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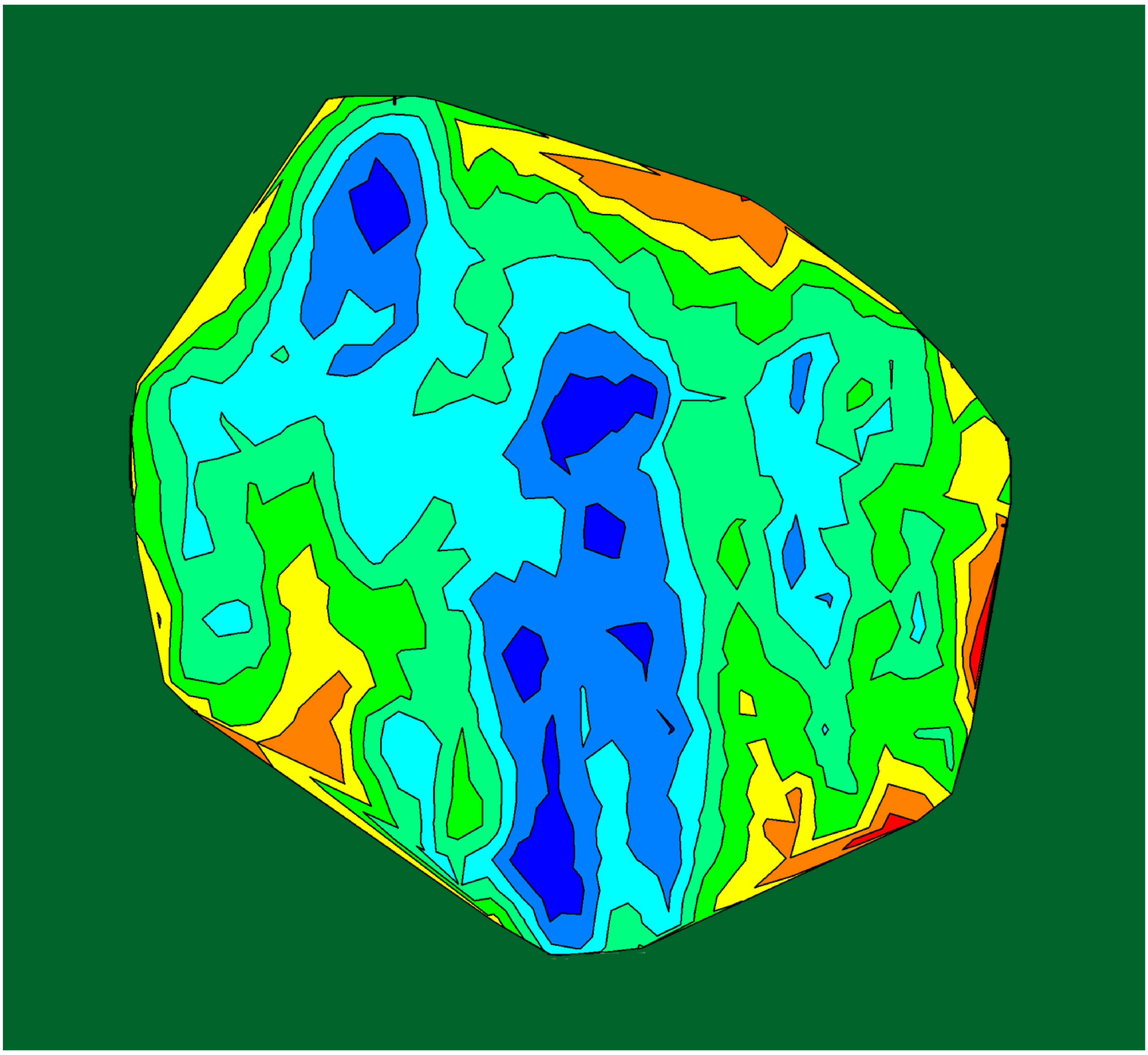

Department of Physics, Prithvi Narayan Campus, Pokhara
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Himalayan Physics

Geodynamics of Gorkha earthquake (Mw 7.9) and its aftershocks

Research Article

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Abstract: A devastating earthquake (Mw 7.9) occurred in Gorkha region on 25 April 2015 caused loss of 8964 human lives and huge property in Central Nepal and adjoining region. Sequence of aftershocks, including four having magnitude greater than 6 occurred within 18 days, confined in a distance of about 150 km from Gorkha to Dolakha. Main shock and its aftershocks series confined in a depth range of 12 to 21 km. In this study, using 11 CMT solutions of earthquakes with magnitude 5 and above, occurred between 2014.12.18 and 2016.11.27 within 84° to 87°E and 27° to 29°N, we analyze faulting pattern of the Gorkha earthquake and associated large aftershocks to reveal recent geodynamics pattern in the central Himalayan region.

Nodal planes of mainshock and four large aftershocks have east west orientation and shallow dip (6° to 23°) towards north, exhibit strong thrust mechanism. Smaller aftershocks scattered within 150 km long rupture zone along NW to SE direction show similar mechanism with large thrust component. Collective dips of nodal plane of ten events indicate northward under thrusting of the Indian plate at shallow angle, though the nodal plane of individual event differ slightly in their orientation. The cross-sectional study of focal mechanism shows the clustering of the seismic events at different depth with diverse faulting pattern. It is inferred that recent seismic activity in central Nepal region is dominated by thrust faulting and the mechanism which were responsible for the formation of Himalaya are still continuing.

Keywords: Seismotectonics • Central Himalaya • Nepal • Clustering

1. Introduction

On 25th April 2015 an intense ground shaking struck Central Nepal that caused tremendous damage and loss. The earthquake occurred as a result of the northward under thrusting of India beneath Eurasia. The main shock, approximately 80 km to the northwest of Kathmandu, occurred in Gorkha at 11:56 (NST) with a magnitude of Mw 7.9 at latitude 27.9°N and 85.3°E which triggered numerous aftershocks [1]. The biggest of the aftershocks was of the magnitude Mw 7.2 approximately 90 km southeast from the Mainshock [1]. Multiple studies were carried out by the researchers on the Gorkha Earthquake and its aftershocks sequence to retrieve the rupture process and its tectonic implications [2–4]. A multi-disciplinary effort to understand the earthquake in the context of tectonic evolution of the Himalaya and associated seismic hazards was carried out and the findings suggest

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that segments of the MHT, up-dip of the 2015 Gorkha rupture, likely have high hazard for future damaging earthquakes in this densely populated and vulnerable region [4]. In this study we analyze the faulting pattern of this devastating event and its major aftershocks using CMT moment tensor solutions.

Geo-tectonics of the region

Central Nepal represents a part of Himalayan geo-tectonic belt. The region is classically divided into four tectonic units from south to north;

1. Sub-Himalaya
2. Lesser Himalaya
3. Higher Himalaya
4. Tethyan Himalaya

Main Frontal Thrust (MFT), Main Boundary Thrust (MBT), Main Central Thrust (MCT) and South Tibet Detachment (STD) separate the four tectonic units (Fig. 1). MFT is the active thrust fault which exposed along the southern edge of the Sub-Himalayan foothills. Both the MFT and MBT sole into the Main Himalaya Thrust (MHT), the detachment along which the Indian plate subducts beneath the Himalaya [5, 6]. MHT dips gently to the north beneath the Lesser Himalaya and further it steepens downward onto a ramp that dives beneath the Higher Himalaya before flattening again northward under the Tethys Himalaya of southern Tibet [7]. It accommodates approximately a half of tectonic convergence between Indian plate and Eurasian plates. Apart from these major thrusts, large number of active faults are identified in the region responsible for frequent generation of earthquake [8] .

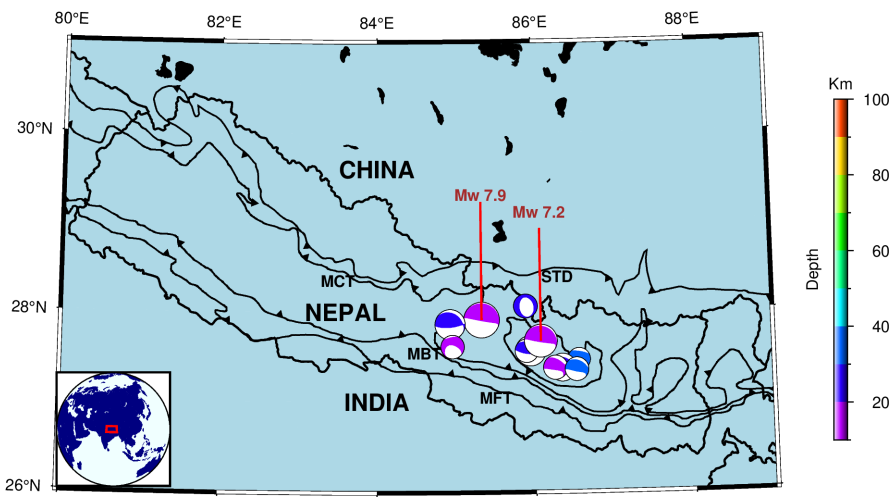

Figure 1. Focal mechanism beachballs solutions of earthquake events (magnitude 5 and above) in the region (26°N-31°N and 80°E-89°E). The red box in the inset map indicates the Nepal in the gobal scenario. The color of the beachball depends on the depth of the event depicted by color bar.

The term focal mechanism is used to refer to the parameters that characterizes an earthquake rupture. It presents the characteristics of the two orthogonal possible ruptures planes on the basis of strike, dip and rake of the slip vector over the plane. Focal mechanism by Centroid Moment Tensor (CMT) method were constrained by first motion solutions and waveform modelling. The method is based on the linear relationship that exists between the six independent elements of a zeroth order moment tensor representation of an earthquake and the ground motion that the earthquake generates [9]. A moment tensor is a complete description of equivalent forces of a general seismic point source [10] in an elastic medium [11]. The term centroid refers to the center of the earthquake moment distribution in time and space defined by four parameters like centroid latitude, longitude, depth and centroid time. Thus, ten parameters altogether provide the point source CMT representation of an earthquake [1].

Focal mechanism analysis able to describe the source mechanism for the fault planes geometrically and mathematically when the earthquakes occurred. In order to understand the various aspects of earthquake like stress perturbation, aftershocks pattern and faulting geometry etc., an immediate determination of focal mechanism is exceedingly important [12–14]. Focal mechanism data also help in assignment of the tectonic regime by providing information on the relative magnitudes of the principal stresses. In the prediction of ground shaking for early warning purpose, the timely derived focal mechanism can provide significant information such as fault orientation and slipping mode. The faults parameters like strike, dip and slip angles are useful to find out whether the earthquakes have similar source mechanism characteristics or not. The objective of this work is to explain focal mechanism of Gorkha earthquakes of magnitude 5 and above to analyze faulting pattern which could reveal recent geodynamics pattern in the region.

2. Data and Methodology

The moment tensor solutions are available for this region in the Harvard CMT Catalogue [3, 4] [Table 1 and Table 2]. We compile the data for the period 2014-1-1 to 2016-12-30 for latitude range 27°N to 29°N and longitude range 84°E to 87°E. The original method of constructing beach ball diagrams was the result of analysis of waveforms (the P-wave first motion) generated by an earthquake and recorded by at least 10 seismographs distributed geographically around the epicenter. Here we use the Generic Mapping Tool (GMT) package to construct the map and visualization of beach balls on the map [15]. More precisely, the syntax 'psmeca' is used for representation of the focal mechanism on map of Nepal (Fig. 1) and the syntax 'pscoupe' to plot cross section of focal mechanism (Fig. 2).

Table 1. : Fault-plane solution parameters of eleven earthquakes from Central Nepal Himalaya and its adjoining regions.

S.N	Date	Centroid Time (GMT)	Lat.	Lon.	Depth (km)	Mw	Ms	Strike (°)	Dip (°)	Slip (°)
1	2014-12-18	15:32:15.4	27.46	86.56	30.3	5.0	5.0	248	26	44
								117	72	110
2	2015-04-25	6:11:58.6	27.91	85.33	12.0	7.9	7.8	287	6	96
								101	84	89
3	2015-04-25	6:45:53.3	27.86	84.93	21.0	6.7	6.6	308	23	131
								85	73	74
4	2015-04-25	17:42:53.3	28.06	85.89	20.8	5.3	5.1	339	40	-105
								178	52	-78
5	2015-04-25	23:16:18.1	27.61	84.96	15.0	5.1	5.1	201	40	-20
								306	77	-129
6	2015-04-26	7:9:20.1	27.56	85.95	20.6	6.7	6.7	289	14	98
								101	76	88
7	2015-04-26	16:26:9.6	27.56	85.95	19.8	5.2	5.0	305	26	115
								98	66	78
8	2015-05-12	7:5:27.5	27.67	86.08	12.0	7.2	7.3	307	11	117
								99	81	85
9	2015-05-12	7:36:59.6	27.37	86.35	20.1	6.1	6.3	299	28	116
								90	65	77
10	2015-05-16	11:34:12.6	27.37	86.26	12.0	5.3	5.5	324	34	138
								91	68	63
11	2016-01-12	23:35:26.0	27.35	86.53	35.4	5.2	5.4	305	24	113
								100	67	80

Table 2. : CMT Harvard Centroid Moment Tensor data (psmeca compatible) where mrr, mtt, mpp, mrt, mrp and mtp are six components of moment Tensor (r for up, t for south and p for east) and Iexp is exponent used to convert the scalar moment to units of dyne-cm

S.N	Lon.	Lat.	Depth (km)	mrr	mtt	mpp	mrt	mrp	mtp	Iexp (dyne-cm)
1	86.56	27.46	30	1.20	-3.08	1.88	2.48	-0.64	1.07	23
2	85.33	27.91	12	1.76	-1.82	0.06	8.04	-1.51	0.48	27
3	84.93	27.86	21	0.68	-0.74	0.06	0.96	0.19	0.25	26
4	85.89	28.06	21	-1.04	0.16	0.87	0.16	0.26	-0.17	24
5	84.96	27.61	15	-2.08	-2.46	4.54	5.53	-0.90	-1.20	23
6	85.95	27.56	21	0.60	-0.67	0.07	1.20	-0.23	0.20	26
7	85.90	27.56	20	5.38	-5.14	-0.24	5.14	-0.18	2.23	23
8	86.08	27.67	12	2.70	-2.62	-0.08	8.25	-1.28	1.22	26
9	86.35	27.37	20	1.37	-1.54	0.17	1.24	0.14	0.43	25
10	86.26	27.37	12	0.75	-0.95	0.20	0.83	0.04	0.63	24
11	86.53	27.35	35	0.56	-0.61	0.05	0.62	-0.08	0.29	24

3. Results and Discussion

The mainshock (7.9Mw) shows N17°E dipping with strike direction N73°W while the aftershocks (Mw 6.6) occurred in the same day shows N38°E dipping with strike direction N52°W. The aftershock (Mw 6.7) on the day after the mainshock shows the dipping with direction N19°E and N71°W and the major aftershocks on 12 May 2015 has again shows dipping with dip direction N37°E and striking with direction N53°W. This indicates that the strike direction is confined on NW and the propagation of the rupture is mainly concentrated along NE direction. The angle of dip of mainshock was 6° and its largest aftershock was 11°. Nodal planes of mainshock and three large aftershocks have east west orientation and shallow dip (6° to 23°) towards north, exhibit strong thrust mechanism. The dips of nodal plane of other larger aftershocks (Mw 5.1 to 6.7) lying between 14° to 40° indicate dipping process at shallow angle in the region, steeper than the detachment MHT which is demarcated as a low-angle northeast dipping at depth of 12-21 km [9].

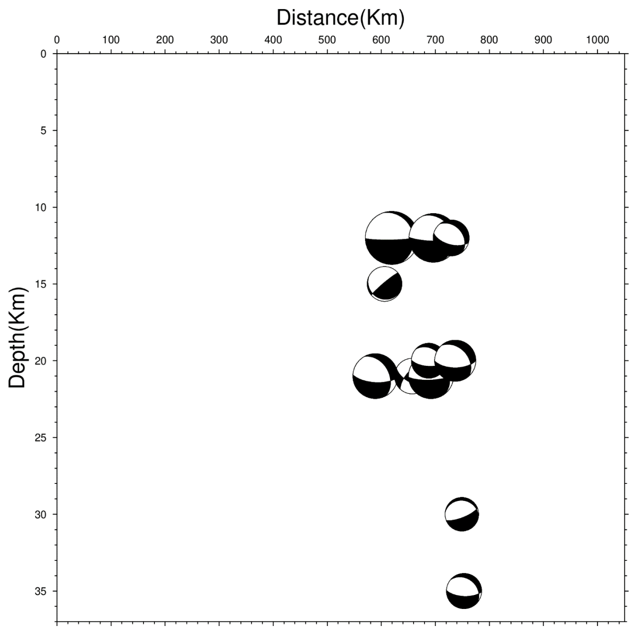

Figure 2. Focal mechanism cross-section of 11 events having magnitude 5 and above (26°N-31°N and 80°E-89°E) with depth.

The cross-section map (Fig. 3) associated with mainshock and aftershocks shows the depth range from 10 km to 35 km. The mainshock (Mw7.9) and major aftershock (Mw7.2) both occurred at depth of 12 km. The focal mechanism cross section map (Fig. 2) shows two remarkable clustering. There is one cluster around depth 12 km and another cluster around 20 km to 21 km. The seismic event gap was noticed between these two clusters. The group of researchers [16] noticed the thrusting on a sub horizontal fault dipping about 10° northwards and the 15 km hypo central depth. They made the conclusion that this earthquake ruptured the MHT, the main fault along which northern India underthrusts the Himalaya at a rate of approximately 2 cmyr^{-1}. Zhang et al. [2] reported the focal mechanism of this earthquake is a thrust fault type and is consistent with the Main Frontal Thrust.

Thus, focal mechanism of Gorkha earthquake explained in this study is agreement with the earlier works.

4. Conclusion

The focal mechanism of the 2015 Nepal earthquake was the thrust fault type, which is consistent with the Main Frontal Thrust. The rupture propagated from the hypocenter toward southeast and did not cause surface rupture. Clustering patterns of events is observed following NW-SE trend of the major thrust. Most of the aftershocks are occurred to the SE of main shock than that in NW of it and within 10 to 35 km depth range. The strong thrust mechanism was exhibited by the events as noticed from orientation of nodal planes of mainshock and four large aftershocks. They have east west orientation and shallow dip (6° to 23°) towards north. The strain resulting from on-going collision between India and Eurasian plates could have cause large slip on the locked segment of the detachment (MHT) to generate the Mw7.9 devastating Gorkha earthquake. Focal mechanism cross sections highlight a region of the MHT that has not ruptured in this event, but is locked, and therefore still has the potential to fail seismically.

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