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THE 26TH DECEMBER 2004 INDIAN OCEAN TSUNAMI: THE INTENSITY FIELD

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Abstract

The Mw=9.3 Sumatra earthquake of 26.12.2004 triggered one of the most devastating tsunamis. A great number of coastal sites were affected around the Indian Ocean from near-field up to distances of more than 6000 km. We compiled field data taken by many research groups, including the present one, from around the Indian Ocean and classified them according to their geographical distribution. In every observation point, the various effects of the tsunami have been transformed to tsunami intensities. The 12-point intensity scale was applied. Maximum intensities ranging between 10 and 12 have been assigned not only to near-field localities of Sumatra and to mid-field localities but also to far-field spots of East Africa. A similar pattern for the maximum wave heights (10 m $\leq h \leq$ 35 m) observed has been found for near- and mid-field locations. However, no such large wave heights were observed in East Africa, which implies that the tsunami intensity is controlled by the wave heights and also by other natural and anthropogenic factors. In fact, wave heights and intensities were mapped along the coast of Sri Lanka, where the dataset is more accurate and complete. For these reasons wave height and intensity practically are not correlated.

Key words: *Indian Ocean tsunami, intensity scale, wave heights.*

Περίληψη

Ο σεισμός μεγέθους Mw=9.3 της Σουμάτρας που συνέβη στις 26.12.2004 πυροδότησε ένα από τα πιο καταστροφικά τσουνάμι το οποίο επηρέασε ένα μεγάλος αριθμός παράκτιων περιοχών στον Ινδικό Ωκεανό από κοντινές αποστάσεις μέχρι αποστάσεις της τάξης των 6000 km. Συλλέξαμε τα δεδομένα που πήραμε από διάφορες ερευνητικές ομάδες, συμπεριλαμβανομένου και της δικής μας, από όλον τον Ινδικό Ωκεανό και τα ταξινομήσαμε ανάλογα με την γεωγραφική τους κατανομή. Σε κάθε σημείο παρατήρησης, οι επιπτώσεις του τσουνάμι μετατράπηκαν σε εντάσεις με τη χρήση της 12-βάθμιας κλίμακας. Οι μέγιστες εντάσεις κυμαίνονται ανάμεσα σε 10 και 12 και αποδόθηκαν όχι μόνο στις κοντινές περιοχές της Σουμάτρας και σε περιοχές ενδιάμεσης απόστασης, αλλά και στα πιο μακρινά σημεία της Ανατολικής Αφρικής. Παρόμοιο πρότυπο για τα μέγιστα ύψη (10 m $\leq h \leq$ 35 m) παρατηρήθηκε στις κοντινές περιοχές της Σουμάτρας και σε περιοχές ενδιάμεσης απόστασης. Στην

περιοχή της Ανατολικής Αφρικής δεν είχαμε μεγάλα ύψη, το οποίο υποδηλώνει ότι η ένταση του τσουνάμι ελέγχεται από τα ύψη του κύματος αλλά και από άλλους φυσικούς και ανθρωπογενείς παράγοντες. Τα ύψη των κυμάτων και οι εντάσεις τοποθετήθηκαν σε έναν χάρτη για την περιοχή της Σρι Λάνκα όπου τα δεδομένα μας είναι πιο πλήρη και ακριβή. Για αυτούς τους λόγους, τα ύψη των κυμάτων και οι εντάσεις του τσουνάμι πρακτικά δεν συσχετίζονται.
Λέξεις κλειδιά: *Τσουνάμι Ινδικού Ωκεανού, κλίμακα έντασης, ύψη κυμάτων.*

1. Introduction

The big earthquake (Mw 9.3) of 26 December 2004, 00:58:53 UTC, which ruptured large part of the Indonesian and Andaman - Nicobar island arcs, generated a large tsunami that spread out all over the Indian Ocean causing more than 220,000 victims and heavy destruction in hundreds of local communities in more than 12 countries. Millions of people were affected; many lost their homes and suffered tremendous grief. The effects of the tsunami were felt as far away as Somalia, Tanzania and Kenya along the east coast of Africa. The economic impact on countries surrounding the Indian Ocean was very significant. Of great interest is to understand the several natural and anthropogenic factors that contributed to the extensive destruction caused by the tsunami. The tsunami intensity is the appropriate parameter to describe the degree of destruction caused in particular localities of the coastal zones affected. Therefore, we constructed the intensity field of the 2004 tsunami which is composed by about 200 different intensity spots assigned all around the Indian Ocean on the basis of the 12-point tsunami intensity scale.

2. The Tsunami Intensity Scale

In the international tsunami literature only very few efforts have been made to quantify the effects of the tsunami waves. Some confusion prevailed in the past decades as far the terms "tsunami magnitude" and "tsunami intensity" are concerned. Table 1 summarizes the tsunami magnitude and intensity scales proposed since the 20's up to the present. The tsunami intensity scale introduced by Papadopoulos and Imamura (2001) incorporates twelve divisions, is consistent with the several 12-point seismic intensity scales and is based on the following basic principles:

(a) Independence from any physical parameter, like the measured or macroscopically observed wave amplitude (or height) in both the tsunami source and the coast affected, or the duration of the seawater disturbance in any observation point.

(b) Sensitivity; that is incorporation of an adequate number of divisions (or grades) in order to describe even small differences in tsunami effects.

(c) A detailed description of each intensity division by taking into account all possible tsunami impacts on the human and natural environment, the vulnerability of structures, etc.

3. Data, Method and Observations

A large number of observations is performed during post-event field-surveys and published in print and in the internet by many research groups including our group (Papadopoulos *et al.* 2005), (Fig. 1).The observational data collected, were compiled in a unified data basis which contains measured wave heights and damage descriptions for over than 200 observation points all around the Indian Ocean. The effects of the tsunami at any particular point were translated to intensity degree according to the 12-point intensity scale.

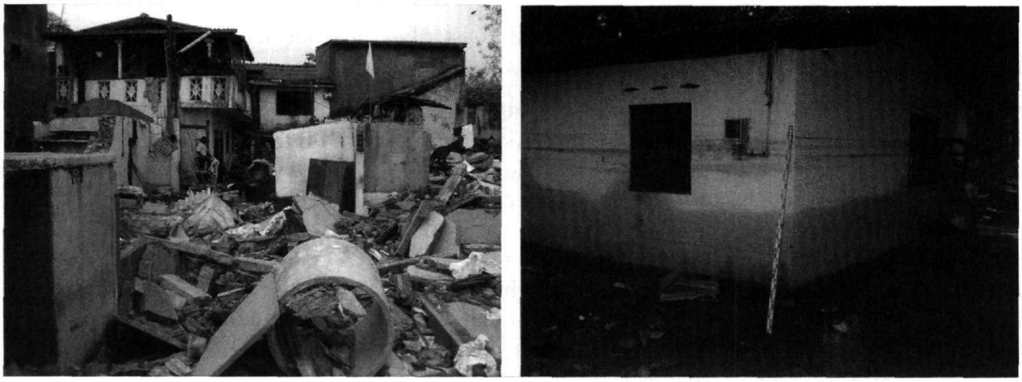

Figure 1 - Examples of field observations in Sri Lanka. Damage in local houses (left) and measurements of water height (right)

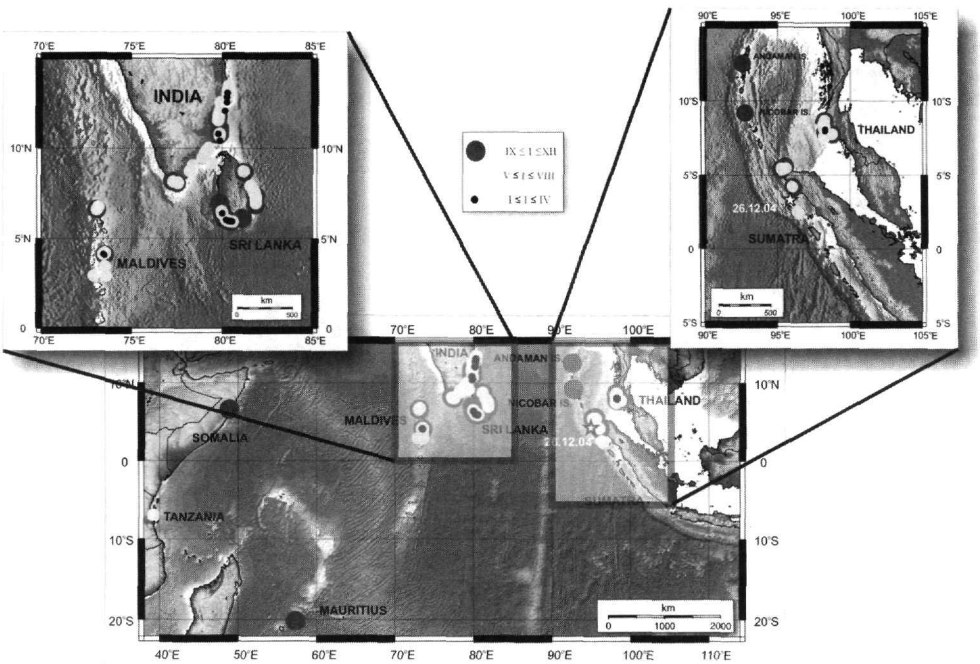

Figure 2 - Spatial distribution of the tsunami intensities around the Indian Ocean

Figure 2 illustrates the spatial distribution of the estimated tsunami intensities. Most of the estimated intensities exceed degree 7 and only some of them fall in the range from 4 to 6. This depends on the coastal geomorphphology, the different types of human constructions, the population density, the observer's personal judgment and other natural and anthropogenic factors. Maximum intensities ranging between 10 and 12 have been assigned to near-field localities of Sumatra and to mid-field localities of Thailand, India and Sri Lanka. It is noticeable that high intensities are also observed at spots, like the east coast of Africa, located very far from the tsunami source.

The spatial distribution of the tsunami wave heights measured is illustrated in Figure 3 which shows that the largest values are measured in near-field (h ~ 35 m in north Sumatra) and in mid-field locations ($10 \leq h \leq 20$ m). The pattern of spatial distribution of the wave heights is similar to that for tsunami intensities for near- and mid-field locations. No large wave heights were observed in East Africa. However, in a more local scale large differences prevail between tsunami intensities assigned to localities that are very close to each other. A good example is the south-west part of Sri Lanka (Fig. 4), where the dataset is more accurate and complete. Intensities range between 6 and 12 degrees, while the wave height ranges between 4 m and 11 m. The high population density along with the lack of tsunami awareness prevailing in most coastal communities of Sri Lanka increased drastically their vulnerability to the tsunami attack. It is worth notice that there is no good correlation between intensity and wave height, which is also valid for the entire intensity field in the Indian Ocean (Fig. 5). Therefore, the tsunami intensity is not controlled only by the wave height but also by other natural and anthropogenic factors.

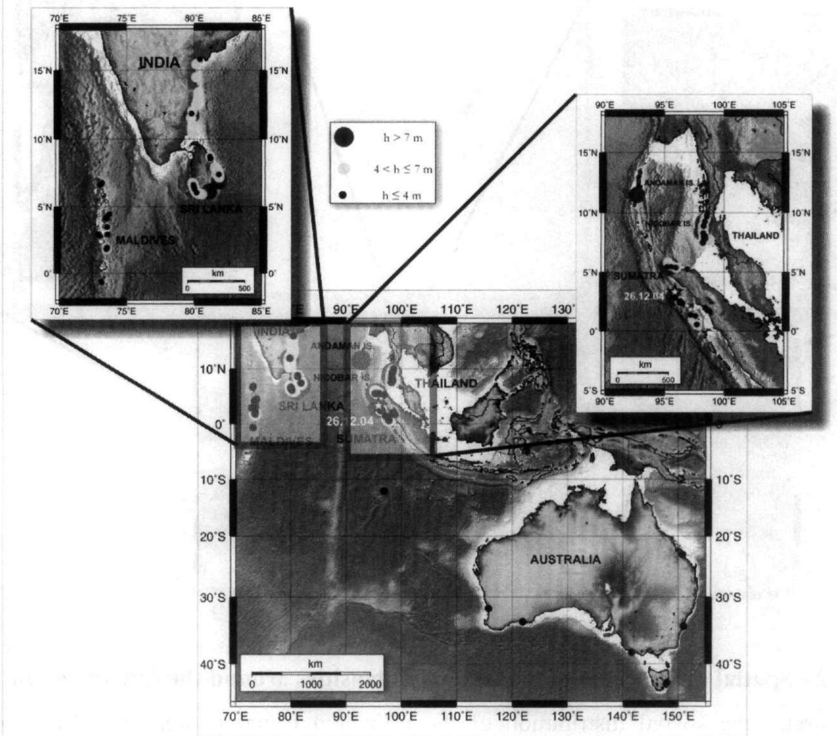

Figure 3 - The spatial distribution of the tsunami wave height around the Indian Ocean

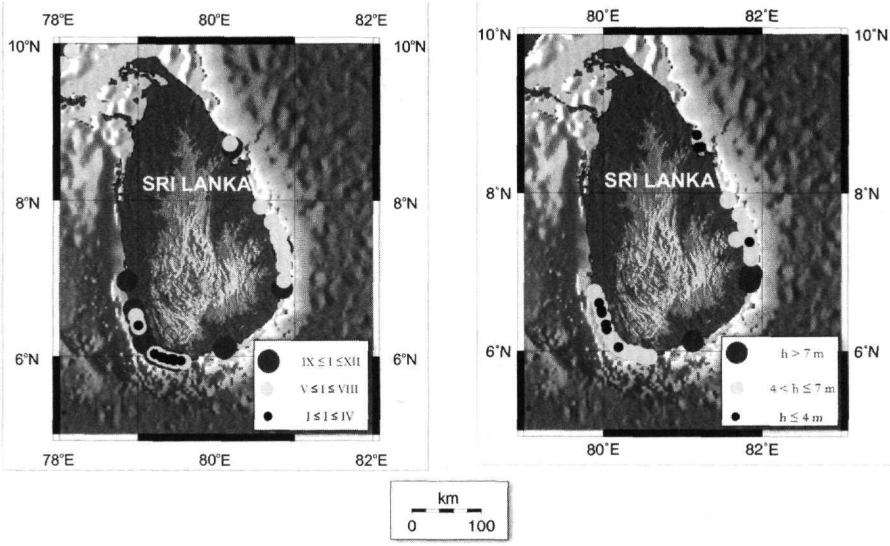

Figure 4 - Tsunami intensities in Sri Lanka (left) and tsunami wave height measured in Sri Lanka (right)

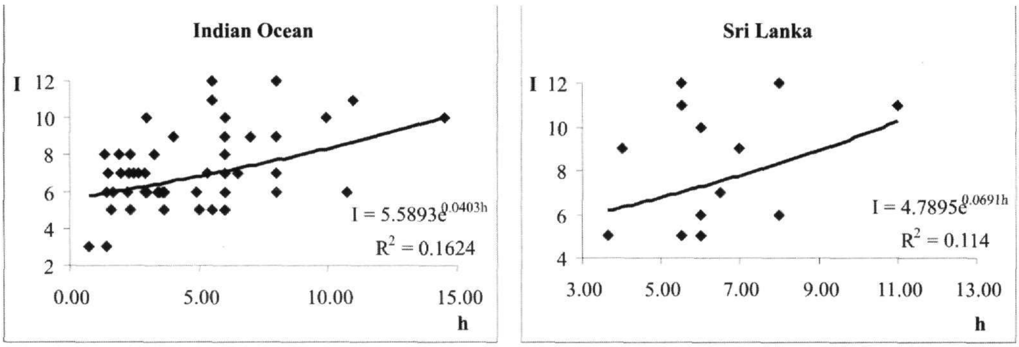

Figure 5 - Best fit for tsunami maximum wave height (h) – intensity (I) in the Indian Ocean (left) and Sri Lanka (right). Parameters h and I practically are not correlated

4. Conclusions

Maximum intensities ranging between 10 and 12 degrees have been assigned not only to near-field localities of Sumatra and to mid-field localities of Thailand, India and Sri Lanka but also to far-field spots of East Africa. A similar pattern for the maximum wave heights (10 m $\leq$ h $\leq$ 35 m) has been found for near- and mid-field locations. However, spots along the east African coast were significantly affected by relatively tsunami wave heights due to high vulnerability of local communities. On a more local scale, e.g. in SW Sri Lanka, a strong spatial variation of the tsunami intensity is observed. These observations clearly imply that the tsunami intensity is controlled not only by the wave heights but also by other natural and anthropogenic factors. This is in accordance with that no good correlation has been found between intensity and wave height for the entire intensity field in the Indian Ocean but also for Sri Lanka. The tsunami caused heavy destruction in population, the buildings and infrastructure, like railway and bridges. The heaviest destruction was noted in the south part of the Island where the maximum values of h were measured, in Galle and Hambantota villages that are located at the South part of Sri Lanka. It is worth noticing that there was serious destruction to buildings and infrastructure not only because of the hydrodynamic action of the wave but also because of its erosional impact in soil. Other physical factors that contributed to the disaster are coastal geomorphology and geology.

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