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Extraction of two tsunamis signals generated by earthquakes around the Pacific rim

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Abstract: As one of the ocean sudden natural disasters, the tsunami is not easily to differentiate from the ocean variation in the open ocean due to the tsunami wave amplitude is less than one meter with hundreds of kilometers wavelength. But the wave height will increases up to tens of meters with enormous energy when the tsunami arrives at the coast. It would not only devastate entire cities near coast, but also kill millions of people. It is necessary to forecast and make warning before the tsunami arriving for many countries and regions around the Pacific rim. Two kinds of data were used in this study to extract the signals of 2011 Tohoku tsunami and 2014 Iquique tsunami. Wave undulations from DART(Deep-ocean Assessment and Reporting of Tsunamis) buoys and SLA from altimetry could extract the tsunami signals generated by this two earthquake. The signals of Tohoku tsunami were stronger than that of Iquique tsunami probably due to the 2011 Tohoku tsunami was generated by a magnitude 9.0 earthquake and the 2014 Iquique tsunami was triggered by a magnitude 8.2 earthquake.

Key words: satellite altimetry; tsunami; sea level anomaly; DART; earthquake

1 Introduction and characteristics of tsunami

The word tsunami originates from a combination of two Japanese hierogliphs, translated together as a 'wave in the harbor'. Other phases, such as 'high-tide wave', 'seismic sea wave', 'seaquake', 'zeebeben' and 'maremoto' were also used to describe the tsunami. This term has already been conventionally adopted in scientific literature in 1963[1]. The tsunami is a series of water waves caused by the displacement of a large volume of a body of water, generally in an ocean or a large lake. It becomes a powerful destructive series of waves when the tsunami arrives at the coast and may devastate or affect the coastal populations.

At present, we do not have enough knowledge about the tsunami generation and propagation due to lack of enough scientific data of the phenomena and this phenomena has not been observed nor measured directly. There are various reasons that cause the tsunami, such as seismic motions of the sea-floor, submarine landslides or collapses, underwater volcanic eruptions, underwater nuclear explosion and the falling of meteorites. Usually, the frequently occurring tsunami is generated by an earthquake in the ocean. It is common sense or can be observed that the large magnitude earthquakes will generate long-period tsunamis. The reverse is also true. Recently, many studies shows that the size of a tsunami is directly related to the features (shape and amount of displacement) of the rupture zone and the depth of the water in the source area. The energy of a tsunami originates in the undersea disturbance and is transmitted to the column of water. The wave propaga-

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tion velocity of tsunami is up to 600 to 1000 km/h, it will be able to cross the ocean in a few hours. It can spread thousands of kilometers but the energy loss is small because the tsunami wavelength is up to hundreds of kilometers. In the open ocean, its wave height is usually less than 1 m, but when it reaches the shallow coastal areas, its wavelength decreases and wave height increases dramatically, up to tens of meters, to form a "water wall" containing enormous energy. Every few minutes or tens of minutes, the roaring water wall repeats once again with devastating energy to destroy banks, flood the land, claim lives and property.

The height of "water wall" or named "runup", the maximum height of the water observed above a reference sea level, is the most straightforward parameters of tsunami. In order to study and compare different tsunami events, some other accurate parameters are needed to describe the scales of tsunami intensity or magnitude. Two terms may be determined from the runup value, the first one is tsunami magnitude, and the second one is tsunami intensity.

There are several definitions of tsunami magnitude, one of them is based on the maximum tsunami-wave height H_{max}, which is defined as

$$m = \log_2 H_{max} \tag{1}$$

The best parameter to estimate the size of different tsunamis would be their total energy. So Murty & Loomis proposed another parameter of tsunami magnitude based on the potential energy E[1,2]

$$ML = 2(\log E - 19) \tag{2}$$

In Murty & Loomis original publication, the ML values were determined from 25 largest Pacific tsunamis, since that time almost no new calculations of ML were made. The reason is that the ML value is not easy to calculate since it requires knowledge of initial displacement in a tsunami source or tsunami waveforms at different locations and azimuths, which is not always possible and rarely used for real tsunamis. Another scale of tsunami magnitude, calculated from[1]

$$M_t = a\log H_{max} + b\log R + D \tag{3}$$

where H_{max} is the maximum tsunami-wave amplitude measured by a tide gauge at a distance R from the epicenter, a, b and D are constants used to make the M_t scale match as closely as possible with the moment magnitude scale.

If the maximum height in equation (1) is replaced with an average height H_{ave} and a constant 1/2 is added to this equation, we can get the second parameter to describe the tsunami, tsunami intensity, which is defined as[1]

$$I = \frac{1}{2} + \log_2 H_{ave} \tag{4}$$

The definition was given by Soloviev, and now is widely used. This scale is conventionally termed as 'Soloviev-Imamura tsunami intensity scale'. Generally speaking, the magnitude scale relates to the source of an event, while the intensity scale describes the resulted effect at impact locations.

The tsunami propagation velocity, except the above mentioned scale of tsunami, is another important parameter of tsunami, especially for warnings and predictions. We need it to calculate the wave front for warning. The tsunami wave velocity in open sea depends on the ocean depth (H) and the acceleration of the force of gravity (g) and can be approximately expressed as

$$v = \sqrt{gH} \tag{5}$$

In reality, we should consider the wavelength λ and use the following equation:

$$v = \sqrt{\frac{g\lambda \tanh(2\pi H/\lambda)}{2\pi}} \tag{6}$$

From equation (6), we can see the shorter the wavelength, the slower it propagates. But as a rough estimate, the wave front position from equation (5) is quite accurate and the error does not exceed the size of the tsunami source about 50–100 km[1].

Several serious tsunamis occurred in the past decade. The most destructive one was Sumatra, Indonesia on 26 December 2004. The 9.1 magnitude earthquake