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Investigating the March 28th 1875 and the September 20th 1920 earthquakes/tsunamis of the Southern Vanuatu arc, offshore Loyalty Islands, New Caledonia

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A B S T R A C T

New Caledonia's Loyalty Islands are located in the southwest region of the Pacific ocean in the highly seismogenic southern Vanuatu subduction zone and therefore may be subject to devastating local tsunamis. Over the past 150 years, two large tsunamis were triggered by major earthquakes on March 28th 1875 and September 20th 1920. In this study, we use historical observations of these tsunamis (mostly in the form of testimonials), earthquake scenarios, and tsunami modeling to derive the magnitudes of these earthquakes, as well as tsunami runup and inundation maps. Assuming that these earthquakes were located on the interplate megathrust zone, the 1875 earthquake's magnitude was M_w8.1–8.2 and the 1920 event's magnitude was M_w7.5–7.8. The tsunami damage inflicted on the Lifou and Maré islands was approximately proportional to these magnitudes, with Maré being less impacted due to favorable wave directivity. Damage at Ouvéa island may have varied irregularly with the magnitude due to the effects of resonance. This study demonstrates that the quantitative characteristics of historical tsunamigenic earthquakes may be derived from qualitative estimates of tsunami runup.

1. Introduction

The Vanuatu subduction zone is a very active seismic area where the Australian Plate subducts beneath the Vanuatu arc (Fig. 1). The southern segment of the subduction zone, which lies to the west of the Erromango/Tana/Anatom islands, is important because it represents the location of two supposedly large earthquakes occurring within the last century and a half: the March 28th 1875 and September 20th 1920 earthquakes. These earthquakes have not been quantitatively documented and their magnitudes have never been clearly identified. Therefore, it is important to determine these magnitudes to derive useful information that may be useful for further studies of the local seismic cycle. However, these events are anterior to the installation of seismic instruments (before 1976) and thus require the implementation of an alternative, indirect option.

Both of these earthquakes triggered tsunamis. Unfortunately, there are no available quantitative data, such as tide gauges or paleo-tsunami records, that can be processed by tsunami inversion to derive the magnitudes of these earthquakes. However, the impacts of the two tsunamis (especially the 1875 one) have been described (mainly through testimonials) with very good precision by missionaries and local newspapers in the Loyalty Islands, west of the southern segment of the Vanuatu arc. Although it is true that testimonials are always subjective, comparing different sources can reveal precious important information. Furthermore, comparing testimonials with simulated tsunami runups based on realistic earthquake scenarios may allow us to derive magnitudes within a certain degree of accuracy. By identifying specific tsunami amplifications or attenuation processes occurring over a limited range of earthquake magnitudes, we also might be able to bracket these events with better precision. These processes may compensate for a lack of quantitative runup in an inversion procedure. The 1875 and 1920 events, and their associated tsunamis, are two prime examples of this technique.

The Loyalty Islands of New Caledonia are located immediately to the west of the Southern Vanuatu subduction zone (Fig. 1) and therefore may be strongly impacted by local tsunamis. Historical records (1729–2016) reveal that two destructive tsunamis have previously struck these islands, one on 20 March 1875 (Louat and Baldassari, 1989) and the other on 20 September 1920 (Sahal et al., 2010). Both tsunamis were generated by local earthquakes. Neither of these earthquakes has been quantitatively well-constrained, but the 1920 event is classified as having a Mw magnitude of 8.1 in the ISC-GEM Global Instrumental Earthquake Catalog (1900–2012). Detailed descriptions of these tsunamis (mostly generated from witness reports) are provided in Louat and Baldassari (1989) and Sahal et al. (2010).

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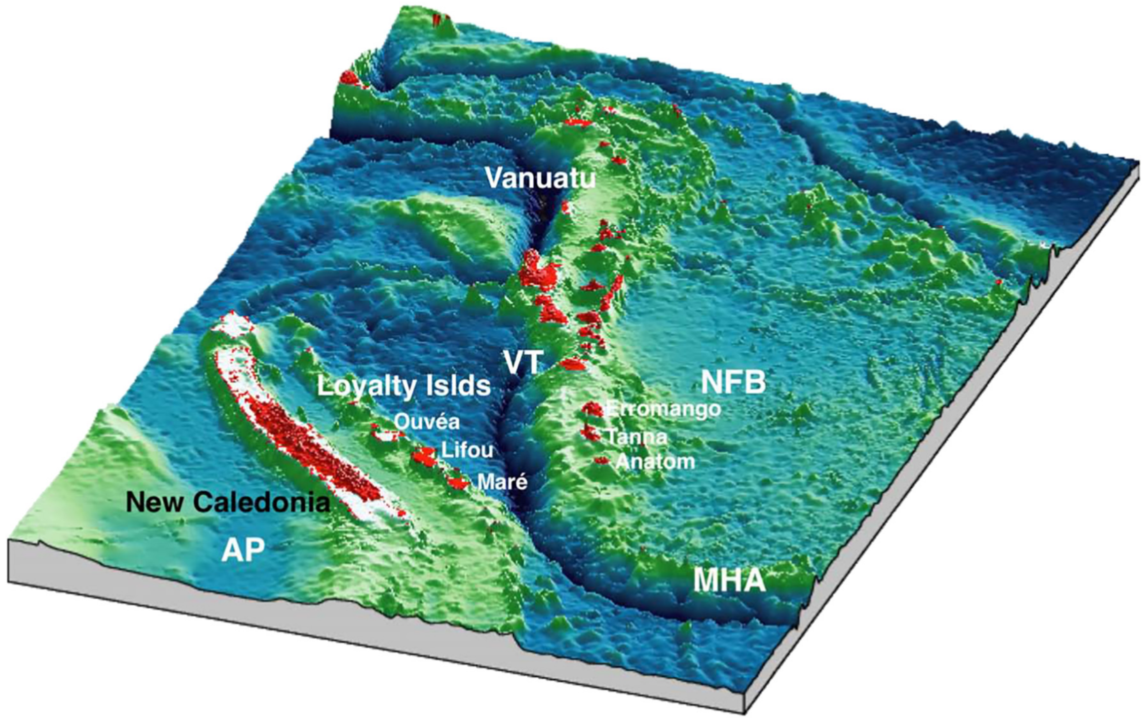

Fig. 1. Bathymetry of the Vanuatu subduction zone (Pillet and Pelletier, 2005; Data from Smith and Sandwell, 1997). NFB represents 'North Fiji Basin', VT is 'Vanuatu Trench', MHA is 'Matthew-Hunter Arc' and AP is 'Australian Plate'.

Tsunami propagation times from local earthquakes to the Loyalty Islands are potentially very short (as little as 10–15 min for Maré island), which limits the efficiency of existing tsunami warning systems. Regional and tele-tsunamis have not yet generated destructive tsunamis (although their wave oscillations have reached up to 1.5 m (Sahal et al., 2010) and thus provide longer warning periods (from 2 to 10s of hours).

The inundation and runup hazard of the Loyalty Islands must be understood to prepare for future tsunamis, particularly local tsunamis that can strike with little warning. In the absence of quantitative data about past tsunamis or their source earthquakes, witness accounts of these events can be combined with knowledge of the local tectonic context and tsunami modeling to constrain past earthquake magnitudes and thus estimate future tsunami hazards.

In this study, we present a deterministic tsunami map (inundation and runup) of the Loyalty Islands, derived from a series of data, including historical accounts of the 1875 and 1920 tsunamis, the tectonic context of the south Vanuatu subduction zone, and detailed bathymetric and topographic maps of the Loyalty Islands and their surrounding areas. We also use the tectonic and earthquake context of Southern Vanuatu to build realistic and coherent earthquake scenarios, and use the *Funwave* tsunami numerical code to model the propagation and runup of these tsunamis. Finally, we compare these models to historical accounts to build a series of tsunami maps and to estimate the magnitudes of the 1875 and 1920 tsunamigenic earthquakes.

2. Observations of the March 28th 1875 and September 20th 1920 tsunamis

The 1875 earthquake triggered a tsunami so significant that Catholic missionaries who had settled in Loyalty Islands sent reports of it to their hierarchy (Louat, 1988; Louat and Baldassari, 1989; New Caledonian Newspaper *Le Moniteur* of April 28th 1875). Because these reports only contain information about the island of Lifou, we assume that Ouvéa and Maré were not significantly impacted. We do not have the detailed presence of the missionaries but we suppose that either they settled on the three islands and they did not observe significant damages in Ouvea and Maré or they were based only in Lifou and they did not hear of significant damages from the population. During this period the missionaries represented a kind of authority that was in charge of listing the population. Therefore we will assume that these tsunami reports describe the complete situation in the three islands. Observations of the 1875 tsunami at Lifou that have been reported by Louat and Baldassari (1989), may be summarized as (Fig. 2):

a. At the village of *We*, within the bay of Chateaubriand, the sea flooded the Catholic church, which is located approximately 50 m away from the coastline at high tide (this is designated as a 'moderate' impact, as seen in Fig. 2).
b. In the southeast region of Lifou, around the *Cap des Pins* between *Mou* and *Luengoni*, the sea flooded and carried away several traditional dwellings while receding. Twenty-five people perished in these circumstances. More detail is available about the effects of this tsunami as it moved from the south (*Mou*) to the north (*Luengoni*). In the village of *Mou* and to its immediate south, the sea flooded cultivated lands (claiming 10 victims, designated as a 'large' impact event). To the north of *Mou*, over several miles, the sea did not cause any damage. However, on the other side of the peninsula, in the village of *Thoth*, the sea was high and violent, killing 15 people and injuring another 25 ('severe'). Northward, from *Thoth* to *Luengoni*, the sea did not cause any submersion. At *Luengoni*, high waves were observed, but they did not kill any people or cause any damage ('moderate').

Lida et al. (1972) proposed a tsunami intensity scale (Table 1), in which the empirical parameter $Hm = 2^m$ represents the maximum coastal wave height, identified here as a runup approximation. They attribute an $m = 2$ tsunami magnitude to the 1875 event. This estimate is supported by the known amount of human losses. It is also supported by the fact that the impact of the tsunami varied significantly on a spatial scale within the Loyalties domain, as the impact at Lifou was moderate to severe whereas the impact at the neighboring Ouvéa and Maré was weak.

It should be mentioned that the correspondence between approximate offshore wave height and actual (coastal) runup listed in Table 1