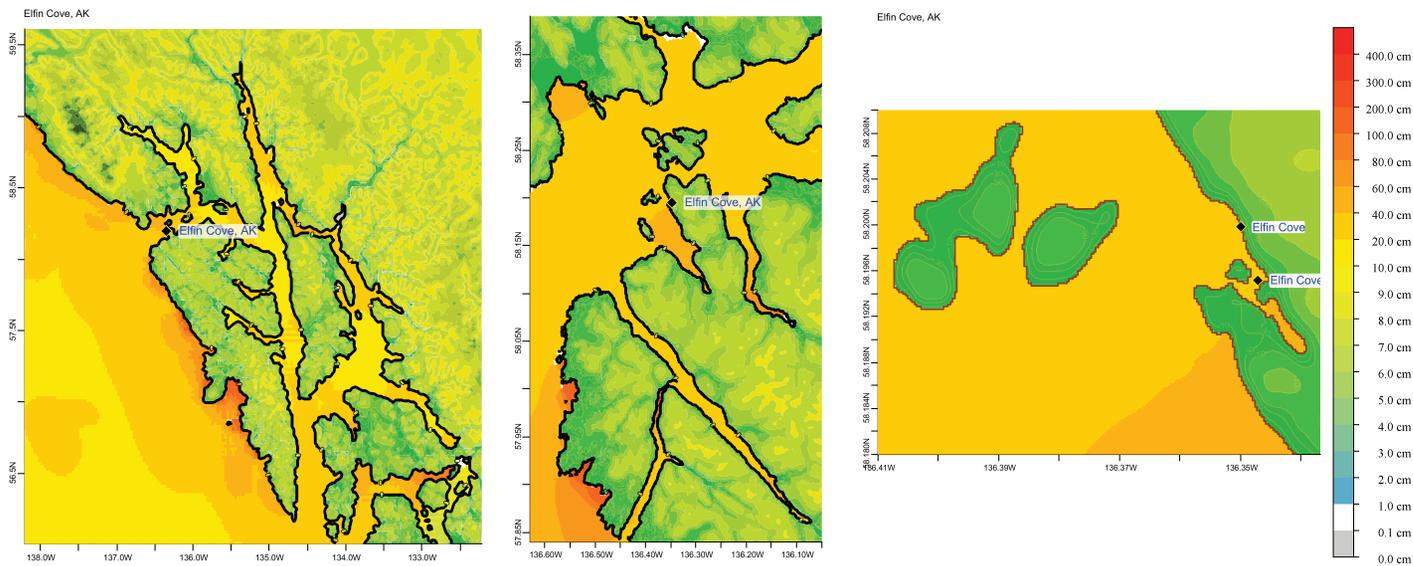


Figure C3: Response of the Elfin Cove forecast model to synthetic scenario CSSZ 89-98 ($\alpha=25$). Maximum sea surface elevation for (a) A-grid, b) B-grid, c) C-grid. Sea surface elevation time series at the C-grid warning point (d).



◆ max @ 12:03 = 38.2 (cm)

◆ min @ 17:29 = -29.5 (cm)

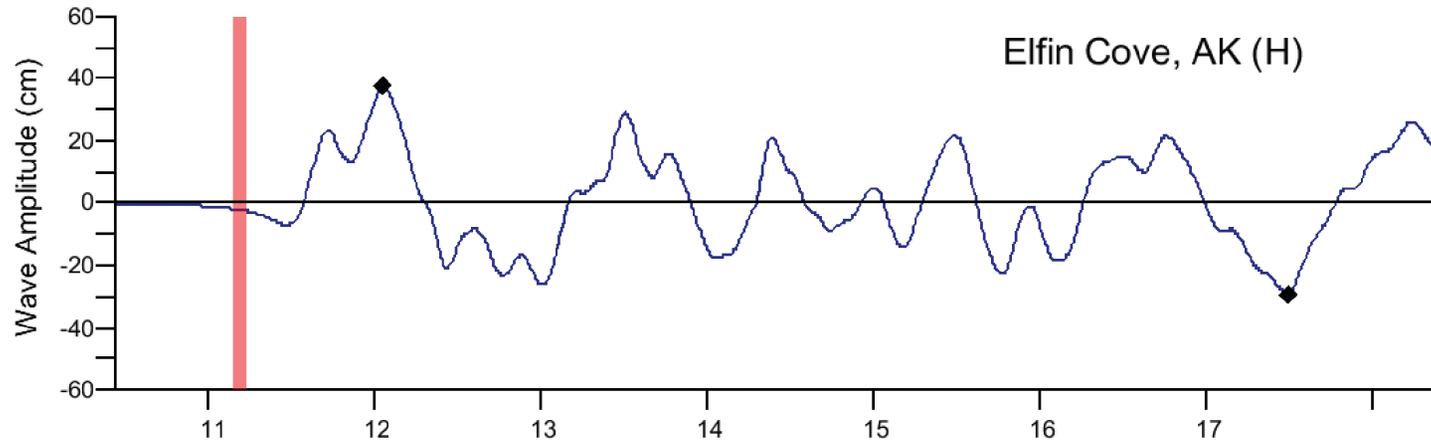


Figure C4: Response of the Elfin Cove forecast model to synthetic scenario NTSZ 30-39 ($\alpha=25$). Maximum sea surface elevation for (a) A-grid, b) B-grid, c) C-grid. Sea surface elevation time series at the C-grid warning point (d).

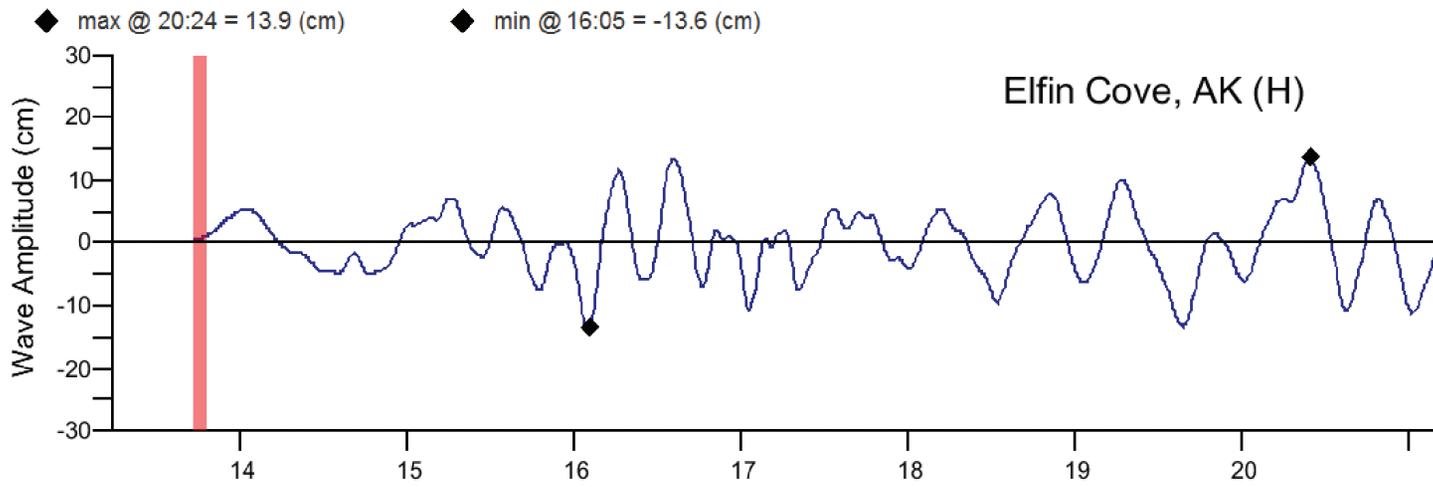
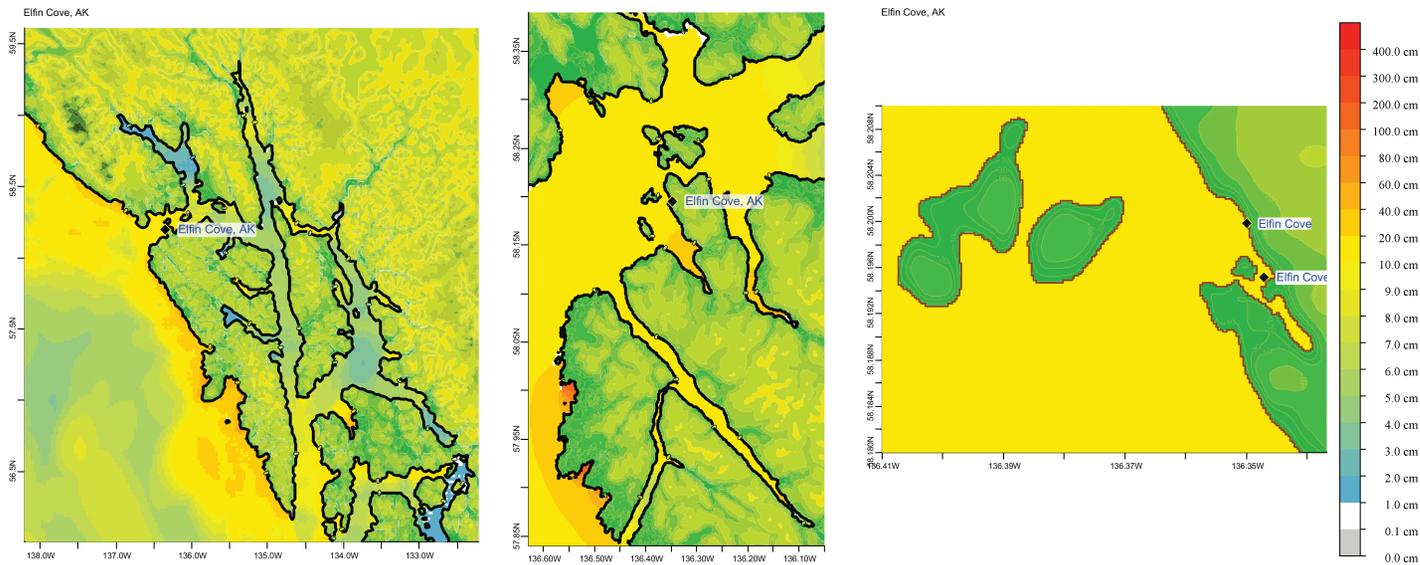


Figure C5: Response of the Elfin Cove forecast model to the 2011 Tohoku tsunami. Maximum sea surface elevation for (a) A-grid, b) B-grid, c) C-grid. Sea surface elevation time series at the C-grid warning point (d).