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Source Process of the Mw = 5.1, Phalla (Islamabad) Earthquake and Its Tectonic Perspective

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The 2015 Phalla earthquake occurred near Islamabad, Pakistan with strong shaking but no damage report. We estimated the focal parameters and slip model of this earthquake by waveform modeling of the local data using moment tensor inversion. We analysis 25 station waveform data retrieved from MSSP (Micro seismic studies Programme). We found strike slip mechanism within thrusting tectonic environment. This left lateral strike slip fault are may be *R* shears of the left lateral strike slip *Jhelum* fault present in East. This ineterplate earthquake was largest strike slip event to occur in HKS (Hazara Kashmir Syntax). The spectral parameters were computed using Brune's model fitting of the data. The moment magnitude, fault length, static stress drop and radiated seismic energy were computed as 5.1, 1.5 km, 90 bar, and 9E11 J respectively. The same spectral analysis was applied to the aftershocks waveform data from near local stations. We tested the scaling of seismic spectrum, and the scale invariance of the apparent stress drop with the earthquake size. The existence of this strike slip mechanism within the subduction zone may play vital role in the segmentation of large thrust faults of the HKS zone which will in turn affect the seismic hazard estimation.

Waveform Inversion Technique

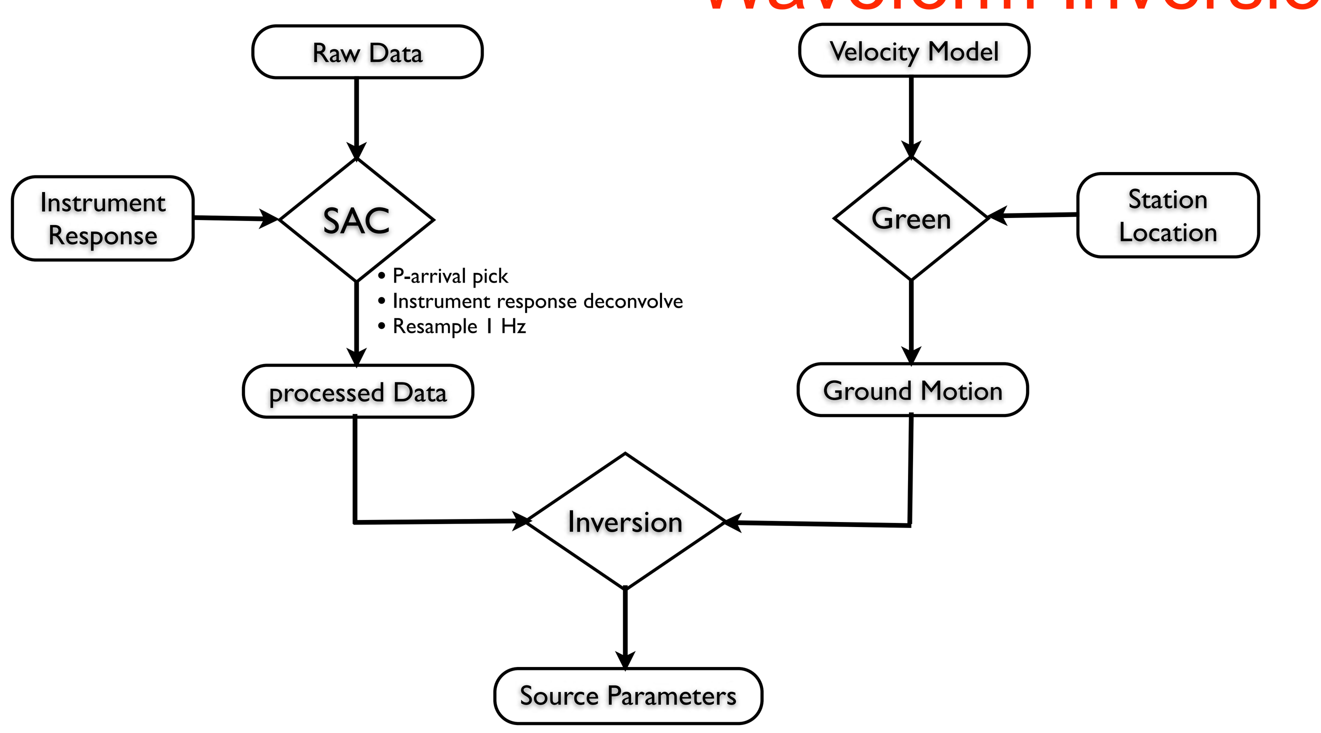


Figure 1: Flowchart of the moment tensor inversion technique, input data files, input parameter files and output data files. User starts with preprocessing sac data using SAC software, alongwith creating a parameter file for Green function. The program GREEN computes Green functions, required station locations and velocity models. The Green function output file, sac data and parameter file for Inversion function used in INVERSION function to compute focal mechanism solution and depth.

We used Yagi and Nishimura (2011) technique of moment tensor inversion for source mechanism study of 24 July, 2015 mainshock (M5.1) and its largest aftershocks (M> 3.0). The goodness of fitting is evaluated through achieved variance reduction between observed and synthetic waveform of one or more stations at regional distance. The variance value is sensitive to amplitude and time shift of both observed and synthetic seismogram. Signals are shifted relative to each other to achieve maximum cross co-relation and minimum variance. Model parameters are taken at minimum variance value. Using grid search, model parameters such as strike, dip, rake, seismic moment and depth of an events are inverted. We computed synthetic ground motions (green's function) for horizontally layered structure using discrete wave number using method developed by Kohketsu (1985). We used Jeffery-Bullen (JB) velocity model in this study, but results were also tested with other velocity models (AKI135, PREM). Uniform weight was assigned to all seismograms during inversion process.

Data Analysis

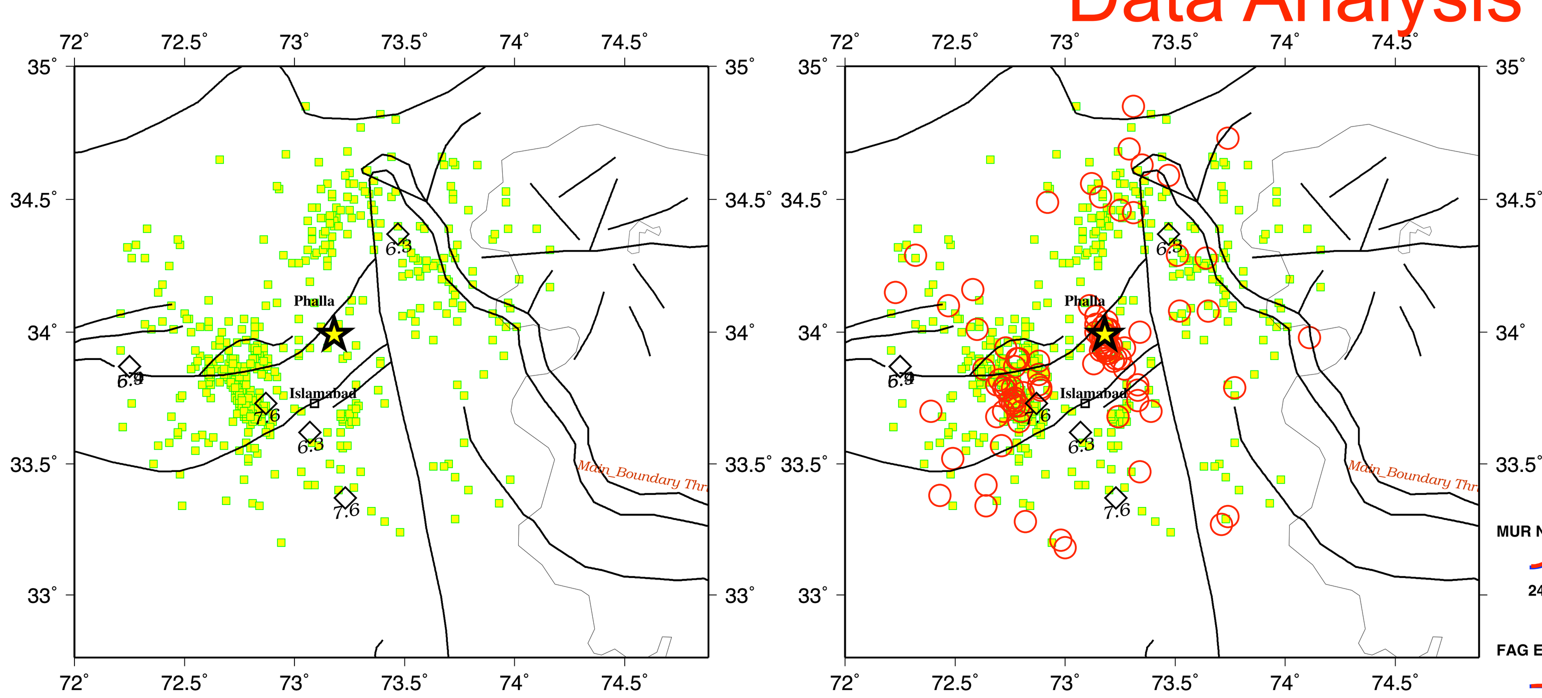


Figure 2: Locations of earthquakes, occurred within 10*SRL (surface rupture length) and one year before and after the mainshock (star). July, 2015 with M5.1. Diamond are the historical events with magnitude at bottom taken from Quitmeyer and Jacob (1979). (a) Events (square) occurred one year before Phalla (mainshock) earthquake. (b) Aftershock (circle) of the Phalla earthquake.

We used earthquake data from local seismic network that consists of 30 broad band three-component seismic stations equipped with Guralp CMG-(3-ESP, 3T), Geo-Tech (GS-13) seismometers and acceleration sensors operating in different parts of Pakistan. We analyzed waveform data of mainshocks and its corresponding aftershock with magnitude greater 3.0. The sampling frequency was 50 Hz. Only stations with good signal to noise ratio were selected. To process the data, first p-arrival were picked manually on each station. Mean, trend and seismic instrument response were removed from data. Band pass filter between 0.07-0.1 Hz were applied, to suppress the near structure effects and data were re-sampled at 1 Hz frequency. Focal mechanism solutions of previous available events were taken from global Harvard CMT (Centriod Moment Tensor) catalogue.

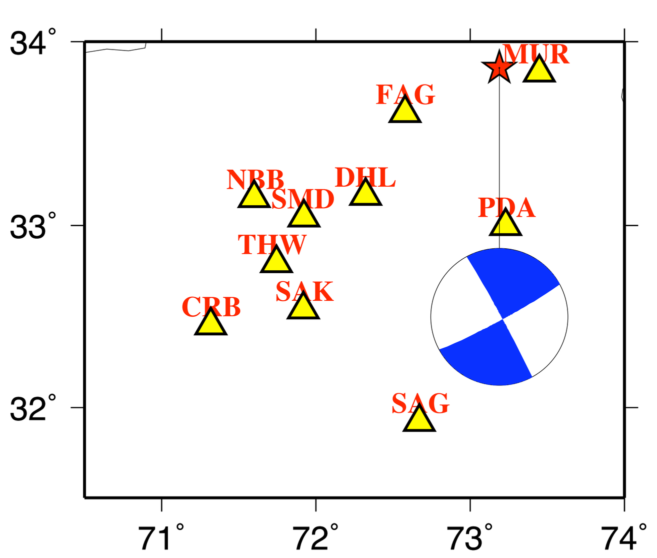


Figure 3: Mainshock (star) location, stations (triangle) used in waveform inversion. Beach ball show focal mechanism solution at best waveform fitting between observed and synthetic.

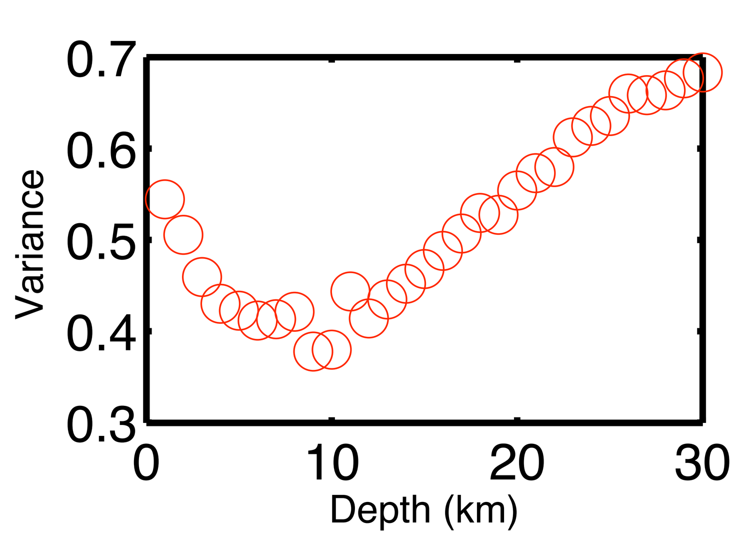


Figure 4: Depth as a function of variance between observed and synthetic waveform fitting. Depth taken at minimum variance.

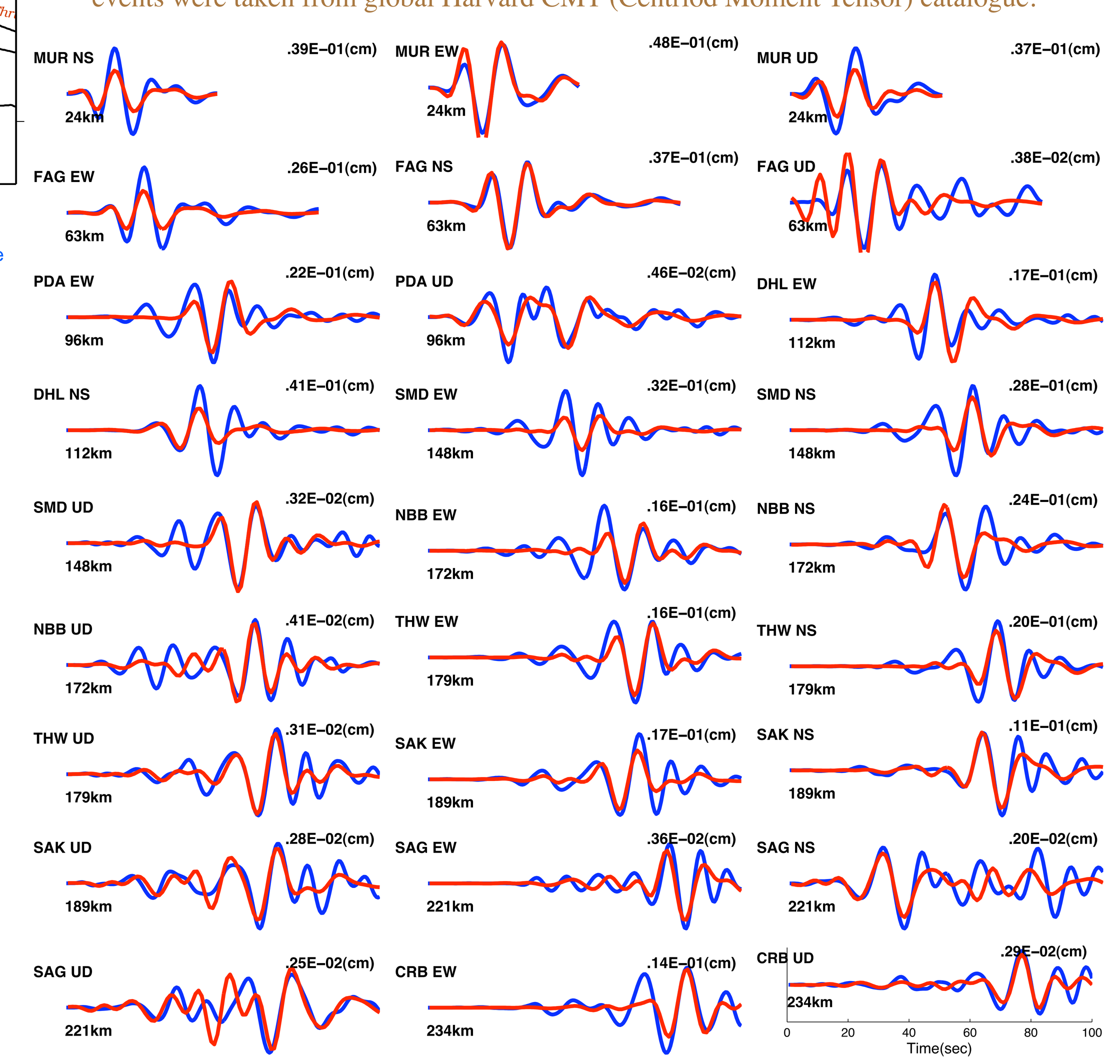


Figure 5: Fit between the observed and synthetic waveforms for the preferred solution for the event of 24 July 2015 for each station used in the inversion. The observed waveforms and the synthetic waveforms are represented in blue and red lines , respectively.

Focal Mechanism Solutions and Stress Inversion

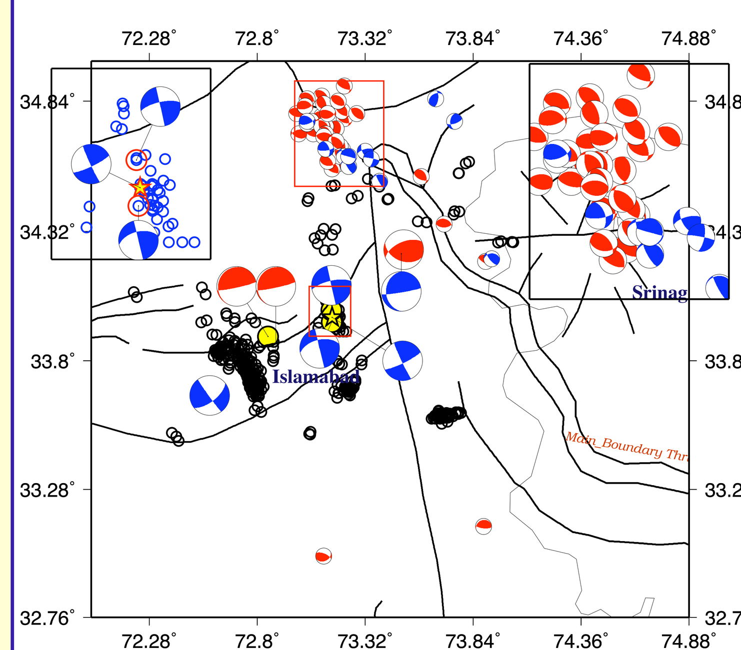


Figure 5: Regional focal mechanism solutions of events occurred surrounding of the study area. For Kashmir focal mechanism solutions are taken from Harvard CMT, whereas within the 20*SRL distance of mainshock are inverting using moment tensor inversion scheme.

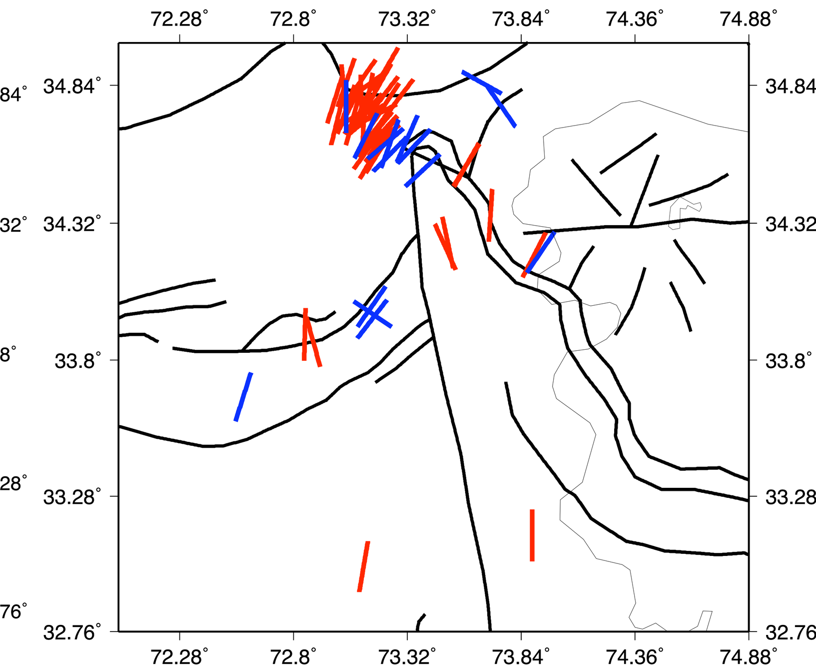


Figure 5: Principal stress axes direction, taken as the maximum principal stress axis

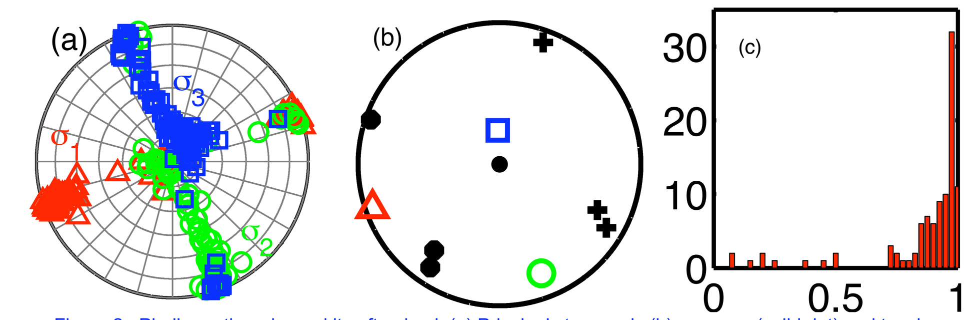


Figure 2: Phalla earthquake and its aftershock (a) Principal stress axis (b) pressure (solid dot) and tension (+) axis (c) shape ratio of stress.

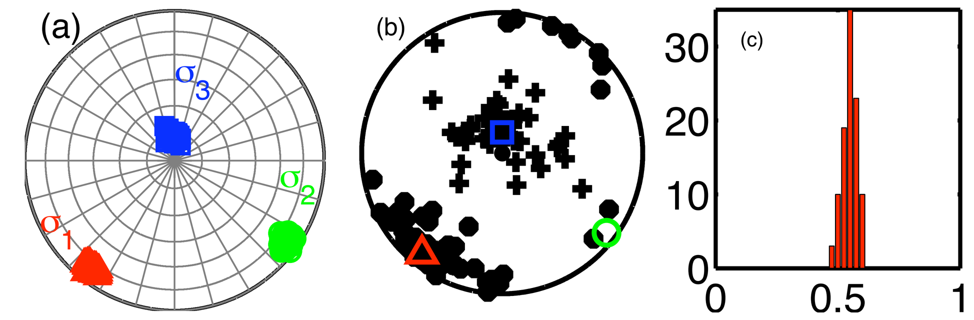


Figure 2: Same as Figure (10) for Kashmir, 2005 earthquake.

We inverted focal mechanism solutions using Michael (1984) technique constrained by Vavrycuk (2014). This technique is linear and iterative search to obtain the best fitting principal stress acting on fault plane. The inversion technique computes minimum rotation angel of principal stresses that is compared with the observed slip direction. The model parameters are taken with smallest total misfit. Principal stress axis are consistent with that of regional stress and support the subduction of Indian plate under Eurasian plate.

Focal Mechanism Solutions and Stress Inversion

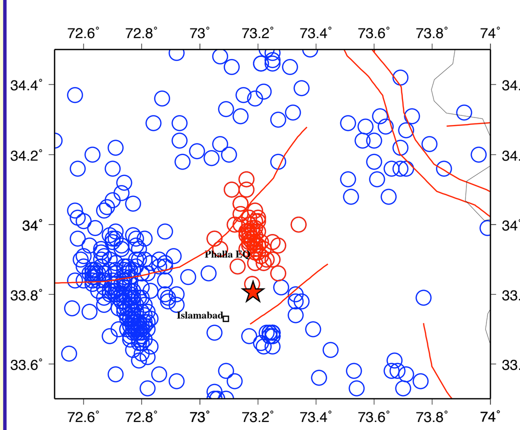
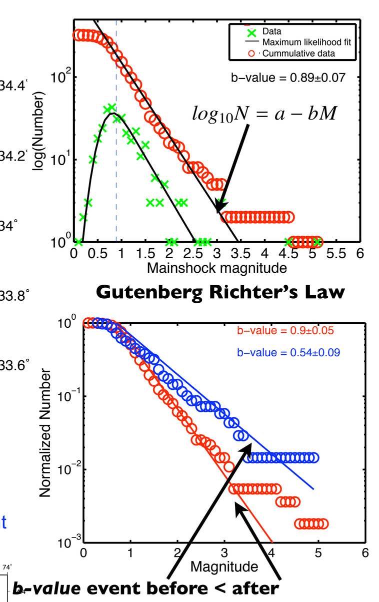
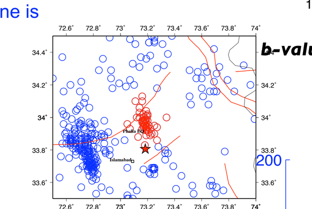


Figure 6: Mainshock and its two largest aftershock (M > 3.0) focal mechanism solution. (a) Focal mechanism solution (b) nodal planes of three events red line represent fault plane, whereas black line is auxiliary plane.





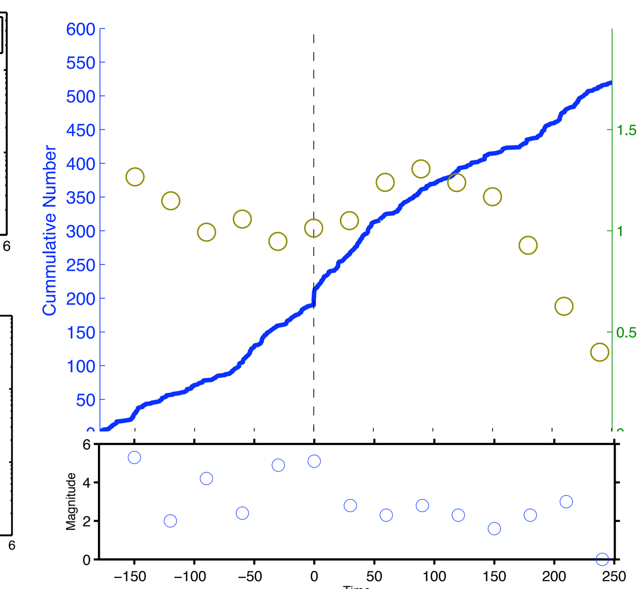


Figure 7: *b*-value before and after Phalla earthquake

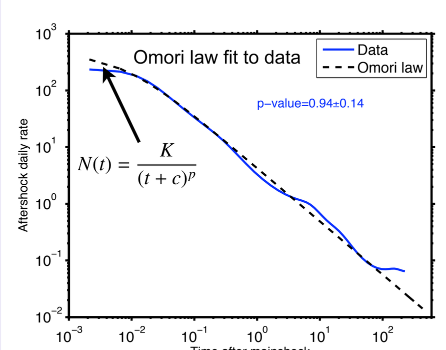


Figure 8: Temporal distribution of aftershock with Omori's law fit to data

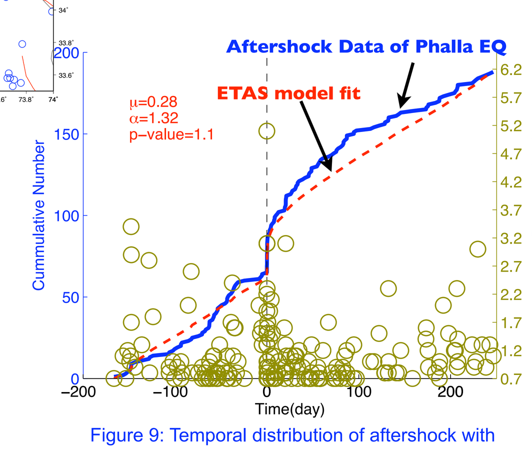


Figure 9: Temporal distribution of aftershock with ETAS law fit to data

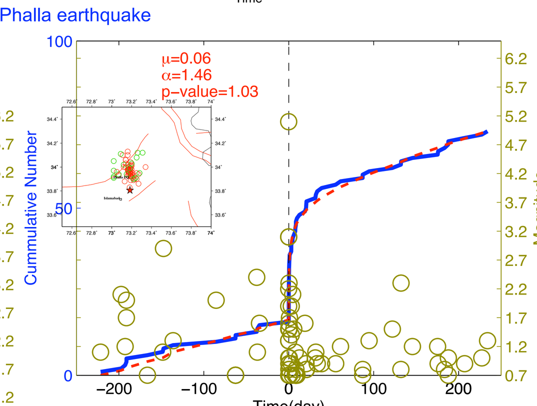


Figure 10: Same as Fig. in left with data only taken 10*SRL.

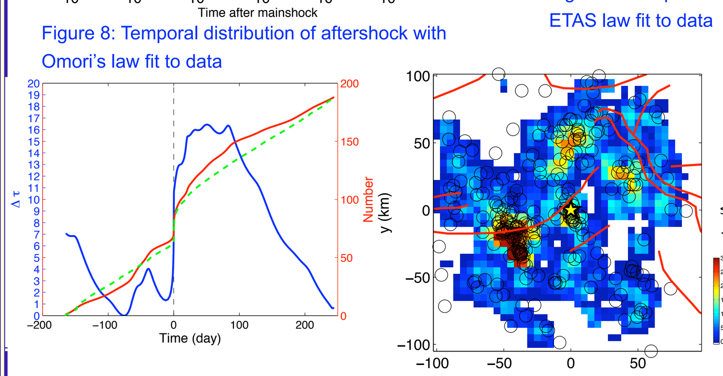


Figure 11: Evolution of shear stress change in Time-Space domain.

Rate and State Friction model

$$R = \frac{r}{\gamma \dot{\tau}_r} \xrightarrow[\text{Steady state}]{R = r} \gamma_o = \frac{1}{\dot{\tau}_r}$$

State evolution with time given as

$$\gamma_n = \gamma_{n-1} exp\left(\frac{-\Delta CFS}{A\sigma}\right)$$

$$t_a = \frac{A\sigma}{\dot{\tau}_r}.$$

Stress are migrating toward west.

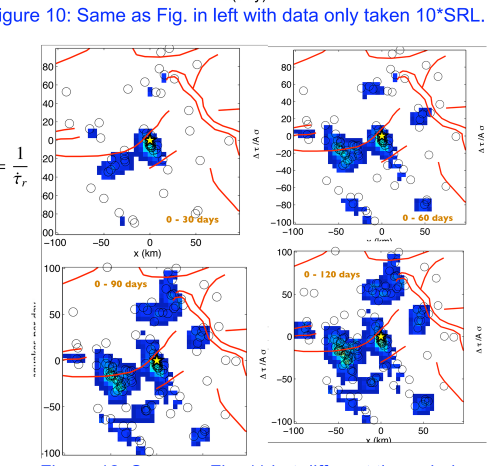


Figure 12: Same as Fig. 11 but different time window

Spectral Analysis

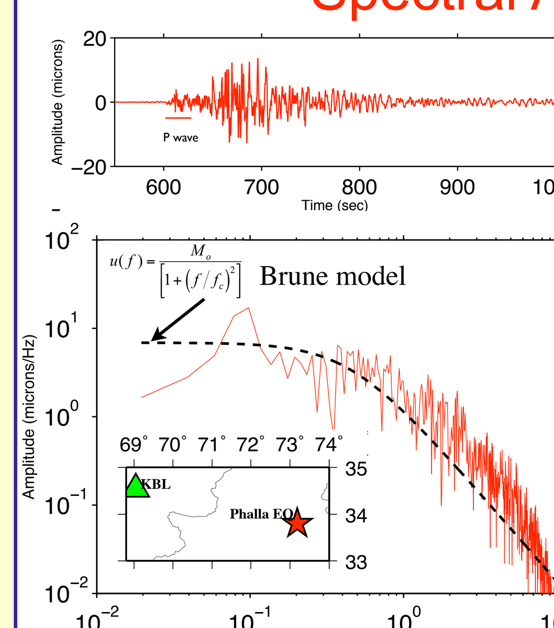
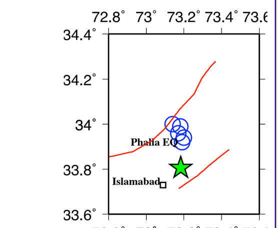


Figure 13: Seismogram at top and its displacement spectra at bottom of Phalla earthquake recorded at Kabul Station.



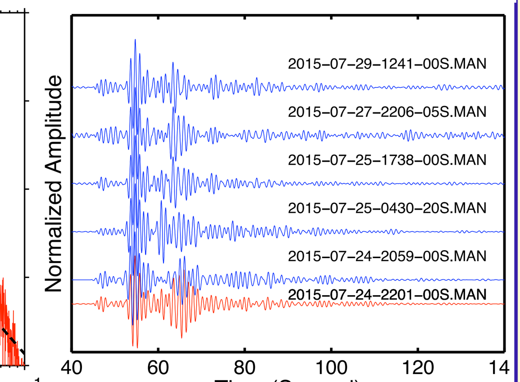


Figure 14: Cluster of similar waveform events recorded at Nilore station.

Brune model fit to displacement source spectra.

Seismic Moment (M_0)	$M_0 = \frac{4\pi\rho v^3 \, r\int u \, dt}{F}$
Corner Frequency (f_c)	
Fault Length	$r = \frac{k\beta}{f_c}$
Apparent Stress Drop ($\Delta\sigma$)	$\Delta\sigma = \frac{7M_0}{16r^3}.$
Seismic Energy	

Assumes a rupture velocity of 0.9*shear wave velocity, $k = 0.21$

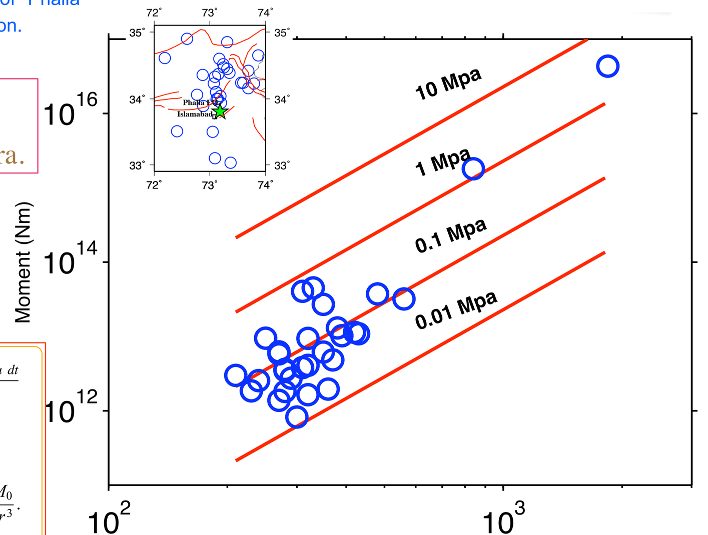


Figure 15: Seismic moment versus source radius. Lines show constant stress drop. Inset figure show aftershock location used for spectral analysis.

Conclusions

The moment tensor inversion show strike slip mechanism of July, 2015 Phalla earthqauke. The sense of the movement and aftershocks distribution suggest left lateral movement, may be represent *R* shear of the Jhelum Fault in East. The direction of Principal stress axis are consistent with regional stress direction. The *b*-value of Gutenberg Richter's law decreases before the occurrence of mainshock. Aftershock distribution show stress are migrating toward west. Invariant scaling law observed in aftershock sequences but the level stress triggering different for mainshock as compare to aftershock.

References

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