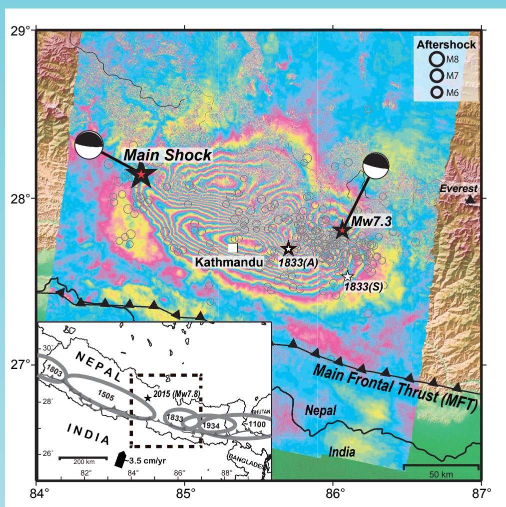
Earth, Planets and Space

The 2015 Gorkha, Nepal, Earthquake and Himalayan Studies: First Results



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Miyake *et al. Earth, Planets and Space* (2017) 69:12
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PREFACE

Open Access

Special issue "The 2015 Gorkha, Nepal, earthquake and Himalayan studies: First results"

Hiroe Miyake[1*], Soma Nath Sapkota[2], Bishal Nath Upreti[3,4], Laurent Bollinger[5], Tomokazu Kobayashi[6] and Hiroshi Takenaka[7]

A devastating earthquake with a moment magnitude of 7.9 struck Nepal on 25 April 2015, resulting in nearly 9000 fatalities. This earthquake, called the 2015 Gorkha earthquake, was followed by large aftershocks to the west and east of the mainshock rupture. The mainshock propagated toward the east, and a large slip occurred beneath the capital city of Kathmandu. Contrary to the huge seismic moment release, the seismic intensity was not as large as expected, except for long-period slip pulses and basin resonance. This earthquake is seismologically remarkable in that the interplate earthquake occurred just below the inland area, which offers an invaluable opportunity to deepen our understanding of earthquakes in the collision zone and disasters related to them. This special issue focuses on multidisciplinary geoscientific research regarding the 2015 Gorkha earthquake and the relevant tectonics along the India–Eurasia plate collision zone.

The special issue includes 17 papers demonstrating the prompt analyses of the 2015 Gorkha earthquake as well as Himalayan studies conducted prior to the earthquake. Overall, the research led to the improved understanding of the 2015 Gorkha earthquake and Himalayan studies.

The unique tectonic setting of the Himalayan region has prompted extensive international scientific research. Consequently, many Himalayan studies had been conducted before the 2015 Gorkha earthquake. Bollinger et al. (2016) revealed the slip deficit and interpreted the repeatability of historical earthquakes. Sapkota et al. (2016) discussed the fatality rates of the 1934 Bihar–Nepal earthquake. Sakai et al. (2016) clarified the geological features of the Paleo-Kathmandu lake. Bhattarai et al. (2016) observed ground motions before the 2015 Gorkha earthquake and estimated the site response in and around the Kathmandu valley.

Unique interferometric synthetic aperture radar (InSAR) images and strong ground motion were recorded during the 2015 Gorkha earthquake; high-rate Global Navigation Satellite System (GNSS) observations were also made. The detailed ground surface changes and fault model are presented with InSAR images of ALOS-2 satellite. Natsuaki et al. (2016) performed InSAR analysis and reported some technical problems and the solutions. Kobayashi et al. (2015) revealed the geodetic slip distribution of the 2015 Gorkha earthquake using ScanSAR-based interferograms and identified the remaining slip region with Mw 7.0 between the mainshock and the largest aftershock. Based on satellite images, Sato and Une (2016) and Lacroix (2016) detected earthquake-induced landslide in the Kathmandu and Langtang valleys, respectively.

Field survey was conducted to the east of the epicentral area around the Kathmandu valley. Although the earthquake magnitude was large, no surface fault was associated with the event (Kumahara et al. 2016). The earthquake survey was not limited from the land and toward the space field. Chum et al. (2016) captured the ionospheric signatures of the 2015 Gorkha earthquake.

With respect to strong motion data, Takai et al. (2016) observed clear differences in the ground motions between the rock and sediment sites in the Kathmandu valley. The rock site ground motion can be used to constrain the source characteristics. The nonlinear soil behavior at the sediment site was investigated by Dhakal et al. (2016). Yamada et al. (2016) performed a building damage survey and carried out microtremor observations in the source region of the 2015 Gorkha earthquake. Kobayashi et al. (2016) and Kubo et al. (2016) performed joint source inversion to estimate the rupture process of the 2015 Gorkha earthquake using various sets of observational data. Ichiyanagi et al. (2016) analyzed the

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aftershock activity of the 2015 Gorkha earthquake based on the local ground motion array. A statistical seismicity monitoring study on the 2015 Gorkha earthquake and aftershock sequence was performed by Ogata and Tsuruoka (2016).

The special issue demonstrates the scientific importance of Himalayan studies. Geospatial observations that captured the earthquake sequence were highlighted. The 2015 Gorkha earthquake ruptured beneath the capital city Kathmandu where urban strong motion data were utilized. The geodetic, seismological, and geological interpretations indicate that the potential remains for earthquakes in the region between the 2015 Gorkha earthquake and the largest eastern aftershock and in the Main Frontal Thrust. Therefore, further research is needed regarding the Himalayan region, which has the world's fastest inland collision rate.

Authors' contributions

All authors read and approved the final manuscript.

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FRONTIER LETTER Open Access

Detailed crustal deformation and fault rupture of the 2015 Gorkha earthquake, Nepal, revealed from ScanSAR-based interferograms of ALOS-2

Tomokazu Kobayashi*, Yu Morishita and Hiroshi Yarai

Earth, Planets and Space 2015, **67**:201 DOI: 10.1186/s40623-015-0359-z
Received: 13 August 2015, Accepted: 6 November 2015, Published: 14 December 2015

Abstract

We have successfully detected widely distributed ground displacements for the 2015 Gorkha earthquake by applying a ScanSAR-based interferometry analysis of Advanced Land Observing Satellite 2 (ALOS-2) L-band data. A major displacement area extends with a length of about 160 km in the east-west direction, and the most concentrated crustal deformation with ground displacement exceeding 1 m is located 20–30 km east from Kathmandu. A quasi-vertical displacement estimated by combining the ascending and the descending data indicates upheaval of about 1.4 m at maximum. We inverted the synthetic aperture radar interferometry (InSAR) data including both of the main shock (moment magnitude (Mw) 7.8) and the largest aftershock (Mw 7.3) to construct a slip distribution model. Our model shows a nearly pure reverse fault motion with a slip amount of approximately 6 m at maximum, and the spatial extent is zonally distributed within a distance of 50 to 100 km from the surface along downdip direction. The downdip end of the slip is quite consistent with that of the interseismic coupling area geodetically inferred in previous studies. On the other hand, there is no significant slip at shallow depth in spite of the fact that the plate interface is thought to be fully locked there, may be suggesting that there still remains a potential of fault slip. The slip distribution unnaturally bifurcates in the east, and we can identify a clear-cut slip deficit area with a radius of ~10 km just west side of the Mw 7.3 event, where the slip amount reaches only 20 cm at most. This area is presumably subjected to a strong shear stress which should promote a reverse fault slip. There is a possibility to produce a fault slip equivalent to Mw ~7.0 in the future although we do not know if the slip heterogeneity would be smoothed out by a seismic event or an aseismic event.

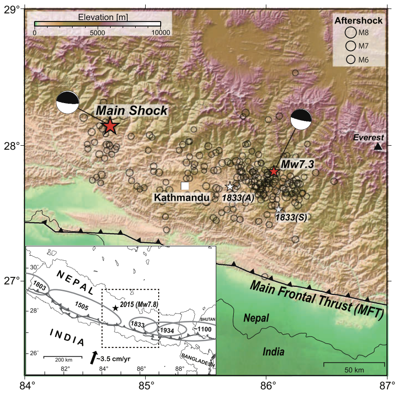

Figure 1

Keywords: ALOS-2, InSAR, ScanSAR, Crustal deformation, Gorkha earthquake, Nepal, Slip distribution, Slip deficit

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FRONTIER LETTER Open Access

Two times lowering of lake water at around 48 and 38 ka, caused by possible earthquakes, recorded in the Paleo-Kathmandu lake, central Nepal Himalaya

Harutaka Sakai*, Rie Fujii, Misa Sugimoto, Ryoko Setoguchi and Mukunda Raj Paudel

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Received: 30 October 2015, Accepted: 12 February 2016, Published: 27 February 2016

Abstract

Sedimentary facies and micro-fossil analyses, and AMS^{14}C dating were performed in order to reveal the water-level fall events and draining process of the lake (Paleo-Kathmandu Lake) that existed in the past in the Central Nepal Himalaya. The sedimentary facies change from the lacustrine Kalimati Formation to the deltaic Sunakothi Formation in the southern and central Kathmandu basin, and the abrupt and prominent increase of phytoliths *Bambusoideae* and *Pediastrum*, and contemporaneous decrease of sponge spicule and charcoal grains around 48 and 38 ka support the lowering of water level at these times. According to the pollen analysis, both events occurred under rather warm and wet climate, thus supporting that they were triggered by tectonic cause and not by climate change. The first event might be linked to a possible occurrence of a large earthquake with an epicenter in the vicinity of the Paleo-Kathmandu Lake. The occurrence of a mega landslide in Langtang area close to the north of the Kathmandu Valley producing pseudotachylite dated at 51 ± 13 ka could be linked to this earthquake. Finally, the water was completely drained out from the remnant lake at the central part of the Kathmandu basin by ca.12 ka.

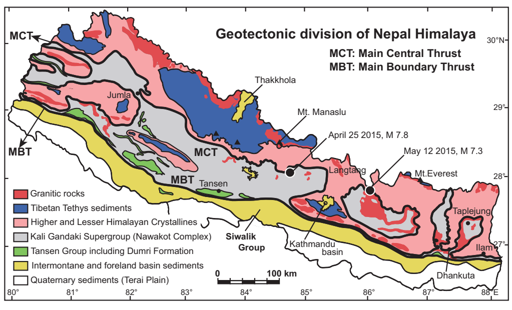

Figure 1

Keywords: Central Nepal, Paleo-Kathmandu lake, Lacustrine sediments, Deltaic sediments, Draining of lake water, AMS^{14}C age

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FULL PAPER **Open Access**

Slip deficit in central Nepal: omen for a repeat of the 1344 AD earthquake?

L. Bollinger*, P. Tapponnier, S. N. Sapkota and Y. Klinger

Earth, Planets and Space 2016, **68**:12 DOI: 10.1186/s40623-016-0389-1
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Abstract

In 1255, 1344, and 1408 AD, then again in 1833, 1934, and 2015, large earthquakes, devastated Kathmandu. The 1255 and 1934 surface ruptures have been identified east of the city, along comparable segments of the Main Frontal Thrust (MFT). Whether the other two pairs of events were similar is unclear. Taking into account charcoal's age inheritance, we revisit the timing of terrace offsets at key sites to compare them with the seismic record since 1200 AD. The location, extent, and moment of the 1833 and 2015 events imply that they released only a small part of the regional slip deficit on a deep thrust segment that stopped north of the Siwaliks. By contrast, the 1344 or 1408 AD earthquake may have ruptured the MFT up to the surface in central Nepal between Kathmandu and Pokhara, east of the surface trace of the great 1505 AD earthquake which affected western Nepal. If so, the whole megathrust system in Nepal broke in a sequence of earthquakes that lasted less than three centuries, with ruptures that propagated up to the surface from east to west. Today's situation in the Himalayan seismic sequence might be close to that of the fourteenth century.

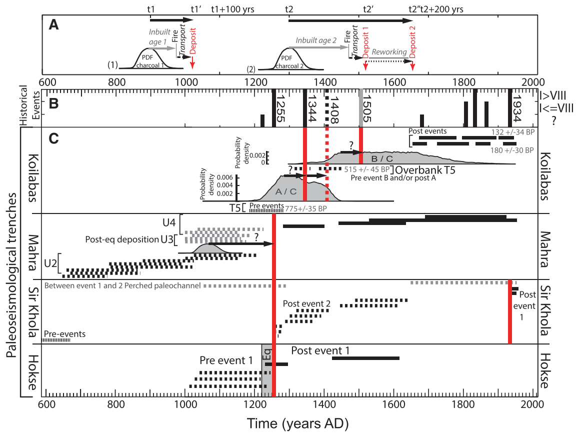

Figure 2

Keywords: Himalayan earthquakes, Seismic cycle, Paleoseismology, Inbuilt age

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FULL PAPER **Open Access**

SAR interferometry using ALOS-2 PALSAR-2 data for the Mw 7.8 Gorkha, Nepal earthquake

Ryo Natsuaki*, Hiroto Nagai, Takeshi Motohka, Masato Ohki, Manabu Watanabe, Rajesh B. Thapa, Takeo Tadono, Masanobu Shimada and Shinichi Suzuki

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Abstract

The Advanced Land Observing Satellite-2 (ALOS-2, "DAICHI-2") has been observing Nepal with the Phased Array type L-band Synthetic Aperture Radar-2 (PALSAR-2) in response to an emergency request from Sentinel Asia related to the Mw 7.8 Gorkha earthquake on April 25, 2015. PALSAR-2 successfully detected not only avalanches and local crustal displacements but also continental-scale deformation. Especially, by the use of the ScanSAR mode, we are able to make interferograms that cover the entire displacement area of the earthquake. However, we did encounter some fundamental problems with the ScanSAR and incorrect settings of PALSAR-2 operation that have now been fixed. They include (1) burst overlap misalignment between two ScanSAR observations, which limits the number of pairs available and the quality of the interferogram, (2) non-crustal fringes which are derived from co-registration error and/or ionospheric effect and, (3) incorrect setting of the center frequency in the Stripmap beam F2-6. In this paper, we describe their problems and solutions. The number of interferometric pairs are limited by (1) and (3). The accuracy of the interferograms are limited by (2) and (3). The experimental results showed that current solutions for (2) and (3) work appropriately.

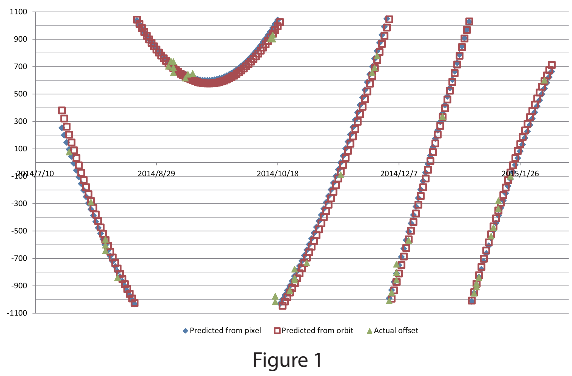

Figure 1

Keywords: Gorkha earthquake, ALOS-2, PALSAR-2, InSAR, Synthetic Aperture Radar (SAR), ScanSAR interferometry, Stripmap-ScanSAR interferometry

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FULL PAPER Open Access

Ionospheric signatures of the April 25, 2015 Nepal earthquake and the relative role of compression and advection for Doppler sounding of infrasound in the ionosphere

Jaroslav Chum*, Jann-Yenq Liu, Jan Laštovička, Jiří Fišer, Zbyšek Mošna, Jiří Baše and Yang-Yi Sun

Earth, Planets and Space 2016, **68**:24 DOI: 10.1186/s40623-016-0401-9
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Abstract

Ionospheric signatures possibly induced by the Nepal earthquake are investigated far outside the epicentral region in Taiwan (~3700 km distance from the epicenter) and in the Czech Republic (~6300 km distance from the epicenter). It is shown that the ionospheric disturbances were caused by long period, ~20 s, infrasound waves that were excited locally by vertical component of the ground surface motion and propagated nearly vertically to the ionosphere. The infrasound waves are heavily damped at the heights of F layer at around 200 km, so their amplitude strongly depends on the altitude of observation. In addition, in the case of continuous Doppler sounding, the value of the Doppler shift depends not only on the advection (up and down motion) of the reflecting layer but also on the compression/rarefaction of the electron gas and hence on the electron density gradient. Consequently, under significant differences of reflection height of sounding radio waves and partly also under large differences in plasma density gradients, the observed ionospheric response at larger distances from the epicenter can be comparable with the ionospheric response observed at shorter distances, although the amplitudes of causative seismic motions differ by more than one order of magnitude.

Keywords: Infrasound, Seismic waves, Ionosphere, Wave propagation, Remote sensing

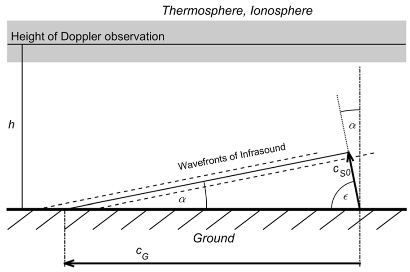

Figure 1

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FULL PAPER Open Access

Detection of the 2015 Gorkha earthquake-induced landslide surface deformation in Kathmandu using InSAR images from PALSAR-2 data

Hiroshi P. Sato* and Hiroshi Une

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Abstract

Previous studies reported that the 2015 Gorkha earthquake (Mw 7.8), which occurred in Nepal, triggered landslides in mountainous areas. In Kathmandu, earthquake-induced land subsidence was identified by interpreting local phase changes in interferograms produced from Advanced Land Observing Satellite-2/Phased Array type L-band Synthetic Aperture Radar-2 data. However, the associated ground deformation was not discussed in detail. We studied line-of-sight (LoS) changes from InSAR images in the SE area of Tribhuvan International Airport, Kathmandu. To obtain the change in LoS caused only by local, short-wavelength surface deformation, we subtracted the change in LoS attributed to coseismic deformation from the original change in LoS. The resulting change in LoS showed that the river terrace was driven to the bottom of the river valley. We also studied the changes in LoS in both ascending and descending InSAR images of the area along the Bishnumati River and performed 2.5D analysis. Removing the effect of coseismic deformation revealed east–west and up–down components of local surface deformation, indicating that the river terrace deformed eastward and subsided on the western riverbank of the river. On the east riverbank, the river terrace deformed westward and subsided. However, in the southern part of the river basin, the river terrace deformed westward and was uplifted. The deformation data and field survey results indicate that local surface deformation in these two areas was not caused by land subsidence but by a landslide (specifically, lateral spread).

Keywords: Landslide, Earthquake, Liquefaction, Lateral spread, Land subsidence, Gorkha, Nepal, PALSAR-2, InSAR

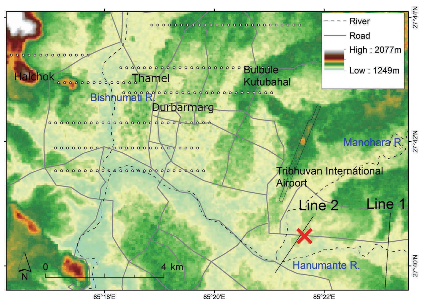

Figure 2

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FULL PAPER Open Access

Establishing a reference rock site for the site effect study in and around the Kathmandu valley, Nepal

Mukunda Bhattarai*, Lok Bijaya Adhikari, Umesh Prasad Gautam, Laurent Bollinger, Bruno Hernandez, Toshiaki Yokoi and Takumi Hayashida

Earth, Planets and Space 2016, **68**:81 DOI: 10.1186/s40623-016-0454-9
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Abstract

We propose a reference site for the site effect study in and around the Kathmandu valley, Nepal. The used data were the accelerograms recorded at two stations, DMG and KKA, and velocity seismograms co-recorded at the PKIN station during nine shallow local and regional earthquakes of local magnitude equal to or greater than 5.0. The DMG station is located on the thick sediments of the Kathmandu valley, whereas the others are rock sites. The KKA station is located on the granite and gneisses of the Shivapuri Lekh about 10 km northwest of the capital, and the PKIN station is in the tunnel of an old iron mine on the southern slope of the Phulchauki Hill about 15 km southeast. The spectral ratios of the ground motion records of the DMG station compared to those of the PKIN station, for all considered earthquakes, confirm that the DMG station has amplification ranging from 1 to 10 in the frequency range of 0.5–10 Hz, and spectral ratios of the KKA station referenced by the PKIN station show that the KKA station has significant amplification in the frequency range of 4–10 Hz and the peak value of the spectral ratio is at most over 25. Therefore, the site amplification in and around Kathmandu valley would be significantly underestimated in the frequency range from 4 to 10 Hz if the records of the KKA station were used as a proxy for input seismic motions to the sediment. Based on the above analysis, we propose that the PKIN station should be considered as a reliable reference site for the assessment of seismic hazards in and around the Kathmandu valley.

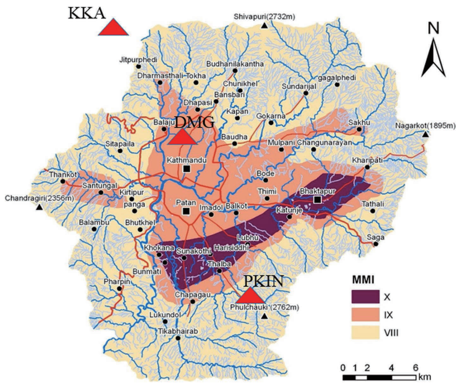

Figure 1

Keywords: Reference site, Site effect, Kathmandu valley, Spectral ratio

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LETTER Open Access

Strong ground motion in the Kathmandu Valley during the 2015 Gorkha, Nepal, earthquake

Nobuo Takai*, Michiko Shigefuji, Sudhir Rajaure, Subeg Bijukchhen, Masayoshi Ichiyanagi, Megh Raj Dhital and Tsutomu Sasatani

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Abstract

On 25 April 2015, a large earthquake of Mw 7.8 occurred along the Main Himalayan Thrust fault in central Nepal. It was caused by a collision of the Indian Plate beneath the Eurasian Plate. The epicenter was near the Gorkha region, 80 km northwest of Kathmandu, and the rupture propagated toward east from the epicentral region passing through the sediment-filled Kathmandu Valley. This event resulted in over 8000 fatalities, mostly in Kathmandu and the adjacent districts. We succeeded in observing strong ground motions at our four observation sites (one rock site and three sedimentary sites) in the Kathmandu Valley during this devastating earthquake. While the observed peak ground acceleration values were smaller than the predicted ones that were derived from the use of a ground motion prediction equation, the observed peak ground velocity values were slightly larger than the predicted ones. The ground velocities observed at the rock site (KTP) showed a simple velocity pulse, resulting in monotonic-step displacements associated with the permanent tectonic offset. The vertical ground velocities observed at the sedimentary sites had the same pulse motions that were observed at the rock site. In contrast, the horizontal ground velocities as well as accelerations observed at three sedimentary sites showed long duration with conspicuous long-period oscillations, due to the valley response. The horizontal valley response was characterized by large amplification (about 10) and prolonged oscillations. However, the predominant period and envelope shape of their oscillations differed from site to site, indicating a complicated basin structure. Finally, on the basis of the velocity response spectra, we show that the horizontal long-period oscillations on the sedimentary sites had enough destructive power to damage high-rise buildings with natural periods of 3 to 5 s.

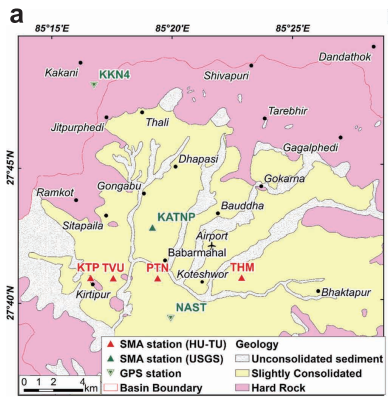

Figure 1

Keywords: 2015 Gorkha Nepal earthquake, Kathmandu Valley, Strong ground motion, Velocity pulse motion, Valley response

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LETTER Open Access

Estimation of the source process of the 2015 Gorkha, Nepal, earthquake and simulation of long-period ground motions in the Kathmandu basin using a one-dimensional basin structure model

Hisahiko Kubo*, Yadab P. Dhakal, Wataru Suzuki, Takashi Kunugi, Shin Aoi and Hiroyuki Fujiwara

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Abstract

The source rupture process of the 2015 Gorkha, Nepal, earthquake was estimated by the joint kinematic source inversion with near-field waveforms, teleseismic waveforms, and geodetic data. The estimated seismic moment and maximum slip are 7.5×10^{20} Nm (M_w 7.9) and 7.3 m, respectively. The total source duration is approximately 50 s. The derived source model has a unilateral rupture toward the east and a large-slip area north of Kathmandu with the maximum slip. Using the estimated source model together with a one-dimensional (1-D) velocity basin structure model, long-period (>4 s) ground motions were simulated at a site located in the Kathmandu basin, where strong ground motions with predominant components in a 4–5s period were observed during the 2015 Gorkha earthquake. This simulation demonstrated that the major features of the observed waveforms can be reproduced by our source model and the 1-D basin structure model.

Keywords: The 2015 Gorkha earthquake, Source rupture process, Long-period ground motions in the Kathmandu basin, Joint source inversion, Waveform simulation

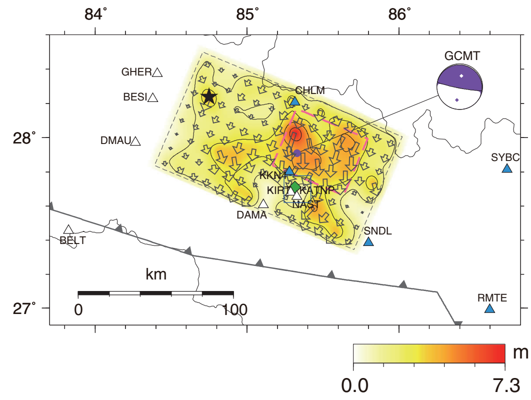

Figure 2

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Aftershock activity of the 2015 Gorkha, Nepal, earthquake determined using the Kathmandu strong motion seismographic array

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Abstract

The characteristics of aftershock activity of the 2015 Gorkha, Nepal, earthquake (Mw 7.8) were evaluated. The mainshock and aftershocks were recorded continuously by the international Kathmandu strong motion seismographic array operated by Hokkaido University and Tribhuvan University. Full waveform data without saturation for all events enabled us to clarify aftershock locations and decay characteristics. The aftershock distribution was determined using the estimated local velocity structure. The hypocenter distribution in the Kathmandu metropolitan region was well determined and indicated earthquakes located shallower than 12 km depth, suggesting that aftershocks occurred at depths shallower than the Himalayan main thrust fault. Although numerical investigation suggested less resolution for the depth component, the regional aftershock epicentral distribution of the entire focal region clearly indicated earthquakes concentrated in the eastern margin of the major slip region of the mainshock. The calculated modified Omori law's *p* value of 1.35 suggests rapid aftershock decay and a possible high temperature structure in the aftershock region.

Keywords: 2015 Gorkha Nepal earthquake, Aftershock activity, Local seismographic array

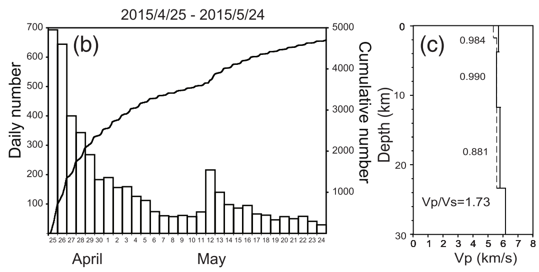

Figure 1

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LETTER **Open Access**

Fatality rates of the M_w ~8.2, 1934, Bihar–Nepal earthquake and comparison with the April 2015 Gorkha earthquake

Soma Nath Sapkota*, Laurent Bollinger and Frédéric Perrier

Earth, Planets and Space 2016, **68**:40 DOI: 10.1186/s40623-016-0416-2
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Abstract

Large Himalayan earthquakes expose rapidly growing populations of millions of people to high levels of seismic hazards, in particular in northeast India and Nepal. Calibrating vulnerability models specific to this region of the world is therefore crucial to the development of reliable mitigation measures. Here, we reevaluate the >15,700 casualties (8500 in Nepal and 7200 in India) from the M_w ~8.2, 1934, Bihar–Nepal earthquake and calculate the fatality rates for this earthquake using an estimation of the population derived from two census held in 1921 and 1942. Values reach 0.7–1 % in the epicentral region, located in eastern Nepal, and 2–5 % in the urban areas of the Kathmandu valley. Assuming a constant vulnerability, we obtain, if the same earthquake would have repeated in 2011, fatalities of 33,000 in Nepal and 50,000 in India. Fast-growing population in India indeed must unavoidably lead to increased levels of casualty compared with Nepal, where the population growth is smaller. Aside from that probably robust fact, extrapolations have to be taken with great caution. Among other effects, building and life vulnerability could depend on population concentration and evolution of construction methods. Indeed, fatalities of the April 25, 2015, M_w 7.8 Gorkha earthquake indicated on average a reduction in building vulnerability in urban areas, while rural areas remained highly vulnerable. While effective scaling laws, function of the building stock, seem to describe these differences adequately, vulnerability in the case of an M_w >8.2 earthquake remains largely unknown. Further research should be carried out urgently so that better prevention strategies can be implemented and building codes reevaluated on, adequately combining detailed ancient and modern data.

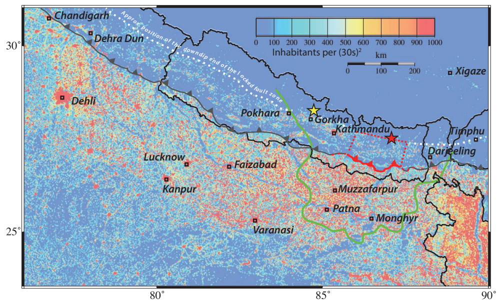

Figure 1

Keywords: Earthquake, Nepal, Mortality, Fatalities, Power law, Building vulnerability, Mitigation measures

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LETTER **Open Access**

Statistical monitoring of aftershock sequences: a case study of the 2015 Mw7.8 Gorkha, Nepal, earthquake

Yosihiko Ogata* and Hiroshi Tsuruoka

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Abstract

Early forecasting of aftershocks has become realistic and practical because of real-time detection of hypocenters. This study illustrates a statistical procedure for monitoring aftershock sequences to detect anomalies to increase the probability gain of a significantly large aftershock or even an earthquake larger than the main shock. In particular, a significant lowering (relative quiescence) in aftershock activity below the level predicted by the Omori–Utsu formula or the epidemic-type aftershock sequence model is sometimes followed by a large earthquake in a neighboring region. As an example, we detected significant lowering relative to the modeled rate after approximately 1.7 days after the main shock in the aftershock sequence of the Mw7.8 Gorkha, Nepal, earthquake of April 25, 2015. The relative quiescence lasted until the May 12, 2015, M7.3 Kodari earthquake that occurred at the eastern end of the primary aftershock zone. Space–time plots including the transformed time can indicate the local places where aftershock activity lowers (the seismicity shadow). Thus, the relative quiescence can be hypothesized to be related to stress shadowing caused by probable slow slips. In addition, the aftershock productivity of the M7.3 Kodari earthquake is approximately twice as large as that of the M7.8 main shock.

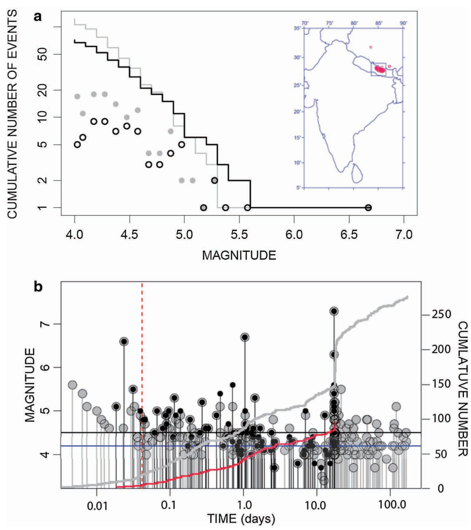

Figure 1

Keywords: Epidemic-type aftershock sequence (ETAS) model, Omori–Utsu formula, Change-point, Probability gain, GUI software package XETAS, Relative quiescence, Seismicity shadow

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LETTER — Open Access

Landslides triggered by the Gorkha earthquake in the Langtang valley, volumes and initiation processes

Pascal Lacroix

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Abstract

The Gorkha earthquake (Nepal, 2015, M_w 7.9) triggered many landslides. The most catastrophic mass movement was a debris avalanche that buried several villages in the Langtang valley. In this study, questions are raised about its volume and initiation. I investigate the possibility of high-resolution digital surface models computed from tri-stereo SPOT6/7 images to resolve this issue. This high-resolution dataset enables me to derive an inventory of 160 landslides triggered by this earthquake. I analyze the source of errors and estimate the uncertainties in the landslide volumes. The vegetation prevents to correctly estimate the volumes of landslides that occured in vegetated areas. However, I evaluate the volume and thickness of 73 landslides developing in vegetated-free areas, showing a power law between their surface areas and volumes with exponent of 1.20. Accumulations and depletion volumes are also well constrained for larger landslides, and I find that the main debris avalanches accumulated 6.95 × 10^6 m^3 of deposits in the valley with thicknesses reaching 60 m, and 9.66 × 10^6 m^3 in the glaciated part above 5000 m asl. The large amount of sediments is explained by an initiation of the debris avalanche due to serac falls and snow avalanches from five separate places between 6800 and 7200 m asl over 3 km length.

Keywords: Landslides, Seismic triggering, Nepal, DEM, SPOT, Volumes, Optical satellite photogrammetry, Debris avalanche

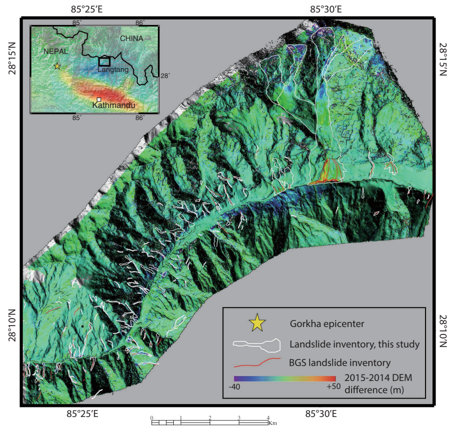

Figure 1

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LETTER — Open Access

Geomorphic features of active faults around the Kathmandu Valley, Nepal, and no evidence of surface rupture associated with the 2015 Gorkha earthquake along the faults

Yasuhiro Kumahara*, Deepak Chamlagain and Bishal Nath Upreti

Earth, Planets and Space 2016, **68**:53 DOI: 10.1186/s40623-016-0429-x
Received: 30 October 2015, Accepted: 18 March 2016, Published: 2 April 2016

Abstract

The M7.8 April 25, 2015, Gorkha earthquake in Nepal was produced by a slip on the low-angle Main Himalayan Thrust, a décollement below the Himalaya that emerges at the surface in the south as the Himalayan Frontal Thrust (HFT). The analysis of the SAR interferograms led to the interpretations that the event was a blind thrust and did not produce surface ruptures associated with the seismogenic fault. We conducted a quick field survey along four active faults near the epicentral area around the Kathmandu Valley (the Jhiku Khola fault, Chitlang fault, Kulekhani fault, Malagiri fault and Kolphu Khola fault) from July 18–22, 2015. Those faults are located in the Lesser Himalaya on the hanging side of the HFT. Based on our field survey carried out in the area where most typical tectonic landforms are developed, we confirmed with local inhabitants the lack of any new surface ruptures along these faults. Our observations along the Jhiku Khola fault showed that the fault had some definite activities during the Holocene times. Though in the past it was recognized as a low-activity thrust fault, our present survey has revealed that it has been active with a predominantly right-lateral strike-slip with thrust component. A stream dissecting a talus surface shows approximately 7-m right-lateral offset, and a charcoal sample collected from the upper part of the talus deposit yielded an age of 870 ± 30 y.B.P, implying that the talus surface formed close to 870 y.B.P. Accordingly, a single or multiple events of the fault must have occurred during the last 900 years, and the slip rate we estimate roughly is around 8 mm/year. The fault may play a role to recent right-lateral strike-slip tectonic zone across the Himalayan range. Since none of the above faults showed any relationship corresponding to the April 25 Gorkha earthquake, it is possibility that a potential risk of occurrence of large earthquakes does exist close to the Kathmandu Valley due to movements of these active faults, and more future work such as paleoseismological survey is needed to assess the risk.

Keywords: 2015 Gorkha earthquake, Active fault, Surface rupture, Tectonic landform, Nepal, Jhiku Khola fault

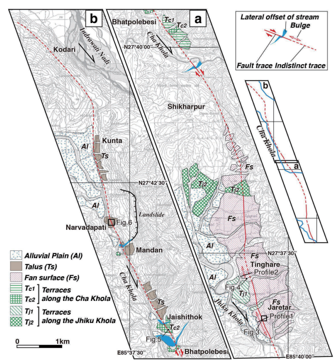

Figure 2

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LETTER **Open Access**

Analysis of strong ground motions and site effects at Kantipath, Kathmandu, from 2015 Mw 7.8 Gorkha, Nepal, earthquake and its aftershocks

Yadab P. Dhakal*, Hisahiko Kubo, Wataru Suzuki, Takashi Kunugi, Shin Aoi and Hiroyuki Fujiwara

Earth, Planets and Space 2016, **68**:58 DOI: 10.1186/s40623-016-0432-2
Received: 2 November 2015, Accepted: 29 March 2016, Published: 12 April 2016

Abstract

Strong ground motions from the 2015 Mw 7.8 Gorkha, Nepal, earthquake and its eight aftershocks recorded by a strong-motion seismograph at Kantipath (KATNP), Kathmandu, were analyzed to assess the ground-motion characteristics and site effects at this location. Remarkably large elastic pseudo-velocity responses exceeding 300 cm/s at 5 % critical damping were calculated for the horizontal components of the mainshock recordings at peak periods of 4–5 s. Conversely, the short-period ground motions of the mainshock were relatively weak despite the proximity of the site to the source fault. The horizontal components of all large-magnitude (Mw ≥ 6.3) aftershock recordings showed peak pseudo-velocity responses at periods of 3–4 s. Ground-motion prediction equations (GMPEs) describing the Nepal Himalaya region have not yet been developed. A comparison of the observational data with GMPEs for Japan showed that with the exception of the peak ground acceleration (PGA) of the mainshock, the observed PGAs and peak ground velocities at the KATNP site are generally well described by the GMPEs for crustal and plate interface events. A comparison of the horizontal-to-vertical *(H/V)* spectral ratios for the S-waves of the mainshock and aftershock recordings suggested that the KATNP site experienced a considerable nonlinear site response, which resulted in the reduced amplitudes of short-period ground motions. The GMPEs were found to underestimate the response values at the peak periods (approximately 4–5 s) of the large-magnitude events. The deep subsurface velocity model of the Kathmandu basin has not been well investigated. Therefore, a one-dimensional velocity model was constructed for the deep sediments beneath the recording station based on an analysis of the *H/V* spectral ratios for S-wave coda from aftershock recordings, and it was revealed that the basin sediments strongly amplified the long-period components of the ground motions of the mainshock and large-magnitude aftershocks.

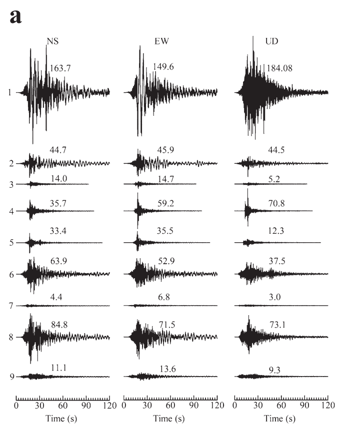

Figure 2

Keywords: Gorkha earthquake, Kathmandu basin, Site effects, Long-period ground motion

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LETTER **Open Access**

Joint inversion of teleseismic, geodetic, and near-field waveform datasets for rupture process of the 2015 Gorkha, Nepal, earthquake

Hiroaki Kobayashi*, Kazuki Koketsu, Hiroe Miyake, Nobuo Takai, Michiko Shigefuji, Mukunda Bhattarai and Soma Nath Sapkota

Earth, Planets and Space 2016, **68**:66 DOI: 10.1186/s40623-016-0441-1
Received: 31 October 2015, Accepted: 11 April 2016, Published: 26 April 2016

Abstract

The 2015 Gorkha earthquake and its aftershocks caused severe damage mostly in Nepal, while countries around the Himalayan region were warned for decades about large Himalayan earthquakes and the seismic vulnerability of these countries. However, the magnitude of the Gorkha earthquake was smaller than those of historical earthquakes in Nepal, and the most severe damage occurred in the north and northeast of Kathmandu. We explore reasons for these unexpected features by performing a joint source inversion of teleseismic, geodetic, and near-field waveform datasets to investigate the rupture process. Results indicate that the source fault was limited to the northern part of central Nepal and did not reach the Main Frontal Thrust. The zone of large slip was located in the north of Kathmandu, and the fault rupture propagated eastward with an almost constant velocity. Changes in the Coulomb failure function (ΔCFF) due to the Gorkha earthquake were computed, indicating that southern and western regions neighboring the source fault are potential source regions for future earthquakes related to the Gorkha earthquake. These two regions may correspond to the historical earthquakes of 1866 and 1344. Possible future earthquakes in the regions are predicted, and the warning for Himalayan seismic hazards remains high even after the Gorkha earthquake.

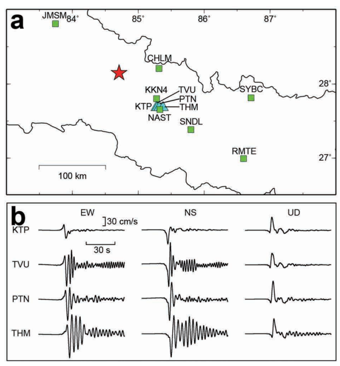

Figure 2

Keywords: Rupture process, Gorkha earthquake, Coulomb failure function

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LETTER Open Access

Building damage survey and microtremor measurements for the source region of the 2015 Gorkha, Nepal, earthquake

Masumi Yamada*, Takumi Hayashida, Jim Mori and Walter D. Mooney

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Abstract

We performed a damage survey of buildings and carried out microtremor observations in the source region of the 2015 Gorkha earthquake. Our survey area spans the Kathmandu valley and areas to the east and north of the valley. Damage of buildings in the Kathmandu valley was localized, and the percentage of the totally collapsed buildings was less than 5 %. East of the Kathmandu valley, especially in Sindhupalchok district, damage of buildings was more severe. In the center of Chautara and Bahrabise, towns in Sindhupalchok district, the percentage of the totally collapsed houses exceeded 40 %. North of the Kathmandu valley, the damage was moderate, and 20–30 % of the buildings were totally collapsed in Dhunche. Based on the past studies and our microtremor observations near the strong motion station, the H/V spectrum in Kathmandu has a peak at around 0.3 Hz, which reflects the velocity contrast of the deep sedimentary basin. The H/V spectra in Bahrabise, Chautara, and Dhunche do not show clear peaks, which suggests that the sites have stiff soil conditions. Therefore, the more severe damage outside the Kathmandu valley compared with the relatively light damage levels in the valley is probably due to the source characteristics of the earthquake and/or the seismic performance of buildings, rather than the local site conditions.

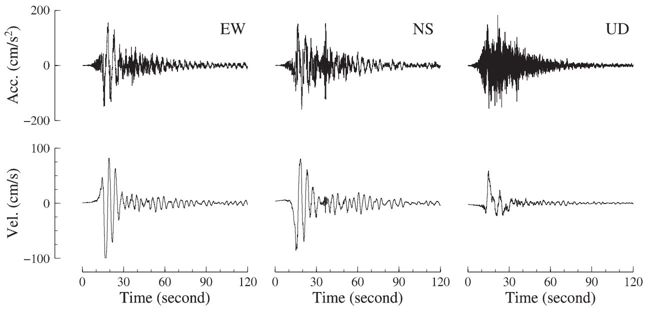

Figure 1

Keywords: 2015 Gorkha earthquake, Masonry structure, Earthquake damage, Strong motion, Microtremor survey

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Information for Contributors

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Correspondence

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