




# The Impact of Post-tsunami Surveys on the NCEI/WDS Global Historical Tsunami Database

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**Abstract**—Since the late nineteenth century, post-tsunami survey teams have been collecting water height data (e.g. maximum inundation, runup, flow depth) as well as other types of data, including geologic and socio-economic effects. The NOAA National Centers for Environmental Information (NCEI) and co-located World Data Service (WDS) for Geophysics provide data management and access to global tsunami data. NCEI's Global Historical Tsunami Database includes information on over 2200 tsunami sources and over 26,000 runup points. The tsunami database has adapted to capture the advancements of post-tsunami survey data collection and distribution methods. The first International Tsunami Survey Team (ITST), which surveyed the impacts of the 02 September 1992 Nicaragua tsunami, spurred the formalization of standards and guidance for post-tsunami surveys. The post-tsunami survey data analyzed are a significant contribution, in quality and quantity, to the runup database. The 26 December 2004 Indonesia and 11 March 2011 Japan events alone account for over 25% of the total number of runup points in the database. Further, the analysis indicates that post-tsunami survey data capture a more complete representation of the tsunami that is being documented, not just the highest runup measurements. This range in post-tsunami survey runup heights for events, in the NCEI/WDS tsunami database, provides a more reliable historical tsunami dataset to test tsunami models against. This study also provides readers an understanding of the evolution of the tsunami database, particularly regarding the ongoing need to adapt to emerging scientific advances and standards.

**Key words:** Tsunami, database, survey, flow depth, runup, wave height, catalog.

## 1. Introduction

On 02 September 1992 (UTC) a deadly tsunami struck the Pacific coast of Nicaragua. Soon after, the first International Tsunami Survey Team (ITST) was formed to survey the affected area (Satake et al. 1993). Although this was the first recognized ITST, post-tsunami field surveys had taken place following the 1946 Aleutian Islands, 1964 Southern Alaska, 1983 Sea of Japan and 1985 Michoacán tsunami events, and many others. However, ITSTs are unique because of their international and interdisciplinary collaboration, as well as the standardization of survey methodology. Due in part to recognition of ITSTs, post-tsunami survey guidance and methodology has been adjusted and expanded over time (Kong 2011). Since their inception, ITSTs have emphasized standardized measurements in maximum runup, maximum water level and inundation extent (Synolakis and Okal 2005; Fig. 1). As a result, the general principles in standardization have allowed these measurements to be compared across continents, events and time. ITSTs have thus far documented a total of 33 tsunami events in the Pacific and Indian oceans and the Caribbean and Mediterranean seas (IOC 2014).

The NOAA National Centers for Environmental Information (NCEI, formerly National Geophysical Data Center) and co-located World Data Service for Geophysics (WDS) global tsunami archive (<https://ngdc.noaa.gov/hazard/tsu.shtml>) consists of the historical tsunami database, imagery, and raw and processed coastal tide gauge and DART ocean bottom pressure data. The NCEI/WDS historical tsunami database includes two related tables: global observations of tsunami sources and tsunami runup records (locations where tsunami waves were observed by eyewitnesses, field reconnaissance surveys, tide

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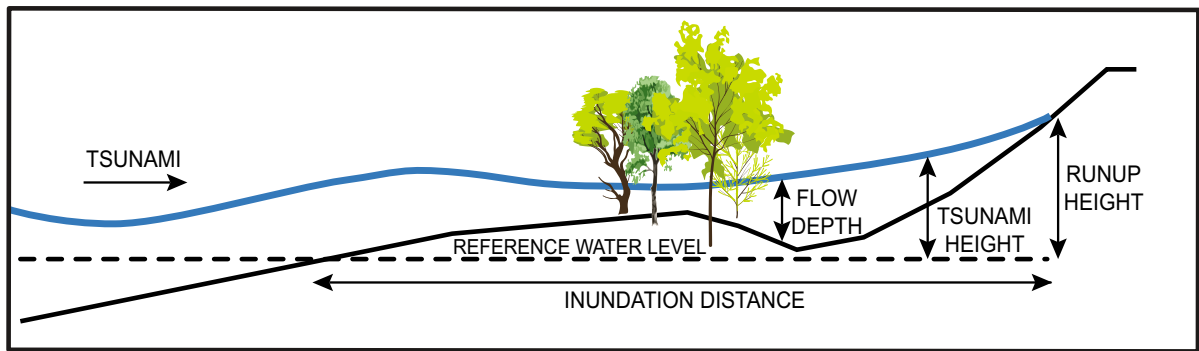


Figure 1  
Tsunami hydrodynamic data terminology (NCEI/WDS)

gauges or deep-ocean sensors). The historical tsunami database incorporates, where available, maximum wave heights or runup data as well as inundation for each coastal location. The NCEI/WDS historical tsunami database has captured post-tsunami field surveys, pre- and post-1992, to enable user communities to access the information in a standardized format.

This study's intent is to assess the impact of post-tsunami surveys on the NCEI/WDS tsunami database with a focus on the pre- and ITST era. The post-tsunami survey data presented are not only a considerable contribution to the runup database, but also add information in locations where permanent data recorders (i.e. tide gauges) are not present. Simply put, post-tsunami surveys collect data in a wide variety of locations and environments to paint a more complete picture of the variation in runup and inundation along the coastline in a tsunami event. In addition, this study documents changes to the NCEI/WDS tsunami database classification of survey information through the same time period.

## 2. Early Post-tsunami Surveys

Arriving to impacted areas soon after a disaster, in this case a tsunami, is critical because as Quartenelli (1997) discusses, over time the collection of perishable data can be limited due to restricted access and limited cooperation among officials and victims. Furthermore, eyewitness accounts are not as reliable

as time passes (Stallings 2007) and evidence of tsunami wave impact may grow faint with time, or is simply removed during post-disaster clean-up or reconstruction efforts. For this reason, post-disaster surveys have been an essential part of scientific data collection.

Tsunami survey teams have been collecting data since the late 1800s (Bourgeois 2009). Surveys are characterized by the systematic measurement and reporting of wave heights. For example, the 15 June 1896 Sanriku earthquake and tsunami resulted in approximately 27,000 deaths and was followed by two of the first post-tsunami surveys, one beginning 20 June and the other 28 July (Tsuji et al. 2014). The NCEI tsunami database contains 72 runup points for the tsunami, but none are currently classified as originating from a post-tsunami survey due to a lack of understanding of the methodology of the data collection at the time of entry into the database. Both post-tsunami surveys describe tsunami heights and socio-economic impacts (i.e. death, property damages) at surveyed locations. The changes in vegetation color, watermarks, debris lines and eyewitness accounts were utilized to measure tsunami heights much like a modern post-tsunami survey. Another early example, the 28 December 1908 Messina Straits tsunami survey included wave heights determined from tsunami traces and eyewitness testimonies. In his post-tsunami survey of the 1908 tsunami, Platania (1909) describes his post-event survey methodology which also includes socio-economic data, one of the first to do so.

Technological improvements have clearly improved aspects of surveys' precision. For the 1896 surveys, illustrative maps were used to convey location (Tsuji et al. 2014) not coordinates. Platania's survey used telescoping levels to determine heights (Platania 1909). The wide-spread use of GPS units and laser range finders in the ITST era have greatly increased the precision and volume of data collected. However, the underlying principles of what to measure (e.g. tsunami height traces, socio-economic data) in the early surveys were not considerably different from modern surveys.

### 3. Historical Tsunami Measurements

As post-tsunami surveys continued to take place in the early and mid-twentieth century, coordination of measurement standards among the scientific community was limited. Eaton et al. (1961) acknowledged a lack of clear guidance or standards in surveying techniques while reporting wave heights on the island of Hawaii following the deadly 22 May 1960 tsunami. Kajiura (1981) stated the challenges in the differing criteria for wave height measurements, noting the variation in datasets taken by different survey teams in the same area for the same tsunami. For instance, before terminology was standardized the phrase tsunami wave height used in pre-ITSTs surveys (e.g., Platania, 1909; Eaton et al. 1961; Tsuji et al. 2014) could refer to either height above sea-level or runup height (Fig. 1). In addition, the reference datum for tsunami wave heights varied. Tsuji et al. (2014) notes that the runup data from the 1896 survey were based on sea-level at the time of measurement. Yet, the Eaton et al. (1961) survey was based on the height above sea-level at the time of measurement, but later adjusted to mean lower low water. The confusion in terminology and the inconsistent reporting methodology could result in data providers and users misinterpreting the wave heights by many meters. This confusion is largely avoided in modern post-1992 surveys, due in large part to the guidance provided to ITSTs to correct water-level data for tidal conditions at the time of the tsunami (IOC 2014).

Runup is currently defined as the height of the land at the tsunami's farthest extent inland (inundation). Although instrumental observations from tide gauges (and DARTs) do not measure a runup on land, measurements from these instruments are listed as runup data in the tsunami database; thereby, enabling database users to more easily view and search across all tsunami wave data types. As such, all instrumental observations are listed as runup data in the database with a separate field to indicate the type of measurement (e.g. tide gauge, DART).

The NCEI/WDS historical tsunami database has endeavored to consistently utilize the terms defined in the Report of the International Measurements Workshop (Lander and Yeh 1995). However, the lack of clarity of datum utilized as well as the influence of tectonic uplift or subsidence are not always known from source documents. Dunbar et al. (2008) explain that despite a detailed data and literature review, the data manager may not be able to determine the survey methodology or datum utilized. However, Lander and Yeh (1995) and the subsequent Post-tsunami Survey Field Guide (IOC 1998) provided clarity, guidance and standardization to the post-tsunami survey community, thereby, creating more consistent datasets from that point going forward.

### 4. Guides and ITSTs

Collecting tsunami wave height or runup data throughout affected coastlines is critical to understanding the impact and cause of that particular event. Moreover, these records help contribute to a database that tsunami models can be reliably tested against. Although technological advances have been made, field work shortly after a hazardous event is still the most common and successful method of data collection (Tierney 2002). Thus, the establishment and updating of the Post-tsunami Survey Field Guide (IOC 1998) continues to be a critical aspect of establishing dependable databases for tsunami modeling and forecasting.

Efforts to standardize tsunami survey measurements began in the early 1980s (IOC 1998) but it was not until the early 1990s that the process began to be formalized by an internationally recognized body,

what is now known as UNESCO's Intergovernmental Oceanographic Commission (IOC). The International Tsunami Information Center (ITIC) led the development of the 1998 Post-tsunami Field Guide (IOC 1998) that encouraged the minimum requirement of measuring runup height, water height and inundation extent, although it was the 1995 International Tsunami Measurements Workshop that initially determined the definitions and requirements of the aforementioned terms (Lander and Yeh 1995). The first ITST in Nicaragua was the basis for much of the guidance established at the 1995 workshop (Arcos et al. 2017). The workshop settled on the following definitions which were utilized by the 1998 field guide and persist with minimal modifications:

- Maximum runup is the difference between the elevation of maximum tsunami penetration and the elevation of the shoreline at the time of tsunami attack
- Maximum water level is the difference between the elevation of the highest local water mark and the elevation of the shoreline at the time of tsunami attack

Other data types highlighted for collection in the 1998 Guide included socio-economic impacts (damages, casualties, etc.) and geological effects. The tsunami database maintains socio-economic impacts with the following fields: deaths, missing, injuries, damages (in USD), and houses destroyed and damaged. A global standard is not applied across countries for reporting economic damages, as a result it is difficult to compare reported economic losses across time and places. However, the damages field provides users a broad understanding of damages sustained, particularly when the only damages reported are not captured by another existing field (e.g. houses destroyed, deaths, etc.). Information on the geological effects of tsunamis, such as erosion and sedimentation, have been documented in modern field surveys including prior to the 1998 field guide (Bourgeois 2009). Geological effects are documented in the historical tsunami database as well as in the NCEI/WDS Global Tsunami Deposits Database (Dunbar and McCullough 2012).

Following the ITST for the 29 September 2009 Samoa Islands tsunami, guidance and protocols were

updated to provide more focus on improved coordination and data sharing (Kong 2011). This aimed to create better distribution of and access to data collected from post-tsunami surveys and gave guidance for combining all event data into a joint report. In 2014, the Post-tsunami Field Guide was updated to encourage the expansion of data collected on field surveys (IOC 2014). The most significant modification to the original 1998 document was the emphasis on measuring flow depth. Historically, flow depths had been measured on field surveys but perhaps not as extensively as following the 2004 Indian Ocean event (e.g. Borrero 2005b; Fritz et al. 2006b; Fritz and Borrero 2006). The increased frequency in flow depth measurements, in combination with the updated field guide, resulted in the addition of a flow depth classification in the NCEI/WDS historical tsunami database in 2010.

While many ITSTs did not have a direct impact on the tsunami database structure, they are worth highlighting for their unique scientific and data contributions. For instance, the 1992 Nicaragua post-tsunami survey recorded distinctive characteristics of "tsunami earthquakes" as eyewitnesses described the weak or soft shaking before the tsunami arrival (Kanamori 1972; Satake et al. 1993). The ITST for the 1993 tsunami in the Sea of Japan measured a 32-m maximum runup that is not consistent with the tsunami's other runup values. A steep valley location was the reason for this outlier runup value; thereby, emphasizing the need of high-resolution topography to determine runup potential (Shuto and Matsutomi 1995). Also, the first image of a leading depression of a tsunami at a local beach was collected by Borrero et al. (1997) during the ITST for the 1995 Manzanillo Mexico tsunami (Synolakis and Okal 2005). Following the 1998 Papua New Guinea tsunami, five marine expeditions took place to survey the offshore area off of the impacted coastline. This was the first large-scale international marine surveying effort to take place so soon after a tsunami (Kawata et al. 1999; Synolakis et al. 2002; Tappin et al. 2008). The marine investigations elucidated the presence of a landslide as the tsunami source as well as facilitated tsunami modeling efforts (Sweet and Silver 2003).

The ITSTs for the 2004 Indian Ocean tsunami had countless pioneering efforts, including the first

analyses of post-tsunami satellite imagery enabling assessments of tsunami impacts (Borrero 2005a; Ramakrishnan et al. 2005). Clearly, ITSTs have contributed data to the tsunami database that are collected in a systematic and consistent manner, though more importantly new data types and data analyses captured in the NCEI/WDS historical tsunami database have preserved and furthered scientific advances.

As scientists develop new techniques to take advantage of emerging technologies, new data types and formats will emerge thus presenting challenges to data providers and managers. For instance, Fritz et al. (2006a) developed a procedure to analyze and determine tsunami flow velocity from amateur video of the 2004 Indian Ocean tsunami. The procedure, based on particle image velocimetry, took an evolutionary step as ground-based LiDAR measurements were incorporated to calibrate video of the 2011 Japan tsunami to determine tsunami flow velocities at Kesennuma Bay, Japan (Fritz et al. 2012). Most recently, Kalligeris et al. (2016) positioned GPS drifters and a camera to capture the arrival of the 16 September 2015 Chile tsunami at Ventura, CA. The data (i.e. flow velocity, current behavior) are important for developing guidance on engineering of structures (including vertical evacuation structures), maritime guidance, and evacuation planning. Consequently, it is critical for the scientific community to reach a consensus on guidance for collecting and distributing data based on video footage, particularly in an era where an increasing amount of amateur footage is available. NCEI/WDS and other data providers must then work with scientific community to determine the best manner for long-term archiving and access to the data for users attempting to validate inundation models or develop engineering guidance.

Following a tsunami when new research or anomalies are discovered, excerpts from published papers are often added to the “Comments” field of the particular tsunami event record. The related reference is also listed with the event. The comments field provides a more complete picture of the data and information from the tsunami and can be used to populate new data fields as they are added.

#### *4.1. Challenges with Pre-ITST Surveys in the Database*

Through the existence of the NCEI/WDS historical tsunami database, information fields have been added and definitions of fields modified to reflect the type of data being collected and scientific consensus on the definition of terms. Originally, the database had classified all wave observations as “runups”, with no clear distinction among the types and quality of the observations. A significant effort was made to distinguish between instrumental (i.e. tide gauges) and non-instrumental (i.e. eyewitness, survey), as well as tsunami waves versus standing waves. The non-instrumental runup data were all assumed to be runup heights, including eyewitness measurements.

After the new post-tsunami survey classifications were added (e.g., flow depth, water height, runup height) the data points classified under runup height in the pre-ITST surveys were moved to the classification of eyewitness account. Consequently, the majority of pre-ITST observations derived from post-tsunami surveys prior to 1992 and added to the database before new classifications were added, are currently classified as “eyewitness measurements” due to lack of resources to revise the database and research whether the source was indeed an eyewitness or a post-tsunami survey. Efforts have been, and continue to be, made to review and correct pre-ITST event runup points to be labeled as post-tsunami survey measurements. This paper focuses on the 8 pre-ITST events with surveys contributing more than five runup points in the database, thereby excluding small survey efforts or events where the database may not be fully corrected. Currently, approximately 1100 runup points from 8 pre-ITST tsunamis have been assigned the classification of post-tsunami survey runup points.

The process of classifying pre-ITST data points as survey data is complicated by under reporting of methods and references. Early sources of tsunami data, such as scientific catalogues and technical reports, did not always provide details regarding their primary sources of data. Soloviev and Go (1974, 1975) are considered authoritative sources of tsunami information for the timespan in the Western and Eastern Pacific regions, respectively. However,



Soloviev and Go (1974) did not always differentiate between an eyewitness account and a post-tsunami survey. Thus, most non-instrumental observations are listed as eyewitness observations in the tsunami database. However, upon closer inspection, research may reveal that some of their listed observations did indeed originate from post-tsunami surveys. Although Soloviev and Go (1974) provide a list of references for each event summary, sources for each individual observation are not readily identifiable. Another consideration is that governments and political situations can delay or prevent the timely reporting of tsunami event data. For example, the USSR restricted the dissemination of data related to the damaging 1952 tsunami. Within the USSR the event did not show up in reports until after 1956 and was not widely released until the 1990s (Savarenskiy et al. 1958; Kaistrenko and Sedaeva 2001).

One example of the challenge of classifying data listed in Soloviev and Go (1974) is the 01 September 1923 earthquake and tsunami event. This event is the deadliest natural disaster in Japanese history, claiming over 140,000 lives primarily due to the ground shaking and subsequent fires. The largest tsunami wave was 13 m at Oshima Island with a total of 140 runup points recorded in the tsunami database. A total of 105 runup points are attributed to Soloviev and Go (1974) but a review of documents cited demonstrates that a post-event survey was conducted. Imamura (1924) discusses that the wave heights provided were collected by colleagues. Suda (1924) also confirms that at least some heights collected at Jogashima were based on traces left by the tsunami. Thus, confirming that at least some of the observations attributed to Soloviev and Go (1974) were not eyewitness accounts, as flagged in the tsunami database. The critical work of ensuring runup data exist in the database has been largely the focus of the quality control database effort, however, work remains to correct and/or refine the classification of the runup data.

### 5. Pre-ITST Surveys in the Database

The 1896 tsunami survey is among the earliest known post-tsunami surveys; however, this is not one

of the eight pre-ITST events that has been corrected to reflect post-tsunami survey measurements. Thus, to compare the pre-ITST and post-1992 post-tsunami survey data, this analysis will be limited to tsunamis beginning in 1900. As of April 2019, only eight pre-ITST events have been revised to correct eyewitness runup points to post-tsunami survey runup points.

Of the 8 pre-ITST events analyzed, the 27 November 1945, 01 April 1946, and 09 July 1956 tsunami events include a significant number of runup points, 9 (out of 9), 89 (out of 416) and 68 (out of 68) respectively, collected decades after the events in the post-1992 era. For the three events, much of the post-tsunami survey runup data collected decades later were based on eyewitness testimonies with runup measurements taken using the post-1992 surveying methods (Okal et al. 2002b, 2009, 2015; Okal and Hébert 2007). Okal et al. (2003) did have some ability to map 1946 tsunami traces as they surveyed some areas that are unpopulated thus more able to preserve such markers. Additionally, the manner of reporting, as is common in modern surveys, is a table format that normally includes location name, coordinates (latitude, longitude), maximum wave height, and measurement type. The surveyors clearly and thoughtfully filtered out any testimonies that may be questionable, ensuring the runup data were accurate; thereby, the runup data are classified as post-tsunami survey runup points in the tsunami database.

The main difference between the tsunami survey methodology used for the post-1992 surveys of the 1945, 1946, and 1956 events and that of other post-1992 surveys conducted soon after the event, is the limited amount of perishable tsunami traces (e.g. water marks, flow direction indicators, wrack/debris lines). This methodology has allowed scientists to collect additional data for historical but underdocumented tsunami events and therefore the tsunami database continues to preserve eyewitness testimonies. In this paper's analysis, the 1945, 1946, and 1956 runup data collected post-1992 are grouped with pre-ITST events due to a combination of (1) the timing of the tsunami events and (2) the limited data centered on tsunami traces.

The post-tsunami surveys for the remaining five pre-ITST events were conducted soon after the event and were aided by tsunami traces. These five

remaining pre-ITST events surveyed had a combination of descriptive and parametric components. Descriptive reports present challenges when converting to a parametric database as they require more interpretation from a database manager (Gusiakov 2009). For instance, the runup point locations are approximations. Moreover, wave heights are typically not calculated based on modern post-1992 reference datum.

Current IOC guidance (2014) insists that water-level data be corrected for tidal conditions at the time of the tsunami. However, post-tsunami survey runup data for the five remaining pre-ITST events did not make the aforementioned tidal corrections. For instance, runup data collected for the Hawaiian Islands was done relative to mean lower low water (Tsunami Technical Review Committee 2002). While the tsunami database notes the reference datum and cites the source of information, database users would not be able to easily or directly compare the runup data to post-tsunami survey runup data collected after 1992. Modern surveys report runup data in a table format that enables users to easily extract and interpret data, in comparison to the more easily misinterpreted descriptive format of pre-ITST surveys.

### 6. ITSTs in the Database

In response to the increase in post-tsunami scientific surveys in recent years, particularly following and including the 2004 Indian Ocean event, the tsunami database made adjustments to the classification of types of measurements to include post-tsunami survey measurements. The following post-tsunami survey classifications now exist within the runup field: runup height, water height, splash mark and flow depth.

The NCEI/WDS Global Historical Tsunami Database includes information on over 2200 tsunami sources and over 26,000 runup points (all measurement types). A total of 33 completed designated ITSTs (Fig. 2) have provided approximately 10,000 runup points to the tsunami database, which is approximately 40% of the tsunami runup table.

### 7. 2004 and 2011 Impact on the Database

Of the 33 ITSTs that have been completed, 2 recent events have had the most impact on the number of runup points in the database. The 26 December 2004 Indonesia and 11 March 2011 Japan tsunamis make up approximately 73% of the ITST post-tsunami survey runup points in the tsunami database. The data collected from these two devastating tsunami events have increased the quantity of runup points in the database and the advancement of the post-tsunami survey guidance allows an improved understanding of the data collected. The 2004 Indian Ocean tsunami event resulted in over 227,000 deaths and the wide-spread impact led to extensive media coverage (NCEI/WDS 2019). Hundreds of researchers and dozens of ITSTs surveyed 19 countries and territories to document the 2004 tsunami event. The 2004 Indian Ocean tsunami provided over 1400 post-tsunami survey runup points from ITSTs, approximately 15% of the ITST post-tsunami survey runup points. The 2011 Japan tsunami provided approximately 5700 post-tsunami survey runup points from ITSTs, approximately 59% of the ITST post-tsunami survey runup points. Approximately 22% of all tsunami runup points in the NCEI database are from the 2011 Japan tsunami post-tsunami surveys. Over 1000 post-tsunami survey runup points were  $\geq 15$  m (Fig. 3).

Most events see a decrease in the number of runup points between 10 and 15 m range to  $\geq 15$  m range, but Fig. 3 displays a curious increase in number runup points for the  $\geq 15$  m range for the 2004 and 2011 events. The 2004 Indian Ocean event has 456 post-tsunami survey runup points on the island of Sumatra, but 426 of those points are on a 250 km stretch of coastline on the north and northwestern part of Aceh province which happens to have some of the highest runup points (including the maximum runup of 51 m) (Fig. 4). The tsunami database shows that the post-tsunami survey data for this coastline was provided by 12 reports, each providing unique runup points. Therefore, it appears the hundreds of researchers and dozens of teams contributing post-tsunami survey runup data were attracted to this maximum runup area resulting in a large number of data points in a relatively small area. This clustering

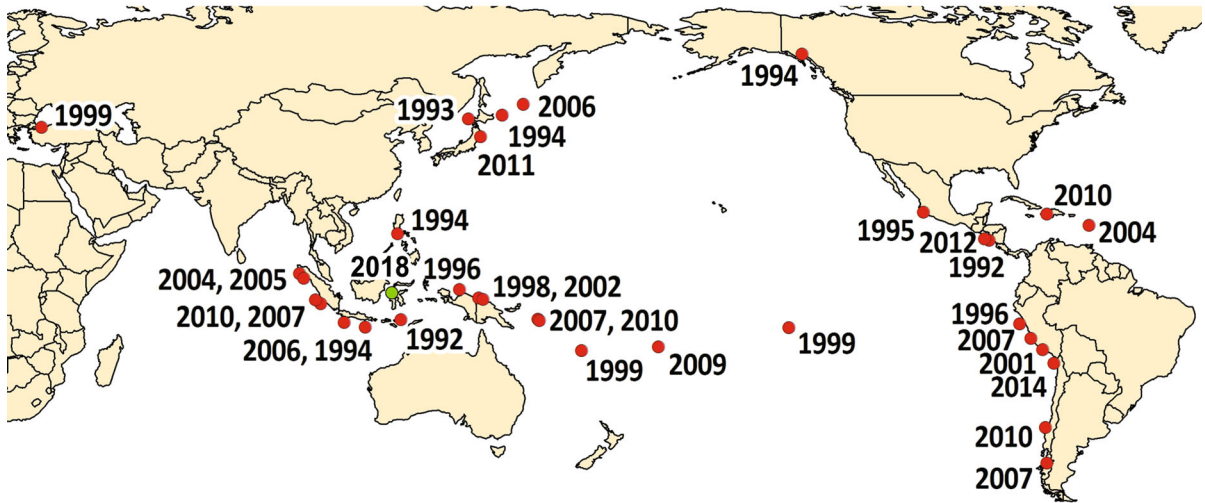


Figure 2

Spatial distribution and dates of ITSTs globally. Red circles (33) are completed ITSTs, green circle (1) is in progress ITST for 28 September 2018 Palu, Indonesia event (modified from Intergovernmental Oceanographic Commission 2014)

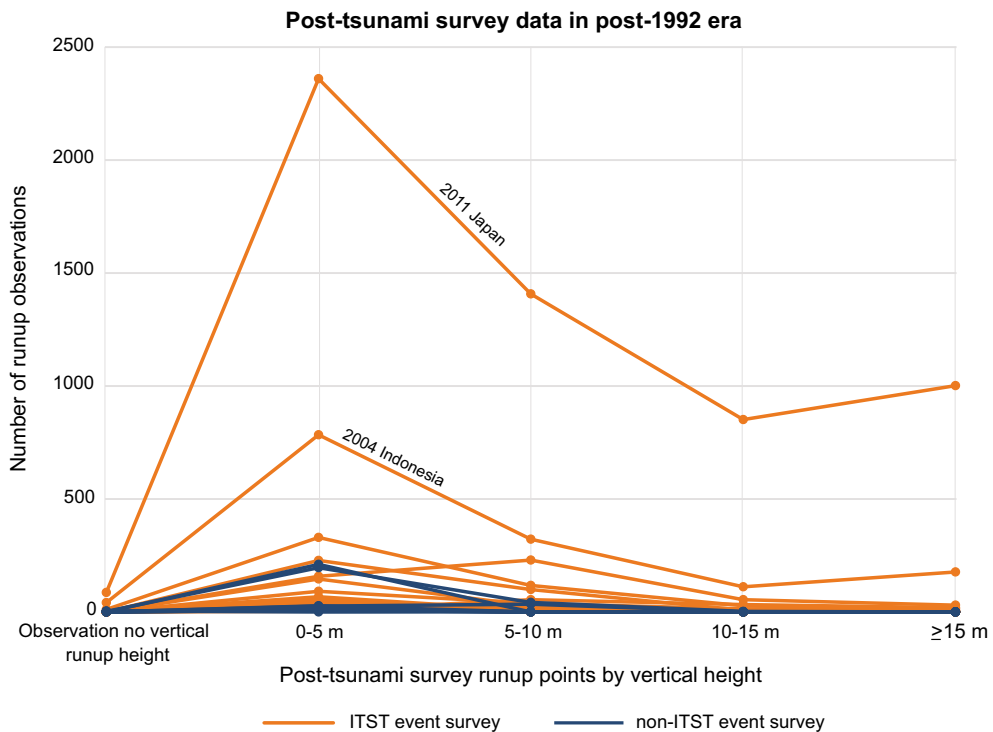


Figure 3

Post-tsunami survey data in post-1992 era in NCEI/WDS tsunami database. Each line represents a single tsunami surveyed by ITST (orange) or other post-tsunami survey team (blue). Runup points collected in the 0–5 m range are more abundant for all but three tsunami events (15 Nov 2006, 27 Feb 2010, 28 Oct 2012). The 2004 and 2011 tsunami events see an increase in number of runup points between 10 and 15 m range to  $\geq 15$  m, possibly due to the more focused post-tsunami survey effort near the highest runup points



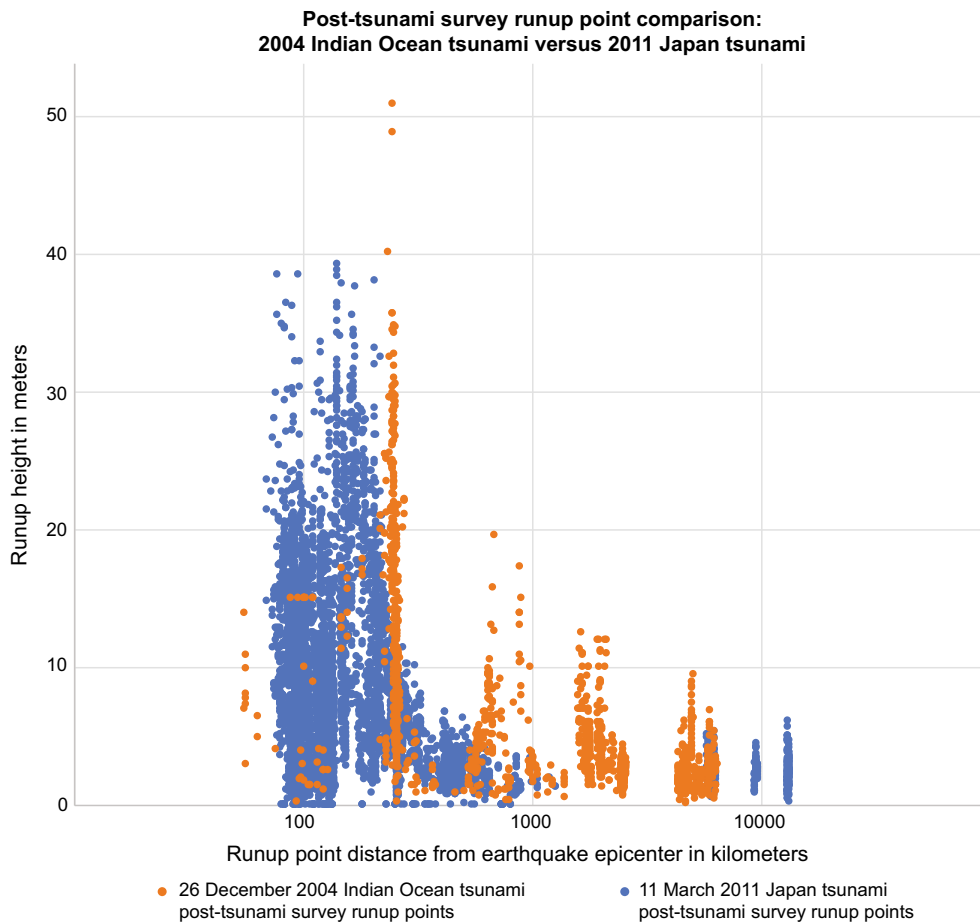


Figure 4

Post-tsunami survey runup point comparison. 2004 Indian Ocean (orange) and 2011 Japan (blue) post-tsunami survey runup heights shown relative to distance from the earthquake epicenter. The 2004 and 2011 post-tsunami survey runup data both show a large amount of data collected at similar distances to the maximum runup, but more than 50% of the 2004 runup data are from the far-field (> 1000 km). The 2011 post-tsunami survey runup data has large clustering in near-field close to the maximum runup, but large amount of data still collected in far-field. Both events show a significant amount of runup data collected below 10 m height, in near- and far-field

of data points was largely restricted to Aceh, as post-tsunami survey data was collected from the event's 19 affected countries and territories. Figure 4 displays the distribution of runup data collected at distances far beyond the epicenter location and the maximum runup points.

Similar to the 2004 post-tsunami survey data, the 2011 Japan tsunami's increase in runup points from 10 to 15 m range to  $\geq 15$  m (Fig. 3) may be a result of focus on the most impacted area. A 450 km stretch of coastline on northeastern Honshu island is where almost all 10–15 m and all  $\geq 15$  m runup data are located despite the entirety of eastern Japan's

coastlines being surveyed. As a result, it appears these unique tsunami events of 2004 and 2011 do in fact see more data collected near the highest runup points; however, as noted the importance of complete geographical coverage was not ignored (Fig. 4). Also, the 0–5 m range of post-tsunami survey runup points for both events is still significant for 2004 and 2011 tsunamis, 55% and 40% of total post-tsunami survey runup points respectively (Table 1).

Table 1  
List of tsunami events with number of post-tsunami survey runup points by vertical runup height in meters in NCEI/WDS tsunami database

Date (UTC)	Source location	Survey	Observation with no vertical height			0–5 m		5–10 m		10–15 m		> 15 m	
			No.	No. near-field <sup>a</sup>	No.	No.	No. near-field <sup>a</sup>	No.	No. near-field <sup>a</sup>	No.	No. near-field <sup>a</sup>	No.	No. near-field <sup>a</sup>
1945-11-27	Makran Coast, Pakistan <sup>c</sup>	E	0	0	4	4	4	4	1	1	0	0	
1946-04-01	Unimak Is., Alaska, USA <sup>c</sup>	E	1	0	207	0	168	8	51	7	18	14	
1952-11-04	Kamchatka, Russia	E	0	0	76	0	3	0	0	0	0	0	
1956-07-09	Greece <sup>c</sup>	E	0	0	61	61	3	3	3	3	1	1	
1957-03-09	Andreanof Is., Alaska, USA	E	0	0	144	0	29	3	3	1	4	3	
1960-05-22	Central Chile	E	0	0	259	0	11	1	2	1	0	0	
1964-03-28	Prince William Sound, Alaska, USA	E	0	0	56	0	1	0	0	0	1	1	
1976-08-16	Moro Gulf, Philippines	E	11	9	7	6	2	2	0	0	0	0	
1992-09-02	Nicaragua	I	0	0	22	22	22	22	0	0	0	0	
1992-12-12	Flores Sea, Indonesia	I	2	2	68	54	8	8	4	3	4	2	
1993-07-12	Sea of Japan	I	0	0	42	13	3	2	0	0	0	0	
1994-06-02	Java, Indonesia	I	0	0	40	40	24	24	3	3	0	0	
1994-10-04	Kuril Is, Russia	I	1	1	21	20	8	8	1	1	0	0	
1994-11-14	Skagway, Alaska, USA	I	0	0	0	0	1	1	0	0	0	0	
1994-11-14	Philippine Is	I	0	0	50	50	4	4	0	0	0	0	
1995-10-09	Manzanillo, Mexico	I	0	0	16	16	2	2	1	1	0	0	
1996-01-01	Sulawesi, Indonesia	P	0	0	16	16	0	0	0	0	0	0	
1996-02-17	Biak, Indonesia	I	0	0	2	2	1	1	0	0	0	0	
1996-02-21	Northern Peru	I	2	2	39	39	1	1	0	0	0	0	
1998-07-17	Papua New Guinea	I	0	0	21	21	6	6	2	2	0	0	
1999-08-17	Izmit Bay, Turkey	I	0	0	19	19	0	0	0	0	0	0	
1999-09-13	French Polynesia	I	0	0	4	4	5	5	0	0	0	0	
1999-11-26	Vanuatu Is	I	0	0	11	11	1	1	0	0	0	0	
2001-06-23	Southern Peru	I	2	2	26	26	10	10	0	0	0	0	
2002-09-08	Papua New Guinea	I	0	0	55	55	1	1	0	0	0	0	
2003-09-25	Hokkaido Is, Japan	P	0	0	211	211	0	0	0	0	0	0	
2004-11-21	Guadeloupe	I	0	0	1	1	0	0	0	0	0	0	
2004-12-26	Sumatra, Indonesia	I	42	7	778	185	319	214	111	94	175	175	
2005-03-28	Simeulue, Indonesia	I	0	0	38	38	0	0	0	0	0	0	
2006-07-17	Java, Indonesia	I	0	0	92	92	38	38	14	14	16	16	
2006-11-15	Kuril Is, Russia	I	0	0	7	7	55	55	33	33	19	19	
2007-04-01	Solomon Is	I	0	0	146	146	28	28	1	1	0	0	
2007-04-21	Southern Chile	I	0	0	0	0	1	1	1	1	1	1	
2007-08-15	Southern Peru	I	0	0	59	59	7	7	1	1	0	0	
2007-09-12	Sumatra, Indonesia	I	0	0	24	24	1	1	0	0	0	0	
2009-09-29	Samoa Is	I	12	12	330	329	118	118	28	28	10	10	
2010-01-03	Solomon Is	I	0	0	30	30	15	15	0	0	0	0	
2010-01-12	Haiti	I	2	2	19	19	0	0	0	0	0	0	
2010-02-27	Central Chile	I	1	0	158	96	230	230	55	55	31	31	
2010-10-25	Mentawai, Indonesia	I	0	0	228	222	100	100	8	8	1	1	

Table 1 continued

Date (UTC)	Source location	Survey Observation with no vertical height				0–5 m		5–10 m		10–15 m		> 15 m	
		No.	No. near-field <sup>a</sup>	No.	No. near-field <sup>a</sup>	No.	No. near-field <sup>a</sup>	No.	No. near-field <sup>a</sup>	No.	No. near-field <sup>a</sup>	No.	No. near-field <sup>a</sup>
2010-12-25	Vanuatu Is	P	0	0	8	8	0	0	0	0	0	0	0
2011-03-11	Tohoku, Japan	I	87	0	2360	1943	1408	1397	852	852	1002	998	0
2012-08-27	El Salvador	I	1	1	22	22	4	4	0	0	0	0	0
2012-10-28	Haida Gwaii, Canada	P	0	0	26	26	35	35	1	1	0	0	0
2014-04-01	Northern Chile	I	0	0	51	51	0	0	0	0	0	0	0
2015-02-19	Vanuatu Is	P	5	4	0	0	1	1	0	0	0	0	0
2015-09-16	Central Chile	P	3	3	196	196	43	43	3	3	0	0	0
2016-11-13	New Zealand	P	0	0	10	10	1	1	0	0	0	0	0
2017-03-19	Iran <sup>b</sup>	P	3	3	11	11	0	0	0	0	0	0	0
2017-07-20	Bodrum, Turkey	P	0	0	28	28	0	0	0	0	0	0	0
2017-09-08	Chiapas, Mexico	P	0	0	8	8	0	0	0	0	0	0	0

E Post-tsunami survey data in pre-ITST era, I International Tsunami Survey Team, P Post-1992 (non-ITST) post-tsunami surveys with > 5 runups

<sup>a</sup>To classify as near-field, runup point is within 1000 km of source epicenter. Note: The point of origin for the 2017 Iran meteo-tsunami was assigned to the city of Bandar Dayyer

<sup>b</sup>Meteotsunami

<sup>c</sup>Include runup points collected post-1992

### 8. Near-Field Versus Far-Field

The broader comparisons in this study do not differentiate near-field versus far-field runup data. Far-field is defined here at a distance greater than 1000 km from the source epicenter, noting the complexities of comparisons of large rupture plane sources. Far-field runup points, in comparison to near-field, tend to be smaller values for the same tsunami event, although local conditions result in exceptions. One such exception is Crescent City, CA, which experiences amplified tsunami waves (Arcas and Uslu 2010). For example, the 1964 Southern Alaska tsunami resulted in a 4.8 m tsunami runup in Crescent City causing ten deaths (plus one death in nearby Klamath, CA) and significant damage. The next highest runup point in California for this event was 3.7 m, while the more than 80% of the 57 non-instrumental (e.g. eyewitness accounts or post-tsunami survey) runup points in California were below 2 m.

When looking at the post-1992 tsunami survey runup data, the vast majority of the data is in the near-field and can be compared (Table 1). The two exceptions are the 1993 Sea of Japan tsunami and the 2004 Indian Ocean tsunami. In regard to the 1993 tsunami, the tsunami database contains over 40 runup points in the near-field provided by the Japan Meteorological Agency. However, the runup data only differentiates observation types between instrumental (i.e. tide gauge) and non-instrumental. As a result, the runup data are not easily identifiable as originating from a post-tsunami survey, though many are probably survey points. The 2004 Indian Ocean tsunami, as previously discussed, was an event with far reaching impacts thus the larger quantity (53%) of far-field runup data is not unexpected. In comparison, the 2011 Japan tsunami had only about 10% of runup points in the far-field; however, as this event is the most well documented event to date it had a considerable amount of post-tsunami survey runup data in the far-field, more than 500 runup points with some distances exceeding 13,000 km from the epicenter location (Fig. 4).

Unlike the post-1992 events, the eight pre-ITST events that are part of this study currently have more far-field runup data (Table 1). Reasons for this

include the previously discussed post-1992 surveys of older events in far-field areas where data was lacking. Another significant reason is the importance of these events in the far-field, particularly in Hawaii. The Hawaii-focused Tsunami Technical Review Committee (2002) document is responsible for approximately 90% of the far-field post-tsunami survey runup points of the eight pre-ITST events. This document highlights the early post-tsunami surveys conducted in Hawaii beginning with the 1946 Alaska tsunami.

In regard to pre-ITST events, the tsunami database currently has a limited amount of runup data classified as being from post-tsunami surveys, particularly in the near-field. However, a broad comparison between pre-ITST and post-1992 runup data still gives the user an understanding of the data available. Meanwhile, comparing post-tsunami survey runup data within each era is appropriate as pre-ITST is largely far-field data and post-1992 is largely near-field data.

### 9. Database Differences Pre-ITST and Post-1992

International Tsunami Survey Teams (ITSTs) are IOC recognized, coordinated, interdisciplinary, international efforts that began with the 1992 Nicaragua tsunami survey. Although some post-tsunami surveys after 1992 Nicaragua tsunami may not formally be recognized by IOC as ITSTs, they often employed many of the same standards. Post-tsunami surveys prior to ITSTs may have had elements of an ITST, but ITSTs help ensure standardized data as well as increased confidence in the data reported. Additionally, ITSTs began in an era when precision measurement devices (e.g. GPS) and data sharing technologies were becoming widespread.

The tsunami database lists 519 confirmed tsunamis from 1900 to the ITST era. However, to limit the study to tsunamis potentially capable of impact to life and property, smaller tsunamis only detected instrumentally (e.g. tide gauge) were removed, resulting in fewer than 300 events. Approximately 3600 runup points are classified as eyewitness (i.e. not tide gauge, DART) for these events. This results in an average of almost 13 eyewitness runup points per event.

Approximately 1100 pre-ITST runup points, from the 8 pre-ITST events, are classified as post-tsunami survey runup points, averaging to about 140 post-tsunami survey runup points per event. However, the 01 April 1946 Alaska tsunami accounts for approximately 40% of those post-tsunami survey runup points. When removing the 1946 event, the average of post-tsunami survey runup points per pre-ITST event drops to just under 100.

The tsunami database lists nearly 280 confirmed tsunamis in post-1992 era, beginning with the 1992 Nicaragua tsunami, this number decreases to 108 when removing events only recorded instrumentally. Approximately 700 runup points are classified as eyewitness, of a total of 94 post-1992 events that contain eyewitness runup data, averaging to over 7 eyewitness runup points per event. Although only 33 (plus the 2018 Palu post-tsunami survey in progress) post-tsunami surveys have been formally recognized by IOC/UNESCO as ITSTs, 50 post-1992 events in the database have runup points classified as post-tsunami survey runup points.

This paper focuses on the 39 post-1992 events with surveys contributing more than five runup points in the database, thereby excluding small survey efforts or events where the database may not be fully updated (Table 2). These 39 events have approximately 10,400 post-tsunami survey runup points. This results in an average of over 260 post-tsunami survey runup points for these events, a stark contrast to the 100 post-tsunami survey runup points from pre-ITST events. However, the 2004 and 2011 events make up nearly 70% of all the post-1992 post-tsunami survey runup points. When removing these two outlier events, the average of post-tsunami survey runup points per post-1992 event drops to approximately 82.

Comparing the number of collected post-tsunami survey runup points between pre-ITST and post-1992 cannot reveal trends given the limited number of corrected pre-ITST runup points in the database. However, the considerable number of points measured imparts that pre-ITST survey efforts were robust and not simply surveying points at, or nearest, the maximum runup height. Efforts to identify and correct more pre-ITST runup points from eyewitness to post-tsunami survey measurements must be made

Table 2  
List of post-1992 tsunami events with > 5 post-tsunami survey runup points in NCEI/WDS tsunami database

Date (UTC)	Source location	Maximum runup (meters)	Number of post-tsunami survey runups	Select post-tsunami survey references <sup>b</sup>
1992-09-02	Nicaragua	9.9	44	Murty et al. (1993), Satake et al. (1993)
1992-12-12	Flores Sea, Indonesia	26.2	86	Tsujii et al. (1995a), Yeh et al. (1993)
1993-07-12	Sea of Japan	32.0	45	Shuto and Matsutomi (1995), Sigríst (1994)
1994-06-02	Java, Indonesia	13.9	67	Maramai and Tinti (1997), Tsujii et al. (1995b)
1994-10-04	Kuril Is, Russia	10.4	31	Gusiakov (1995), Yeh et al. (1995)
1994-11-14	Philippine Is	7.3	54	Imamura et al. (1995)
1995-10-09	Manzanillo, Mexico	11.0	19	Borrero et al. (1997), Trejo-Gómez et al. (2015)
1996-01-01	Sulawesi, Indonesia	3.4	16	Polinovsky et al. (1997)
1996-02-21	Northern Peru	5.1	42	Bourgeois et al. (1999)
1998-07-17	Papua New Guinea	15.0	29	Lynett et al. (2003), Kawata et al. (1999)
1999-08-17	Izmit Bay, Turkey	2.5	19	Alunok et al. (2001), Yalçiner et al. (2000)
1999-09-13	Fatu Hiva, Marquesas, F.P.	8.0	9	Okal et al. (2002a)
1999-11-26	Vanuatu Is	6.6	12	Caminade et al. (2000)
2001-06-23	Southern Peru	8.8	38	Dengler et al. (2003)
2002-09-08	Papua New Guinea	5.5	56	Borrero et al. (2003)
2003-09-25	Hokkaido Is, Japan	4.4	211	Tanioka et al. (2004)
2004-12-26	Banda Aceh, Indonesia	50.9	1425	Borrero (2005b), Fritz (2006b), Fritz and Borrero (2006), Tsujii et al. (2006)
2005-03-28	Simeulue, Indonesia	4.2	38	Borrero et al. (2011)
2006-07-17	Java, Indonesia	20.9	160	Fritz et al. (2007)
2006-11-15	Kuril Is, Russia	21.9	114	MacInnes et al. (2009)
2007-04-01	Solomon Is	12.1	175	Fritz and Kalligeris (2008)
2007-08-15	Southern Peru	10.1	67	Fritz et al. (2008)
2007-09-12	Sumatra, Indonesia	5.0	25	Borrero et al. (2009)
2009-09-29	Samoa Is	22.4	498	Okal et al. (2010), Lamarche et al. (2010)
2010-01-03	Solomon Is	7.5	45	Newman et al. (2011)
2010-01-12	Haiti	3.2	21	Fritz et al. (2013)
2010-02-27	Central Chile	29.0	475	Fritz et al. (2011), Reymond et al. (2013)
2010-10-25	Mentawai, Indonesia	16.9	337	Hill et al. (2012), Satake et al. (2013)
2010-12-25	Vanuatu Is	4.1	8	Gibson (2015)
2011-03-11	Tohoku, Japan	38.9	5709	Mori et al. (2011), Satake et al. (2012), Suppassi et al. (2012)
2012-08-27	El Salvador	6.3	27	Borrero et al. (2014)
2012-10-28	Haida Gwaii, Canada	13.0	62	Leonard and Bednarski (2014)
2014-04-01	Northern Chile	4.6	51	Catalán et al. (2015)
2015-02-19	Vanuatu Is	8.0	6	Gibson (2015)
2015-09-16	Central Chile	13.6	245	Aránguiz et al. (2016), Contreras-López et al. (2016)
2016-11-13	New Zealand	6.9	11	Power et al. (2017)
2017-03-19	Iran <sup>a</sup>	3.0	14	Salaree et al. (2018)
2017-07-20	Bodrum, Turkey	1.9	28	Yalçiner et al. (2017)
2017-09-08	Chiapas, Mexico	2.7	8	Ramírez-Herrera et al. (2018)

<sup>a</sup>Metotsunami

<sup>b</sup>Selection based on greatest number of post-tsunami survey runups attributed in the dataset analyzed in this study, noting that some references may be overview documents and not the original source of data. Complete listing of references available at NCEI/WDS and Intergovernmental Oceanographic Commission (2014)



Table 3

*List of pre-ITST era tsunami events with > 5 post-tsunami survey runup points in NCEI/WDS tsunami database*

Date (UTC)	Source location	Maximum runup (meters)	Number of post-tsunami survey runups	Select post-tsunami survey references <sup>b</sup>
1945-11-27	Makran Coast, Pakistan <sup>a</sup>	13.7	9	Okal et al. (2015)
1946-04-01	Unimak Is, Alaska, USA <sup>a</sup>	42.0	445	Okal et al. (2002b), Okal et al. (2003), Tsunami Technical Review Committee (2002)
1952-11-04	Kamchatka, Russia	23.0	79	Tsunami Technical Review Committee (2002)
1956-07-09	Greece <sup>a</sup>	30.0	68	Okal et al. (2009)
1957-03-09	Andreanof Is., Alaska, USA	22.8	180	Tsunami Technical Review Committee (2002)
1960-05-22	Central Chile	25.0	272	Tsunami Technical Review Committee (2002), Vitousek (1963)
1964-03-28	Prince William Sound, Alaska, USA	51.8	58	Lander et al. (1993), Leipold and Wood (1966)
1976-08-16	Moro Gulf, Philippines	9.0	20	Stratta and Haas (1977)

<sup>a</sup>Include runup points collected post-1992

<sup>b</sup>Complete listing of references available at NCEI/WDS

to have better understanding of pre-ITST survey data, as well as to provide database users with a more accurate account of the available data.

Currently, the post-1992 era appears to have resulted in fewer runup points collected in post-tsunami survey runup measurements, discounting outlier events. However, it should be noted that pre-ITST events' runup points identified as originating from post-tsunami surveys were mostly large tsunami events, with a median maximum runup of 24 m (Table 3). In comparison post-1992 events had a median maximum runup of 9 m, as a greater number of lower runup local and regional tsunamis were being more thoroughly investigated than in the pre-ITST era (Table 2).

### 10. Post-Tsunami Survey Runup Values

Typically, the larger the tsunami runup, the more data are collected for the event. Figure 5 validates the aforementioned statement, as there is generally a correlation between runup height and number of data points collected. Although the 1998 Papua New Guinea post-tsunami survey follows the aforementioned pattern, surveys for several other landslide-generated tsunamis are notable exceptions. The very localized extent of landslide tsunami impacts do not necessitate geographically extensive surveys

resulting in a large number of data points despite the extreme runup measurements (e.g. 2007 Chile, 2015 Alaska, 2017 Greenland etc.) (Fig. 5). Other exceptions do exist and may be attributed to a variety of associated factors including, but not limited to, environmental conditions and stronger investment in scientific data collection due to socioeconomic reasons (e.g. high number of tsunami deaths, investment in scientific studies, etc.). The most striking examples of socioeconomic influence on the extent of post-tsunami surveys include the 2004 Indian Ocean event, resulting in over 227,000 deaths in 15 countries, and the 2011 Japan event, over \$200 billion (USD) in damage and 18,454 deaths (NCEI/WDS 2019). Though such conditions are not investigated in this study, they should be considered for future work.

The collection of lesser runup values, it has been stated, are often overlooked by survey teams and, consequently, in tsunami databases (Fryer 2011). However, a closer analysis may prove otherwise. In the tsunami database, the eight pre-ITST events discussed with a 24 m median maximum runup have a range of 9–52 m (Table 3). However, the surveys demonstrate adequate coverage as most events show the majority of runup points collected to be between 0 and 5 m (Fig. 6 and Table 1). The 1976 Philippines tsunami is an anomaly since much of the post-tsunami survey data in the Stratta and Haas (1977) report, largely focused on structural

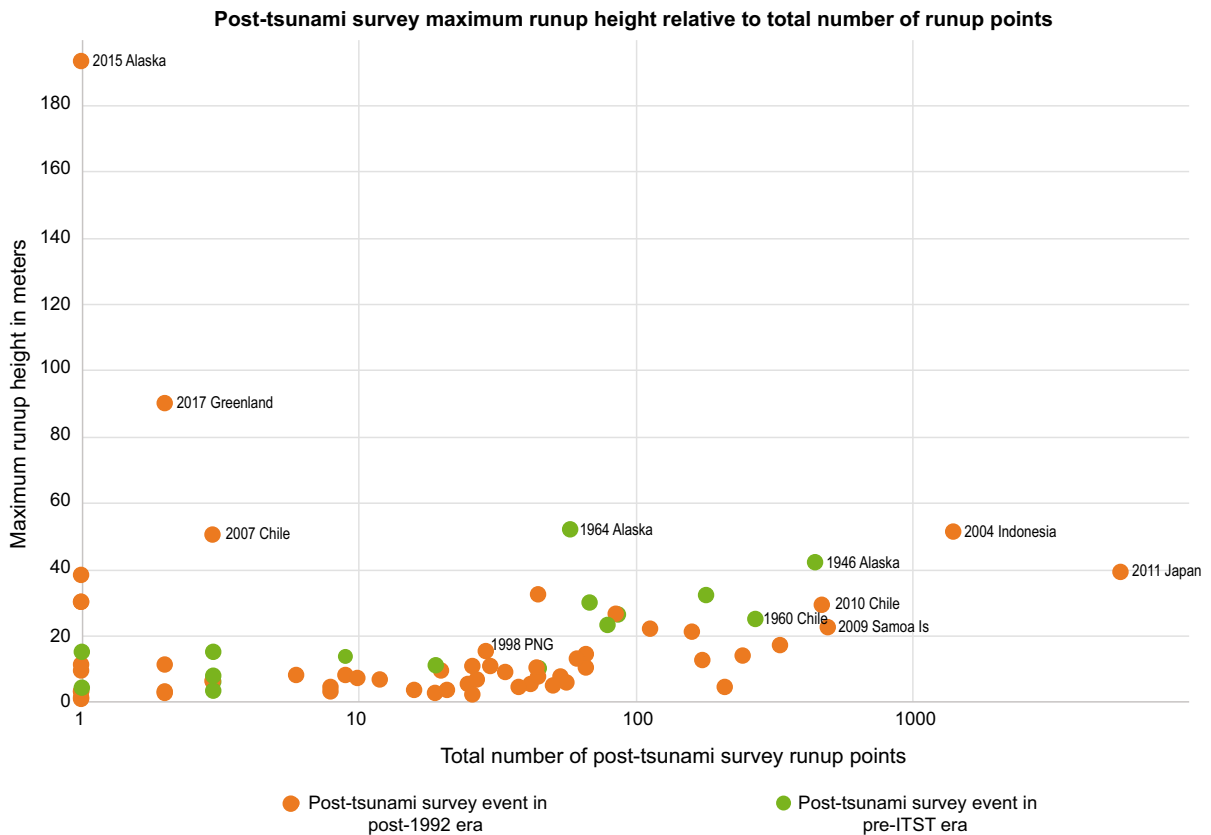


Figure 5

Post-tsunami survey maximum runup height relative to total number of post-tsunami survey runup points in NCEI/WDS tsunami database. Each circle represents a post-tsunami survey. Typically, the larger the tsunami runup, the more data are collected on that particular event. Although the 1998 Papua New Guinea post-tsunami survey follows the aforementioned pattern, surveys for several other landslide-generated tsunamis are notable exceptions. The very localized extent of landslide tsunami impacts do not necessitate geographically extensive surveys resulting in a large number of data points despite the extreme runup measurements (e.g. 2007 Chile, 2015 Alaska, 2017 Greenland etc.) (Note: 1946 Alaska includes runup points collected post-1992)

performance/damage, did not include runup heights, though some runup measurements were included in some other reports (e.g. Pararas-Carayannis 1976). Consequently, not only were a large quantity of data points collected in the eight pre-ITST events, but these survey efforts were not restricted to the highest runup points (Figs. 6 and 7). However, it should be noted that the post-tsunami survey runup points for the pre-ITST events were largely in the far-field, thus smaller values are expected (Fig. 6 and Table 1).

Similar to the pre-ITST events, post-1992 event runup points collected were more abundant in the 0–5 m range with three exceptions (15 Nov 2006, 27 Feb 2010, 28 Oct 2012 tsunamis). The three exceptions may be attributed to challenges in accessibility,

consideration of other coastal processes, and clustering of data collection due to logistical considerations. The survey data from the 2009 Samoa Islands tsunami has a significantly higher number of runup points in the 0–5 m range; this may be attributable to the large number of scientists conducting the survey and improved coordination along a smaller coastline (Kong 2011) (Fig. 7 and Table 1). Further, even at epicentral distances where the runup points for 2004 and 2011 were well over 10 m, runup measurements were also recorded in the 0–5 m range (Fig. 4). If only considering ITSTs, approximately 50% of all ITST event runup observations were 0–5 m (Fig. 3 and Table 1).

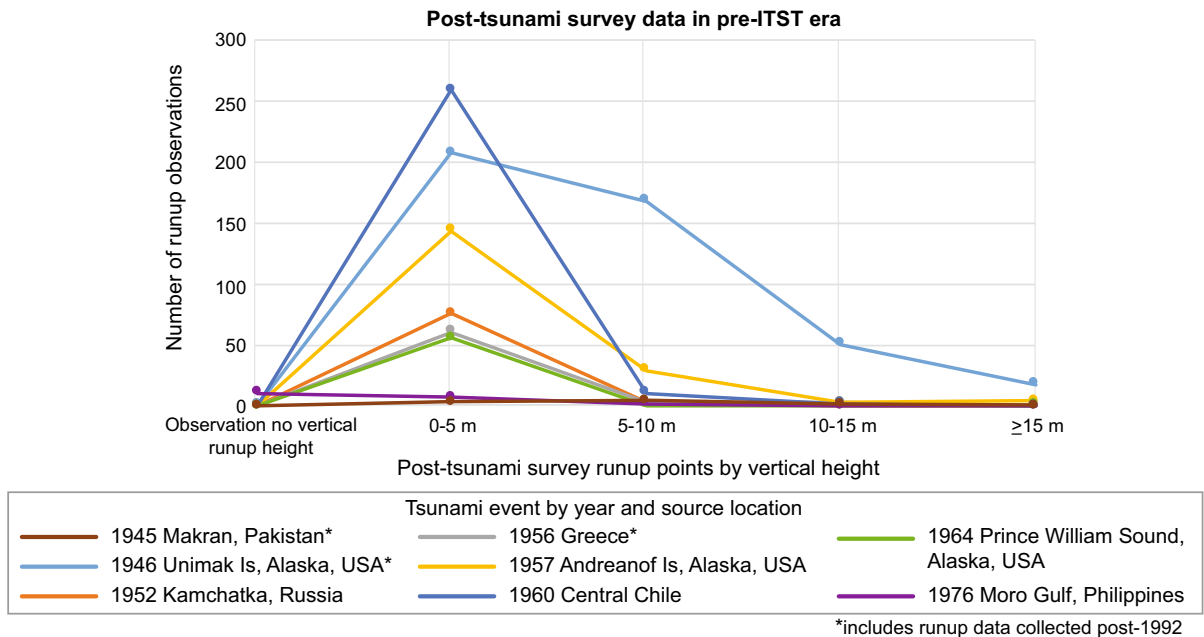


Figure 6

Post-tsunami survey data in pre-ITST era (1900–1992) with > 5 runup points in NCEI/WDS tsunami database. Each line represents a separate tsunami surveyed. Post-tsunami surveys in pre-ITST era collected a large quantity of data points, with the 0–5 m range being the most abundant range. The post-tsunami survey runup points collected for 1960 Chile tsunami were largely in the far-field, thus smaller values are expected. The 1976 Philippines tsunami post-tsunami survey runup data had limited inclusion of runup heights, as it was largely focused on structural performance/damage

## 11. Discussion and Conclusion

Post-tsunami surveys have contributed new data types, as well as increased quantity and quality of data. Additionally, new scientific fields have emerged due to post-tsunami surveys. A prominent example being the 1998 Papua New Guinea tsunami ITST survey data that allowed for modeling techniques that assist in determining the source of a tsunami (seismic versus landslide) (Okal and Synolakis 2004). Further, post-tsunami surveys contribution to the NCEI/WDS database is significant. The NCEI/WDS tsunami database includes information on tsunami events throughout the world that range in date from 1610 B.C. to present. However, post-tsunami survey measurements, ITSTs in particular, make up the majority of the runup data with the 2004 and 2011 events accounting for a disproportional percentage of runup points in the database.

The analysis presented in this paper reinforces that 1992 was a turning point in post-tsunami data

collection, as a great number of runup data began to be collected systematically for local and regional tsunamis. The most important deductions from our analysis are the similarities between pre- and post-1992 runup heights, noting the limited runup data classified as post-tsunami survey for pre-ITST events. These similarities in measurement methodology impart a high level of confidence in pre-ITST surveys; however, the database must account for uncertainties in reference datum. Additionally, confidence in the extent of post-tsunami surveys is further strengthened as it is clear that best efforts have been made to capture a complete representation of a tsunami by documenting smaller runup values.

End users of tsunami data rely on consistent and comparable data between events and locations within a single event. For example, tsunami models studying sources or location-specific wave effects are validated using historical tsunami data, thus enhancements to tsunami data are vital to tsunami mitigation and forecasting. As a growing number of scientists are

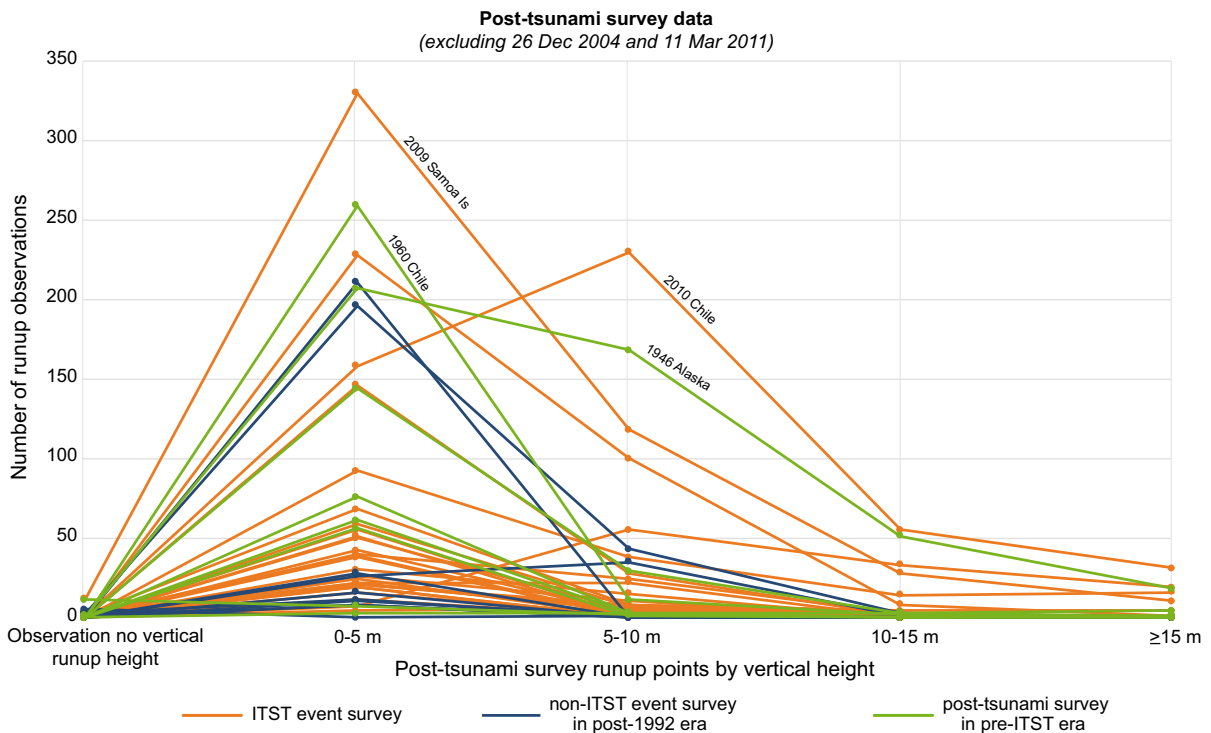


Figure 7

Post-tsunami survey data (excluding 26 December 2004 and 11 March 2011) with > 5 runup points in NCEI/WDS tsunami database. Each line represents a single tsunami surveyed by ITST (orange), post-tsunami survey team in post-1992 era (blue), or post-tsunami survey team in pre-ITST era (green). Regardless of era (pre- or post-1992) or ITST designation, runup points collected from post-tsunami surveys are more abundant in the 0–5 m range, with the three exceptions (15 Nov 2006, 27 Feb 2010, 28 Oct 2012 tsunamis). These exceptions may be attributed to challenges in accessibility, consideration of other coastal processes, and clustering of data collection due to logistical considerations

trained in surveying techniques, more data are likely to be collected. Continuing improvements to surveys, through standardization and technological advancements, result in larger datasets as well as improved data. This means that databases must keep up with the growing quantity of data and parameters.

The NCEI/WDS tsunami database reflects these advancements in data quality and quantity as evidenced by the addition of post-tsunami survey classifications. However, data collectors (i.e. ITST scientists) must continue to consider data providers, namely data centers, so that their data can be accessed. Data sharing helps save lives and protect property, but also advances the scientific fields of data collectors. For instance, ITST researchers also may be tsunami modelers that benefit from robust data sets accessible from data centers (e.g. NCEI/WDS). Thus, the responsibility is on both data centers

and researchers to engage each other to ensure a reliable, robust, and continually adapting data center. ITSTs and their associated guidance have made significant progress to facilitate sharing of and consistency in tsunami data, and these efforts must continue to be nurtured.

The tsunami database must still assess pre-ITST era events to determine the origin of runup heights to better represent runup data. Recognizing the pre-ITST events may have employed a variety of survey methodologies (e.g. reference datum), the tsunami database may consider a distinct classification for pre-ITST post-tsunami survey data. The post-tsunami survey guidance developed since 1992 has encouraged consistency and cooperation in modern surveys. The tsunami database reflects these efforts and should continue to strive to better reflect pre-ITST post-tsunami surveys as well.

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### Appendix

NCEI (<http://www.ngdc.noaa.gov/hazard>) and the ITIC (<http://itic.ioc-unesco.org>) are committed to delivering data and information that enables informed decision-making and supports multiple uses of data. Most of the data in the NCEI archive are within the public domain and may be used without restriction, although users should cite data sources. These data can be searched via web maps or text interfaces by attribute (date, location, magnitude, etc.) and displayed as tables, reports, interactive maps, and imagery. Additional details of the archive are described by Dunbar et al. (2008).

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