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Full length Article

Hybrid stochastic ground motion modeling of the M_w 7.8 Gorkha, Nepal earthquake of 2015 based on InSAR inversion

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ABSTRACT

We derive the coseismic slip distribution on a fault for the 2015, M_w 7.8 Gorkha earthquake based on ALOS-2 wide scan data and the inversion code, SDM (Steepest Descend Method). The results show that the maximum slip is 4.7 m, and the total released seismic moment is 6.02×10^{20} N m, equivalent to an earthquake of $M_w \sim 7.82$. Static stress and slip heterogeneity analyses show that both the average stress drop and corner wavenumber are at a low level. Additionally, we model the observed impulsive behavior at the near-source KATNP station using a hybrid stochastic approach, which combines an analytical approach at low frequencies with a stochastic approach at high frequencies. The good agreement between the hybrid modeling and observed records reveals that the input parameters, such as stress drop or slip distribution, are suitable for the Gorkha earthquake. The success of the modeling indicates that, in addition to the smooth onset of STF (slip-rate time function), the low stress drop and low degree of slip heterogeneity are also responsible for the low level of high-frequency ground motion during the Gorkha earthquake.

1. Introduction

On April 25, 2015 (local time 11:56 a.m.), an earthquake of M_w 7.8 occurred along the Himalayan front, with its hypocenter located in the Gorkha region (approximately 80 km north–west of Kathmandu), devastating the region at the rim of the High Himalayan range and affecting the Kathmandu valley, causing tremendous damage and loss. The Center for Disaster Management and Risk Reduction Technology reported that the total economic loss is on the order of 10 billion U.S. dollars, which is approximately half of Nepal's gross domestic product. This was the largest event since the M_w 8.1 Bihar–Nepal earthquake in 1934. Studies indicate that this earthquake ruptured the MBT (Main Boundary Thrust), the main fault along which northern India underthrusts the Himalayas at a rate of approximately 2 cm/yr (Avouac et al., 2015). The focal mechanism from the USGS (2015) indicates that thrusting is on a subhorizontal fault dipping approximately 10° northwards and at approximately 10 km hypocentral depth (see Fig. 1).

Strong motion observation networks in Nepal are not well developed, and recorded data are not publicly accessible. Currently, recorded time-history data of strong motion are only available at the KATNP station, which provides critical quantification of strong ground motions in the Kathmandu Valley. Records from KATNP indicated a pulse-like rupture, and a strong impulsive long-period motion was observed (Galetzka et al., 2015). The geometry of the velocity pulse and ground motion can be considered an effect of forward rupture directivity or tectonic offset (Mavroeidis and Papageorgiou, 2003). On the other hand, this record displays surprisingly low peak ground acceleration (PGA), only ~16% of g. Records from KATNP are not an isolated case; the low PGA value and general character of the waveforms are consistent with a recording from the NDMG (Nepali Department of Mines and Geology) instrument (Amod et al., 2015). Nobuo et al. (2016) show that four additional observed PGA values were smaller than predicted. Shaking intensity estimates from Nepal reveal that damage in Kathmandu was lower than would have been predicted given the magnitude and rupture (Stacey et al., 2015; Galetzka et al., 2015).

Galetzka et al. (2015) have shown that the smooth onset of the STF and related large slip-weakening distance could explain the relatively low amplitude of high-frequency intensity measures such as PGA. The purpose of this article is to determine other source parameters affecting high-frequency motion. We also simulate the observed impulsive behavior at near-source KATNP station using a hybrid stochastic approach to validate the slip model parameters we inverted from InSAR data.

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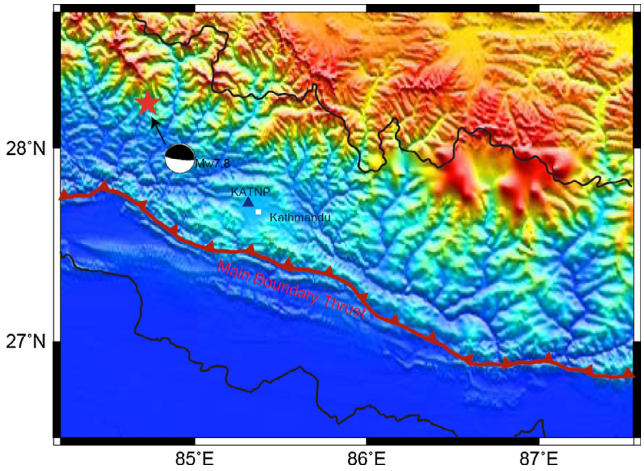

Fig. 1. General seismotectonic map of the April 25th, 2015, Gorkha earthquake. The red star corresponds to the epicenter. The blue triangle corresponds to the KATNP national seismic network station.

2. Slip model from InSAR

In the past decades, InSAR (Interferometric Synthetic Aperture Radar) has been widely used to measure surface displacements with unprecedented spatial coverage and resolution. In this paper, we use ALOS-2 wide scan data to obtain wide coverage of the coseismic deformation field, and then the inversion code, SDM, developed by Wang et al. (2013) is used to derive the coseismic slip distribution on the fault. SDM code is a slip inversion code, which adopts the Steepest Descend Method and Laplacian smoothing to solve slip distribution and regularize the solution. Discussing the steepest descent method is beyond the scope of this paper, and the interested reader may refer to Wang et al. (2013) for a detailed presentation.

Raw radar scenes were obtained from the ALOS-2 satellite. The ALOS-2 data were processed using the JPL/Caltech ROI_PAC software, and the phase was unwrapped using FRAM-SABS software. The scenes and data used in this study are shown in Table 1. The resulting unwrapped interferograms and line-of-sight (LOS) displacement are shown in Fig. 2. To make the computation feasible and efficient, it's necessary to down-sample the InSAR observations into limited numbers. We employed a Quadtree method (Jónsson et al., 2002) to down-sample the data points.

During the inverting process, the fault geometry is generally guided by the focal mechanism reported by the USGS (2015). We assumed planar fault geometry with a strike of 295° and a dip of 11°. The fault dimension is 210 km along the strike and 160 km in the down dip direction. We discretized the fault plane into 21 × 16 patches. Both dip- and strike-slip were allowed for each fault patch, while the rake was set to vary in a range from 65° to 120° in order to be consistent with the focal mechanism. Using a layered crustal structure (Table 2) and InSAR observations collected in this study, the best-fit slip distribution of the mainshock suggests that the most slip was concentrated within depths of 11–19 km. A maximum slip of 4.7 m occurred at a depth of 16 km. The total released seismic moment was 6.02×10^{20} N m, equivalent to an earthquake of M_w ~7.82.

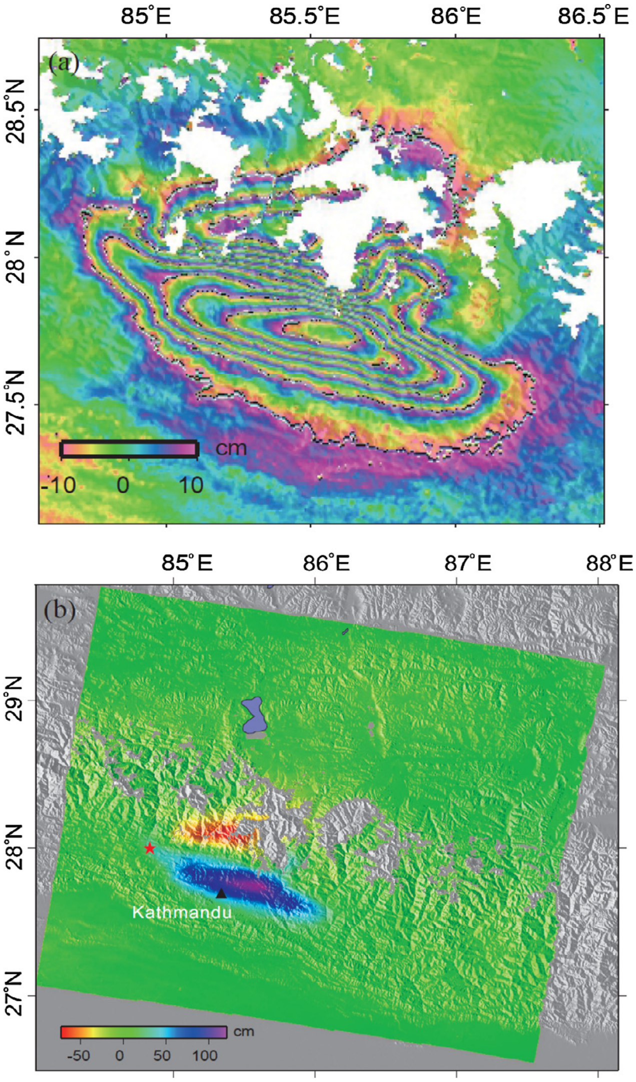

Fig. 2. (a) Coseismic interferogram from ALOS-2 descending Path 50 covering the M_w 7.8 Gorkha earthquake. (b) LOS displacement for the subarea covered by ALOS-2 along descending Path 50.

Because of differences in the data used, discretization schemes, fault geometry simplifications, constraints on slip rake and smoothness of the slip distribution, our slip model is slightly different from other results (Wang and Fialko, 2015; Feng et al., 2015, 2016; Diao et al., 2015; Feng et al., 2016). However, our slip model and these results all resemble the slip pattern and magnitude of the mainshock. Fig. 3 shows a comparison between our results and the slip model inverted from broadband waveforms provided by the USGS (2015). The peak slip value of the USGS model is lower than our inverted model. Both place the largest slip on the shallow part of the megathrust, approximately 16 km below the ground surface.

Table 1
Interferograms used in this study.

Satellite	Flight direction	Track	Master	Slave	Incident angle	PerpB[a]
ALOS-2	Descending	50	20150405	20150503	25–40°	7.067

[a] PerpB is for perpendicular baseline.