Geophysical Research Abstracts
Vol. 15, EGU2013-12732, 2013
EGU General Assembly 2013

2011 Tohoku tsunami hydrographs, currents, flow velocities and ship tracks based on video and TLS measurements

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The March 11, 2011, magnitude Mw 9.0 earthquake off the Tohoku coast of Japan caused catastrophic damage and loss of life to a tsunami aware population. The mid-afternoon tsunami arrival combined with survivors equipped with cameras on top of vertical evacuation buildings provided fragmented spatially and temporally resolved inundation recordings. This report focuses on the surveys at 9 tsunami eyewitness video recording locations in Myako, Kamaishi, Kesennuma and Yoriisohama along Japan's Sanriku coast and the subsequent video image calibration, processing, tsunami hydrograph and flow velocity analysis. Selected tsunami video recording sites were explored, eyewitnesses interviewed and some ground control points recorded during the initial tsunami reconnaissance in April, 2011. A follow-up survey in June, 2011 focused on terrestrial laser scanning (TLS) at locations with high quality eyewitness videos. We acquired precise topographic data using TLS at the video sites producing a 3-dimensional "point cloud" dataset. A camera mounted on the Riegl VZ-400 scanner yields photorealistic 3D images. Integrated GPS measurements allow accurate georeferencing. The original video recordings were recovered from eyewitnesses and the Japanese Coast Guard (JCG). The analysis of the tsunami videos follows an adapted four step procedure originally developed for the analysis of 2004 Indian Ocean tsunami videos at Banda Aceh, Indonesia (Fritz et al., 2006). The first step requires the calibration of the sector of view present in the eyewitness video recording based on ground control points measured in the LiDAR data. In a second step the video image motion induced by the panning of the video camera was determined from subsequent images by particle image velocimetry (PIV) applied to fixed objects. The third step involves the transformation of the raw tsunami video images from image coordinates to world coordinates with a direct linear transformation (DLT) procedure. Finally, the instantaneous tsunami surface current and flooding velocity vector maps are determined by applying the digital PIV analysis method to the rectified tsunami video images with floating debris clusters. Tsunami currents up to 11 m/s were measured in Kesennuma Bay making navigation impossible (Fritz et al., 2012). Tsunami hydrographs are derived from the videos based on water surface elevations at surface piercing objects identified in the acquired topographic TLS data. Apart from a dominant tsunami crest the hydrograph at Kamaishi also reveals a subsequent draw down to minus 10m exposing the harbor bottom. In some cases ship moorings resist the main tsunami crest only to be broken by the extreme draw down and setting vessels a drift for hours. Further we discuss the complex effects of coastal structures on inundation and outflow hydrographs and flow velocities. Lastly a perspective on the recovery and reconstruction process is provided based on numerous revisits of identical sites between April 2011 and July 2012.