Re-evaluating source mechanisms for the 1998 Papua New Guinea tsunami using revised slump estimates and sedimentation modeling

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Abstract. The nature of the source mechanism for the 17 July 1998 Papua New Guinea tsunami continues to be controversial. A previous investigation (Titov and González, 1998) used a numerical model to examine differences between landslide and tectonic model sources for the tsunami; this study failed to find conclusive evidence that would favor one of the generation mechanisms. We have revisited the problem, using new scientific information as input to the model: slump generation now conforms to a model reconstructed from seismic profiles and new bathymetric and topographic data are used in the grids. Distinct features of the inundation caused by tectonic and/or slump generation mechanisms will be discussed, and model run-up flow estimates will be compared with estimates derived by a tsunami sedimentation model used to interpret field data.

1. Introduction

The 17 July 1998 Papua New Guinea (PNG) tsunami has been intensively studied for more than 2 years. However, in spite of the wealth of scientific data now available, the nature of the source mechanism for this event continues to be controversial. Although most scientists now agree that a landslide did occur offshore, many disagree on whether it moved during the 1998 event and, if so, whether it generated a significant tsunami.

A previous investigation (Titov and González, 1998) used the Method Of Splitting Tsunamis (MOST) numerical model to examine differences between landslide and tectonic model sources for the PNG tsunami by comparing model run-up estimates with observed inundation heights. Based solely on the amplitude, this study failed to find definitive evidence that would favor one of the generation mechanisms. However, numerical results indicated substantial differences in water particle velocities during inundation for different source models. One of the conclusions, therefore, was the need for independent velocity estimates to constrain the inundation model.

Such independent estimates came from modeling of sedimentation data collected during the second PNG post-tsunami field survey (Jaffe *et al.*, 1998; Gelfenbaum *et al.*, 2001). We used new scientific information for input to

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the MOST model: slump generation now conforms to a model reconstructed from seismic profiles (Sweet and Silver, 2000) and new bathymetric and topographic data are used in the computational grids. Distinct features of the inundation caused by tectonic and/or slump generation mechanisms are discussed, and MOST model run-up flow estimates are compared with estimates derived by a tsunami sedimentation model used to interpret field data.

2. Velocity Estimates from Tsunami Sedimentation Model

2.1 Concept

Deposits left by a tsunami can be interpreted to estimate flow velocity in the tsunami. The thickness and grain size of the deposit is the result of sediment transport during the tsunami. In general, thicker deposits with larger grain sizes indicate faster flows. A deposit is formed by spatial gradients in transport (more coming into an area than leaving it), by change in storage of sediment in suspension in the water column, or by a combination of these processes. The variation in grain size in the deposit may be used to constrain the relative contributions of transport gradients and sediment storage in the water column to forming the deposit. For example, when sediment settles from suspension (change in storage in the water column) the deposit will have particles with higher settling velocities near the bottom and particles with lower settling velocities near the top. When the density of particles is similar, larger particles have higher settling velocities. The resulting deposit will have larger particles near the bottom creating a normal grading (Jaffe, in preparation).

A simple model for formation of the Papua New Guinea tsunami deposits is that the sediment deposited was in equilibrium with the maximum landward flow velocity. When the flow stopped, the turbulent eddies that suspended sediment were quickly dissipated and all of the sediment in suspension settled out of the water forming a normally graded deposit. This simple model is supported by normal grading observed in the Papua New Guinea tsunami deposits. The Tsunami Sedimentation (TS) model calculates the flow velocity that created the deposit.

2.2 Tsunami sedimentation model

The TS model calculates flow velocity from the thickness and grain size distribution of the tsunami deposit. Steady uniform flow is assumed. At equilibrium, the downward settling of sediment is balance by upward mixing resulting in a steady concentration profile described by:

$$C(z) = Ca(z/z_o)^{ws/kU*}$$

where z is the elevation above the bed, Ca is the reference concentration (a function of excess shear stress and the resuspension coefficient, Υ_o), z_o is the bottom roughness parameter, ws is the sediment settling velocity, k is Von Kármán's constant, 0.41, and $U*$ is the shear velocity.

The TS model iteratively adjusts sediment source distribution and shear velocity (a parameterization of turbulent mixing intensity) to match the observed bulk grain size distribution and thickness of the tsunami deposit. Standard formulations and values are used for coefficients of the model. The resuspension coefficient, Υ_o, is 1.4×10^{-4} (Hill *et al.*, 1989). The bottom roughness parameter, z_o, is a combination of the Nikaradse grain roughness and a moveable bed roughness (Wiberg and Rubin, 1989). A linear eddy viscosity profile parameterizes the vertical variation in turbulent mixing. The bulk grain size distribution of the tsunami deposit is measured from field samples. The TS model used 45 size classes at $\frac{1}{4}\ \phi$ intervals (ϕ is equal to $-\log_2$ of the grain size in millimeters) to characterize the concentration profiles (45 profiles) in the water column. After determining the shear velocity needed to produce the deposit, flow velocity is calculated using the logarithmic velocity profile (law of the wall):

$$U(z) = \frac{U*}{k} \ln\left(\frac{z}{z_o}\right)$$

The maximum flow velocity ($z =$ depth of the flow) is reported in the Preliminary Results section.

3. Model of Tsunami Generation and Inundation

Tsunami simulations are performed with the MOST model. The model uses depth-averaged non-linear shallow water wave equations to simulate long wave propagation and inundation. Details and validation of the model can be found elsewhere (Titov and Synolakis, 1995, 1998; Titov and González, 1998).

A comparison of the results from the MOST and TS models is not valid at all points on the profile. The MOST model uses moving boundary conditions to compute inundation of tsunami waves on dry land. The moving boundary algorithm does not require bottom friction to perform run-up computations. Frictionless inundation simulations have shown excellent agreement with laboratory data and with many historical tsunami field data. The MOST model of the 1993 Okushiri tsunami (Titov and Synolakis, 1997) produced estimates of the flow velocities during overflow of the Aonae peninsula that were confirmed by field observation estimates, proving the validity of the approach. Nonetheless, the flat topography of the Sissano area presents a challenge for this inundation modeling approximation, since frictionless flow propagates great distances inland without energy dissipation and, therefore, without decline of flow velocity. Assigning different roughness coefficients to portions of the topography may confine the computed inundation area close to observed flooding, and furthermore, may help reproduce a given (measured) flow velocity along a profile. However, since there are no independent estimates of the roughness values for the inundation model, applying bottom friction models would not give us additional insight about the source of the

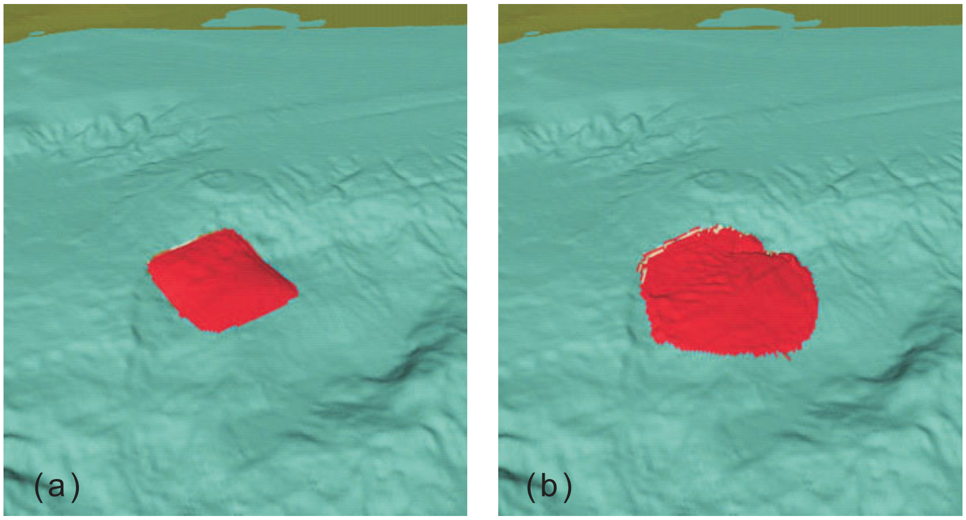

Figure 1: Perspective view (from the North) of the model of the landslide evolution. Landslide mass (red color) deformation is shown at (a) 10 s and at (b) 40 s after the slide initiation.

wave. Therefore, the focus of this study has been frictionless estimates of the flow velocities close to the shoreline, where topography roughness does not reduce the values substantially.

Tsunami generation is modeled using seismic dislocation and landslide-slump models. The models are similar to those used by Titov and González (1998). Parameters and locations of the sources are now adjusted to correspond to new evidence collected by the post-tsunami field surveys. Figure 1 shows a preliminary model of the landslide source evolution over the bathymetry profile. Parameters not constrained by field evidence are varied to estimate their influence on tsunami inundation.

4. Preliminary Results

Tsunami deposits from three locations on a shore-normal transect at Arop School (Fig. 2) were modeled to determine the landward variation in maximum flow velocities. Model inputs (thickness and grain size distribution) were measured in the field and laboratory, respectively. Thickness of the deposits varied from 2 to 8 cm. Deposits were thinnest at the most landward site (3), but, surprisingly, were thicker at the intermediate site (2) than at the most seaward site (1) (Jaffe *et al.*, 1999; Gelfenbaum *et al.*, 2001). Mean grain size tended to fine landward (Gelfenbaum *et al.*, 2001). However, the mean grain size did not completely describe the distribution of the deposits. The sorting and, in particular, the skewness were important descriptors of the distribution. The amount of sediment in suspension is a strong function of the grain size and the larger particles in the deposit constrained the model results. The TS model predicts that the maximum flow velocity during the 17 July 1998 tsunami decreased from approximately 15 m/s at 253 m inland

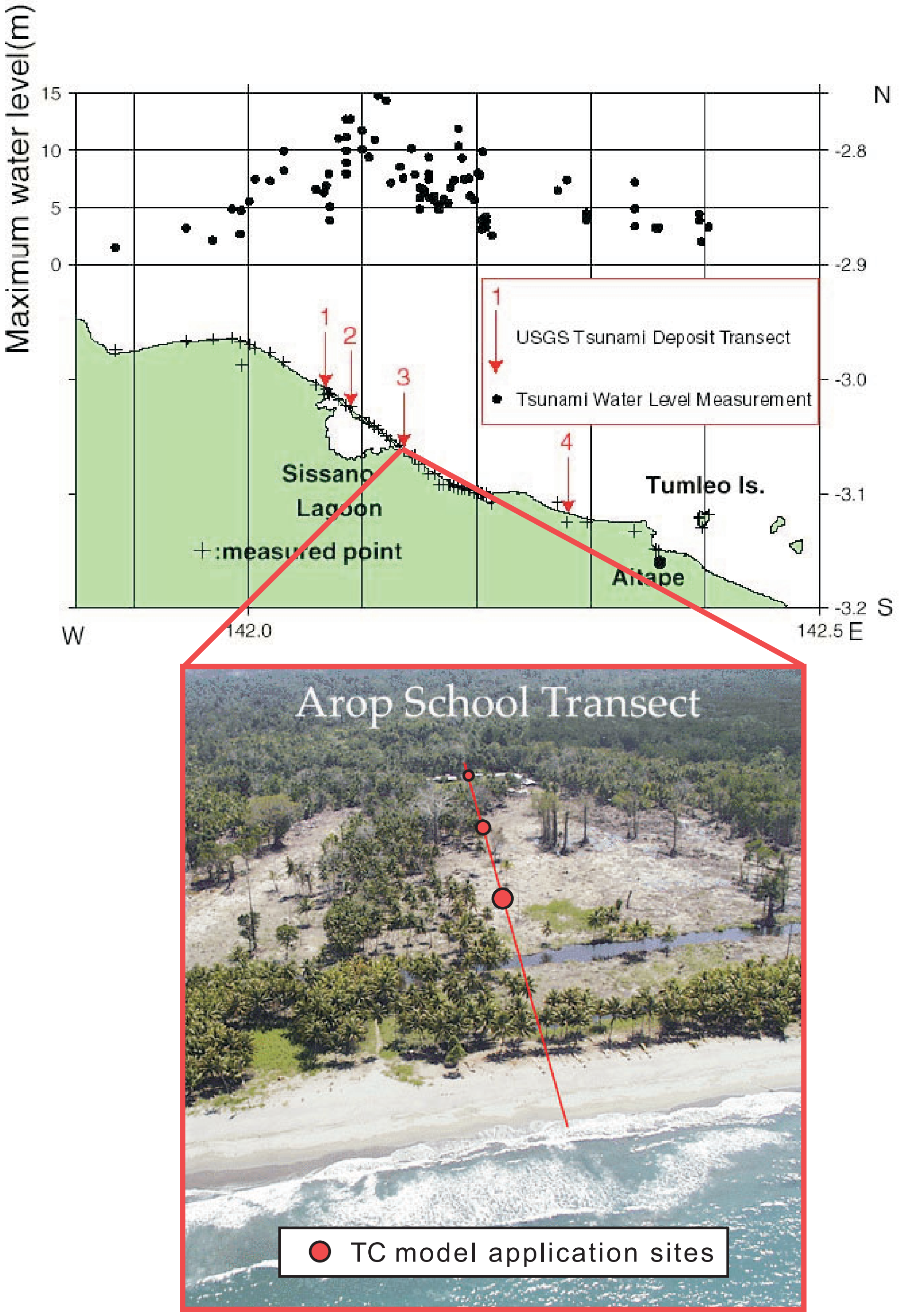

Figure 2: Location of Arop School transect with sites where TS model was applied.

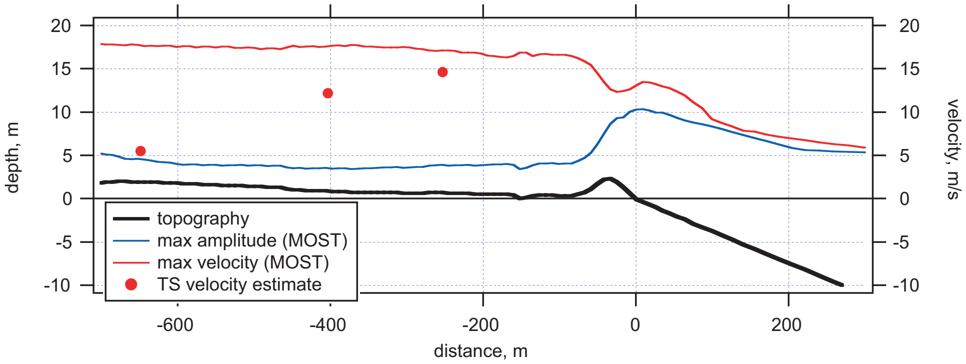

Figure 3: Comparison between preliminary results of the 1-D inundation model and TS model velocity estimates.

to approximately 5 m/s at 649 m inland (Fig. 3). The limit of inundation measured in the field was 718 m inland.

Figure 3 shows comparison between the three TS model velocity estimates (dots) and preliminary results of the 1-D (one spatial dimension) inundation model (solid lines) for one source model. Computed maximum flow velocities (blue line) and maximum computed flow depth (red line) profiles over the Arop transect are plotted. The figure demonstrates that both models predict similar flow velocities near the shoreline. Further inland, the inundation model does not show velocity decay predicted by the TS model. This is a manifestation of the frictionless nature of the inundation model. The 1-D model flow does not slow down over nearly horizontal topography profile, which indicates that the moving boundary condition does not induce any additional friction to the model.

These preliminary results demonstrate the validity of the approach. The full paper will discuss and compare results of two-dimensional (two spatial dimensions) tsunami inundation models from different sources.

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