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Tsunamigenic predecessors to the 2009 Samoa earthquake

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ABSTRACT

We analyze historical earthquakes of the past century having generated regional tsunamis in Samoa, by means of epicentral relocation and quantification of spectral amplitudes of waveforms from historical seismograms. The only tsunami with a level of destruction comparable to the 2009 event was generated by the earthquake of 26 June 1917 in the Samoa corner. Yet, a memory of this event is largely absent from the ancestral heritage of the present population of Samoa, which we tentatively attribute to the nearly simultaneous occurrence of the influenza epidemic in 1918. While not able to fully resolve focal geometries, we document a diversity of mechanisms, which add an element of unpredictability to the forecast of any future tsunami in the region.

Contents

1. Introduction

The purpose of this paper is to conduct a study of predecessors to the 2009 Samoa earthquake. This major event ($M_0 = 1.8 \times 10^{28}$ dyn cm) generated the first tsunami in 45 years to create significant damage and casualties on U.S. soil, which was also the most devastating one in at least 92 years in the South Pacific West of the South American subduction zone.

The 2009 earthquake featured normal faulting in the outer rise of the curving subduction interface, in a complex geometry defined as a STEP ("Subduction-Transform Edge Propagator") by Govers and Wortel (2005). Its source was itself complex, featuring a strong non-double-couple component ($\varepsilon = 0.15$ to 0.30) as a result of the

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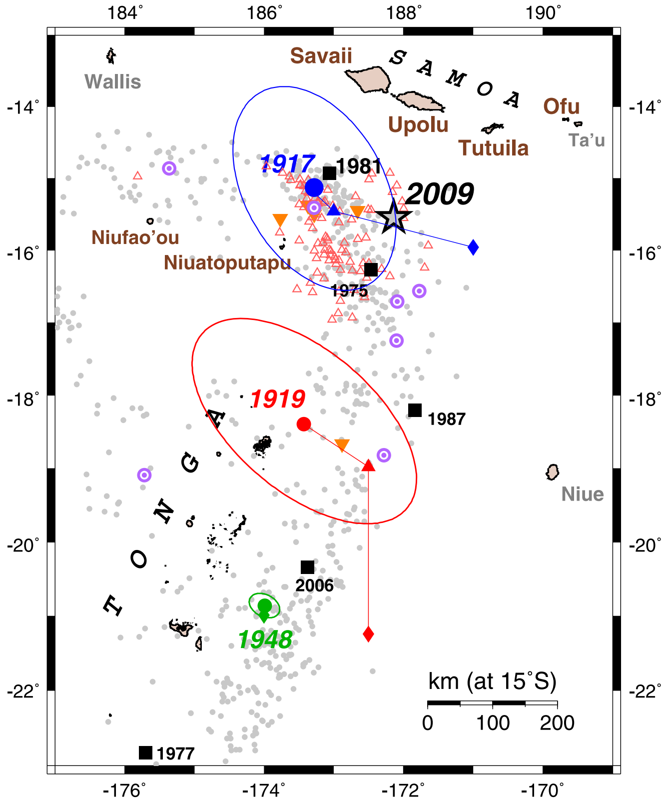

Fig. 1. Location map of the study area. The boundary of the Pacific plate is defined by the database of CMT solutions shallower than 50 km (small gray dots); those with a moment greater than 10^{26} dyn cm are shown as bull's eye symbols. The large earthquakes of 26 June 1917, 30 April 1919 and 08 September 1948, relocated using the algorithm of Wysession et al. (1991), are shown as solid dots (with confidence ellipses); the triangles are Gutenberg and Richter's (1954) epicenters, and the diamonds the ISS solutions. The 2009 Samoa earthquake is shown as the gray star. Other earthquakes with decimetric tsunamis in Samoa are shown as black squares; the inverted triangles are relocated epicenters of other events North of 20°S, predating 1963, with at least one magnitude >7 and without tsunami reports. The small red open triangles are earthquakes occurring during a 24-h window following the mainshock of 29 September 2009. Adapted from Okal et al. (2004) and Okal et al. (2010).

triggering of coseismic slip on the subduction interface following the outer rise rupture, a model proposed by Li et al. (2009) and later refined by Lay et al. (2010). As difficult as the concept of recurrence times may be for regular subduction events, we know even less about the repeat patterns of outer rise events, except that they are usually thought to feature much longer cycles (Kirby et al., 2008).

In this context, it is worth examining in detail the historical seismicity of the Samoa corner; we focus in this paper on those events in the 20th century that were large enough to generate observable or locally damaging tsunamis, and for which instrumental seismic data is available. The record of tsunamis in the Tonga–Samoa area was compiled as part of Solov'ev and Go's (1975, translated in 1984) monumental and authoritative monograph, based on various original reports, and augmented by its complement for the years 1969–1982 (Solov'ev et al., 1986). Later, Pararas-Carayannis and Dong (1980) complemented their analysis by researching newspaper accounts of the events reported by the individual chronicles compiled by Solov'ev and Go (1975).

2. Methodology

For each of the events considered (Fig. 1), we present a general description, including the effects of the tsunami, as compiled from various literature sources. We then conduct a seismological study combining the following approaches:

2.1. Relocations

For events predating the dawn of modern seismology (1963), we use the techniques of Wysession et al. (1991) to relocate the earthquake sources based on arrival times published by the International Seismological Summary (ISS). This interactive iterative least-squares method uses a Monte Carlo algorithm to inject Gaussian noise into the dataset in order to define a confidence ellipse for the relocated epicenter; the standard deviation of the noise varies from $\sigma_G = 1$ s for modern events (ca. 1963) to $\sigma_G = 15$ s in the 1910s. We take the present opportunity to relocate not only the targeted tsunamigenic earthquakes, but also other major events in the area. Our relocation results are given in Table 1. Incidentally, we note that only one of the events studied here (01 January 1919) was relocated by Engdahl and Villaseñor (2002).

2.2. Focal solutions

For earthquakes postdating 1976, these are available from the CMT catalogue (Dziewonski et al., 1981 and subsequent quarterly updates). For the period 1963–1975, we use WWSSN analog data, permanently archived at Northwestern University, to build focal solutions based on first motion *P*-wave data, and obtain long-period seismic moments from the analysis of spectral amplitudes of selected mantle waves recorded at high-quality long-period stations. For historical earthquakes predating 1963, we have found it generally impossible in the present cases to use the PDFM algorithm introduced by Reymond and Okal (2000), and which consists of inverting only

Table 1
Parameters of seismic events relocated in this study.

Date D M (J) Y	Origin time (GMT)	Latitude (°N)	Longitude (°E)	Depth (km)	Number of stations		R.M.S. σ (s)
					Available	Used	
01 MAY (121) 1917	18:26:40.0	−29.39	−179.29	10.0	20	12	7.75
26 JUN (177) 1917	5:49:40.8	−15.13	−173.28	10.0	28	22	7.55
16 NOV (320) 1917	3:19:36.8	−28.67	−178.42	10.0	19	15	6.34
01 JAN (001) 1919	3:00:11.3	−19.52	−177.61	246.4f	21	13	3.30
30 APR (120) 1919	7:17:16.6	−18.48	−173.35	20.0	24	21	5.32
27 FEB (058) 1921	18:23:35.7	−18.60	−172.99	10.0	30	27	3.84
08 JUN (159) 1939	20:46:54.8	−15.56	−173.77	86.5f	62	60	2.88
29 JUN (181) 1948	10:28:34.0	−15.45	−172.66	15.0	81	79	3.06
08 SEP (252) 1948	15:09:11.9	−20.89	−173.94	10.0	76	72	3.18
18 APR (108) 1949	21:34:45.7	−15.50	−173.28	35.9f	33	33	1.76
27 NOV (331) 1949	8:42:15.0	−17.69	−173.23	7.8f	59	56	2.71
14 APR (104) 1957	19:18:00.0	−15.38	−173.37	10.0	166	165	2.90

f: floated depth; all others constrained during relocation.