Seismic attenuation tomography of the North-Western Himalaya using Coda waves

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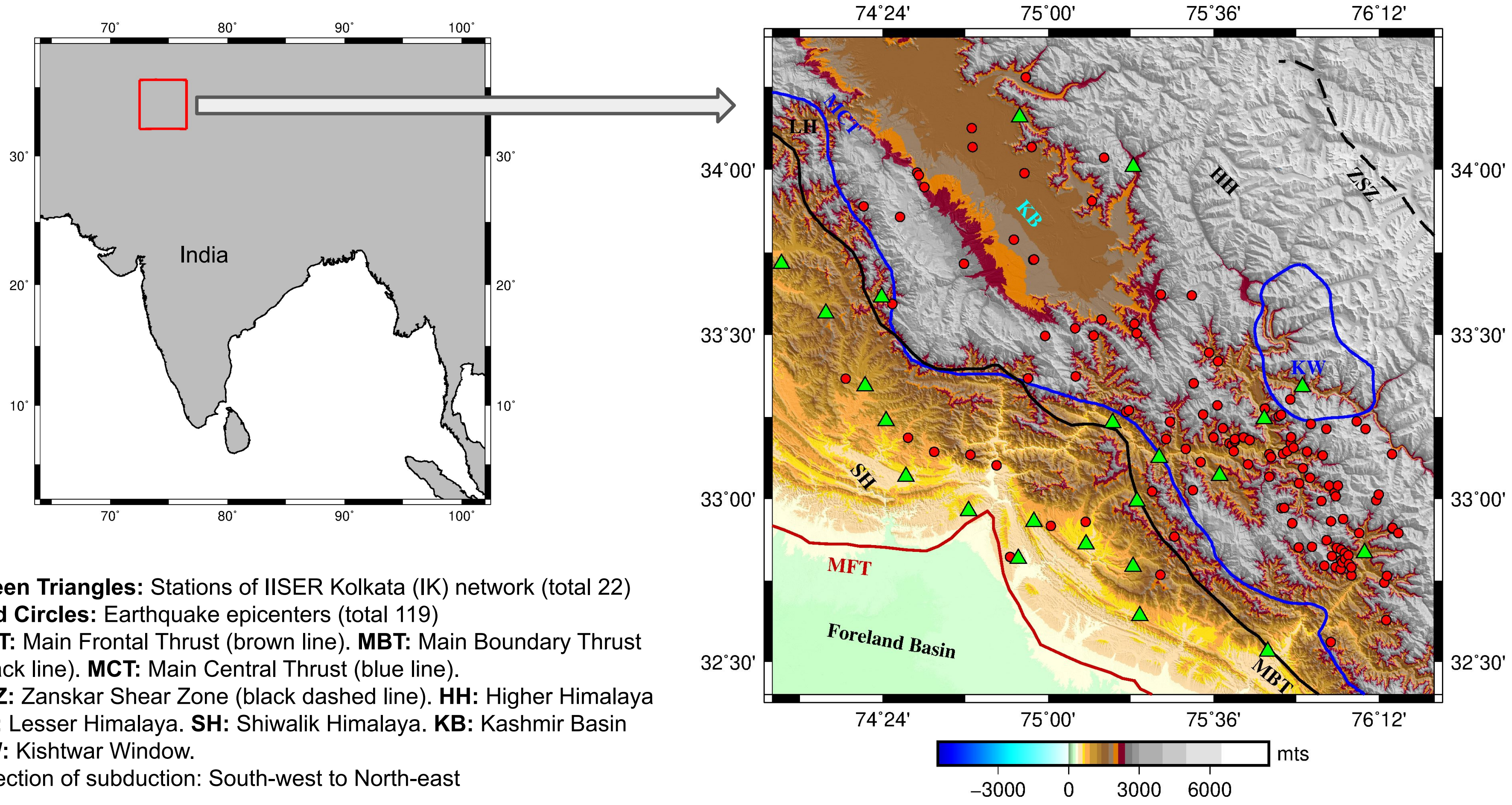
Study area: North-Western Himalaya with events and stations



Green Triangles: Stations of IISER Kolkata (IK) network (total 22)
Red Circles: Earthquake epicenters (total 119)
MFT: Main Frontal Thrust (brown line). **MBT:** Main Boundary Thrust (black line). **MCT:** Main Central Thrust (blue line).
ZSZ: Zanskar Shear Zone (black dashed line). **HH:** Higher Himalaya
LH: Lesser Himalaya. **SH:** Shiwalik Himalaya. **KB:** Kashmir Basin
KW: Kishtwar Window.
Direction of subduction: South-west to North-east

Workflow

- We utilize the amplitude decay nature in the coda part of a waveform to calculate the quality factor (Q_f) at several frequencies (1Hz to 14Hz).

$$A(f,t) = S(f)t^{-\beta}e^{\frac{-\pi f t}{Q(f)}}$$

Given by Aki & Chouet (1975)

- We use the equation of power law dependence of Q on frequency to calculate Q_0 and frequency dependence parameter η.

$$Q = Q_0(f/f_0)^{\eta}$$

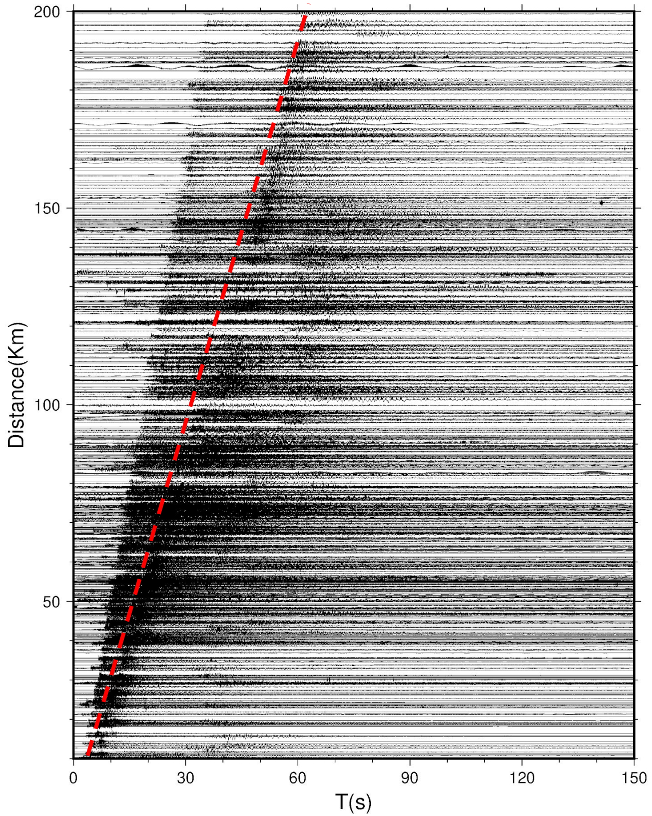
- Here we are using the multiple forward scattering model in which it is considered that energy loss what we see in the receiver is dominantly dependent on the intrinsic loss of energy along the raypath connecting the source and the receiver. $Q_c^{-1} = Q_i^{-1}$
- To see the lateral variation of Q in our study area, we have produced 2-D maps by combining the Q_f measurements together in a tomography by modifying the back-projection algorithm (given by Xie & Mitchell, 1990) to calculate the length overlap of traces with the gridded region.

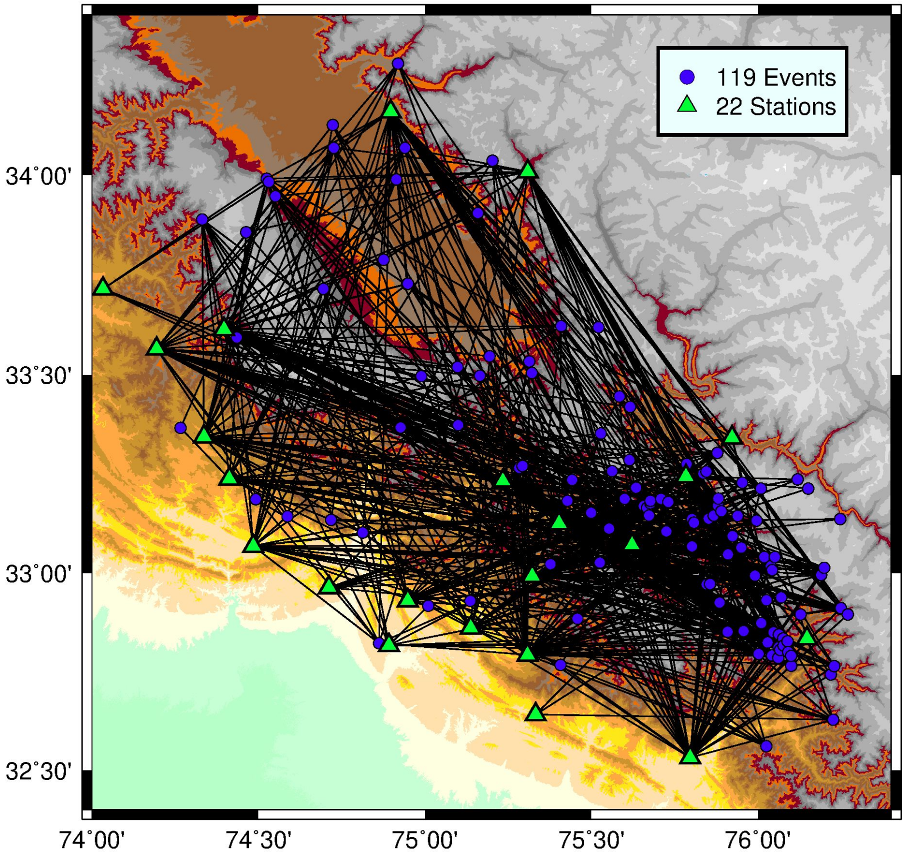
$$\frac{1}{Q_x} = \frac{1}{\Sigma_{g=1}^{N_g} S_{gx}} \Sigma_{g=1}^{N_g} \frac{S_{gx}}{Q_g} + \epsilon_x$$

$$\frac{1}{Q_g^{i+1}} = \frac{1}{Q_g^i} + \frac{1}{N_i} \sum_{x=1}^{N_d} \frac{\epsilon_x^i s_{gx}}{\sum_{j=1}^{N_g} s_{jx}^2}$$

- We estimate attenuation (attenuation ∝ 1/Q) characteristic beneath North-Western himalaya. We are going to estimate ground shaking from future earthquake and also properties of the medium.

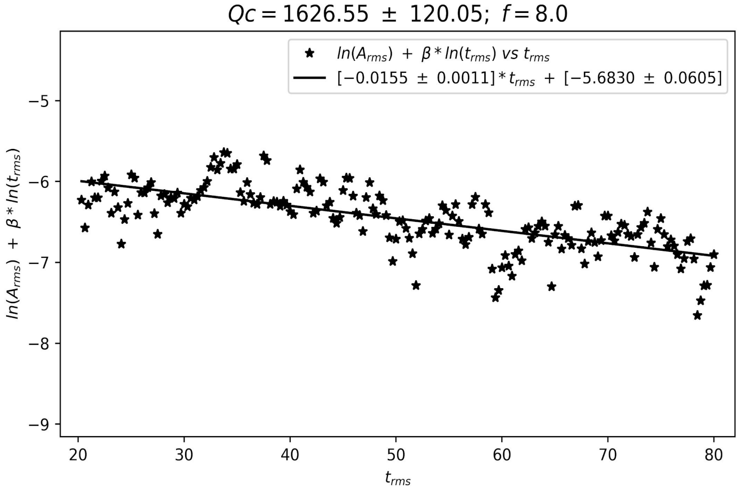
Record Section and raypath plot

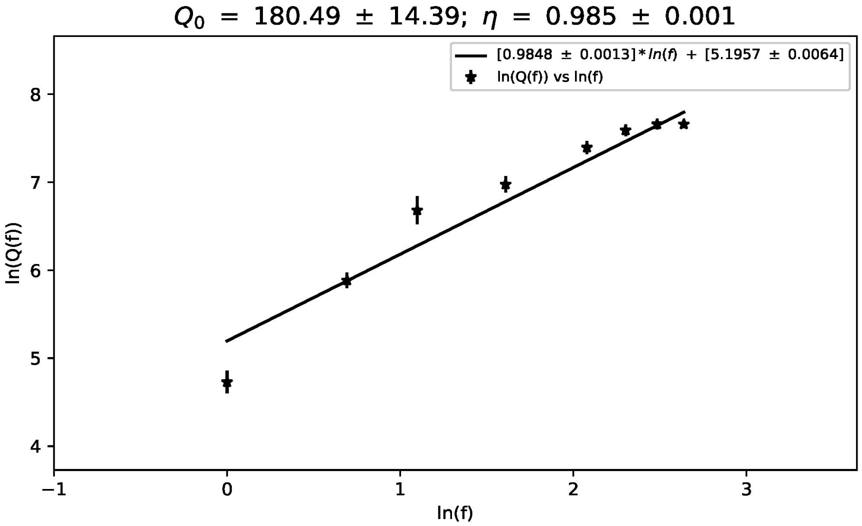




No. of Waveforms: 696, $3.0 < M_W < 6.0$, Epicentral Distance: 10 km to 200 km, Signal to noise ratio > 2
Red dashed line in record section plot: least square fitted t_s time line

Least Square analysis to calculate Q_f , Q_0 and η for each trace

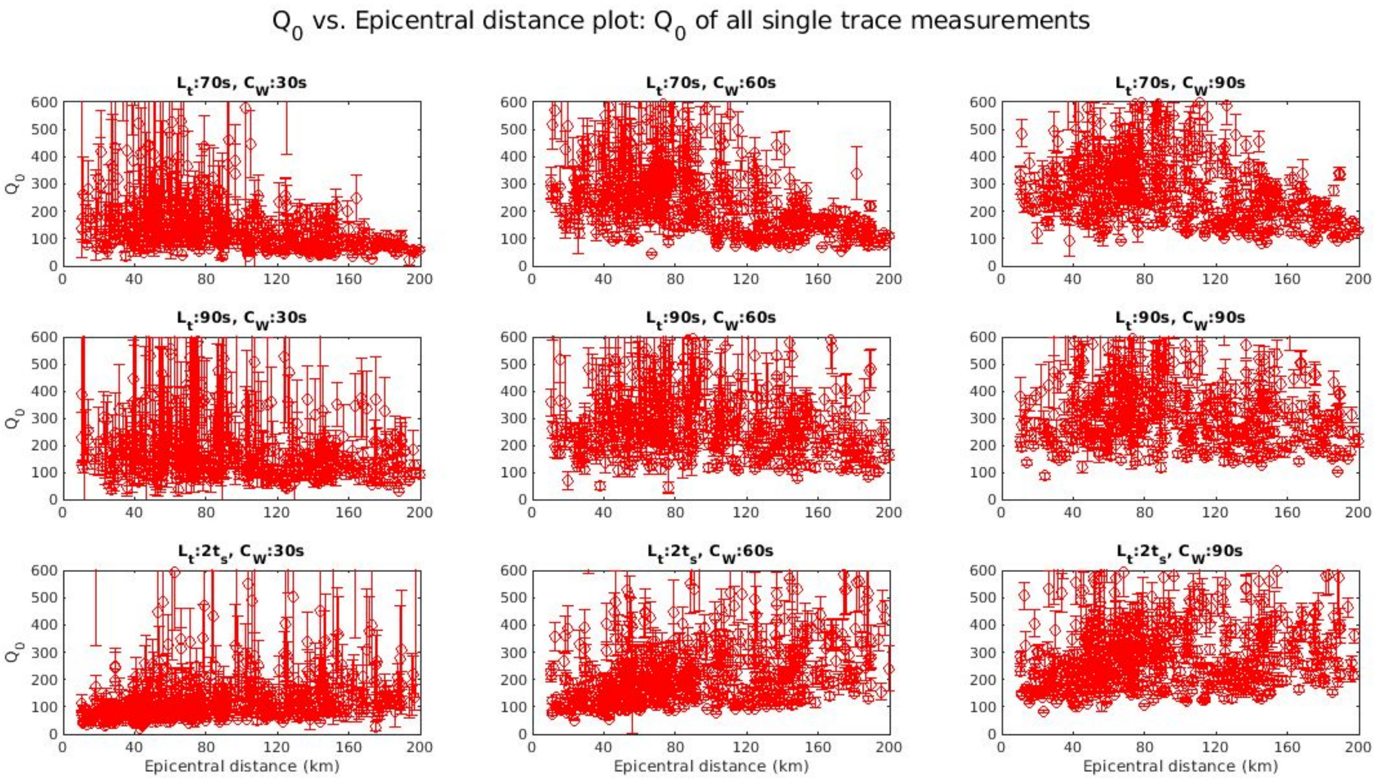




Left image: Using the logarithm of temporal decay of amplitude equation (Aki & Chouet, 1975) and doing the least square analysis we get Q_f and corresponding error at frequencies 1, 2, 3, 5, 8, 10, 12 and 14 Hz.

Right image: Here we use weighted least square method to calculate Q_0 and η at a reference frequency which is set to 1Hz. For the weight, we use the error of the Q_f calculation from least square method.

Choosing suitable lapse time (L_t) and coda window length (C_W): Q_0 of each trace vs epicentral distance



We have taken 70s, 90s and 2ts (2 x S-wave time arrival) as trial L_t and 30s, 60s, 90s as trial C_W for the analysis of choosing suitable L_t and C_W.

Q_0 doesn't vary with epicentral distance.

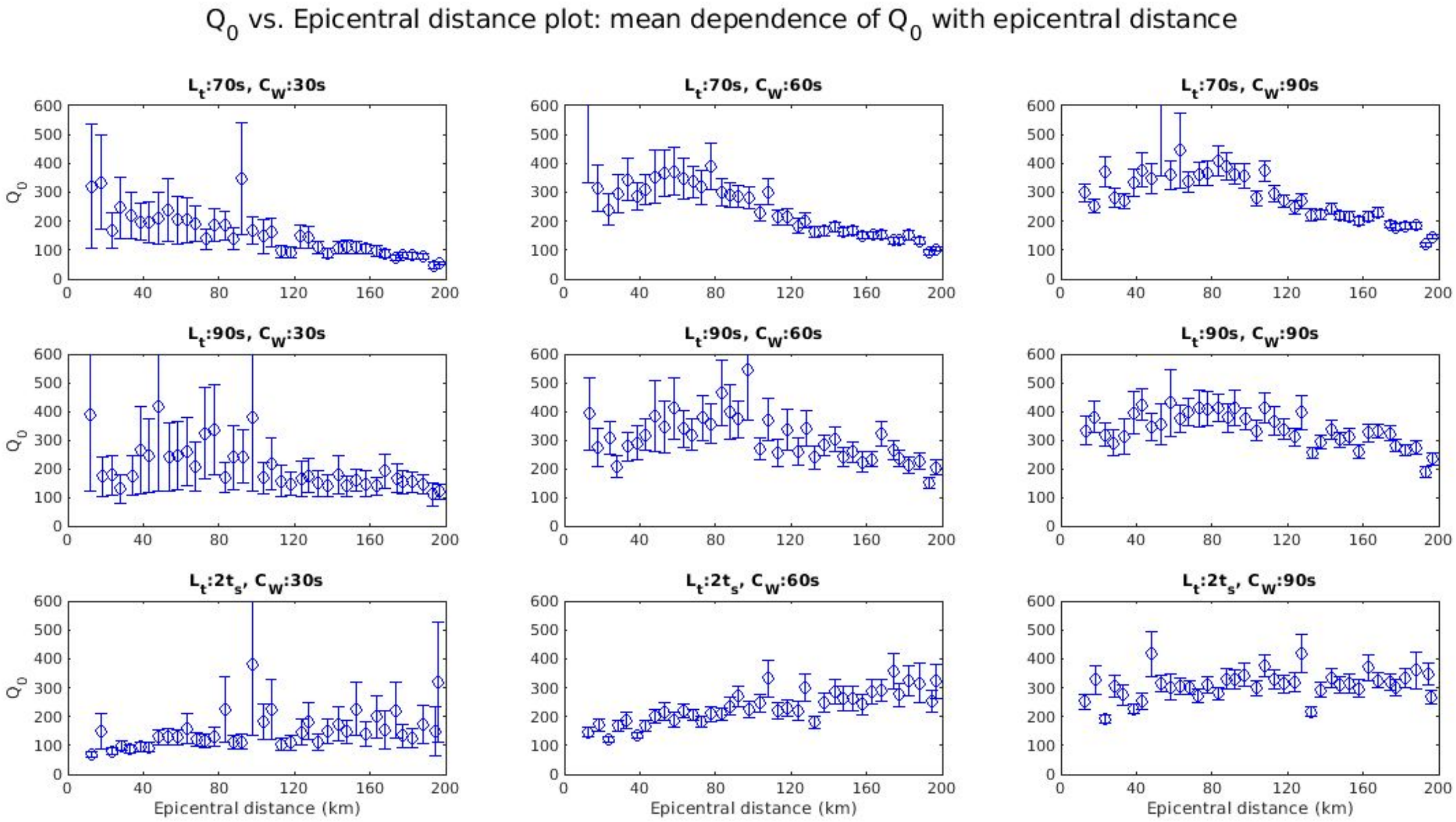
Here we can see that at 70s L_t Q_0 is varying at < 150 km epicentral distance but not changing at > 150 km epicentral distance. But for 70s and 90s L_t Q_0 is randomly varying with epicentral distance which indicate that there is no systematic bias in calculation of Q_0 at 70s and 90s L_t.

Choosing suitable lapse time (L_t) and coda window length (C_W): mean Q_0 vs epicentral distance

At each 5 km interval we calculate mean Q_0 of traces within that interval.

It is highly expected that the mean Q_0 is not going to vary much with the epicentral distance because Q_0 is not depended on epicentral distance.

We see from the plot that at 2ts L_t the mean Q_0 is not varying. So we choose 2ts as L_t for plotting tomography.



Choosing suitable lapse time (L_t) and coda window length (C_W): Q_0 vs Coda window length at different L_t

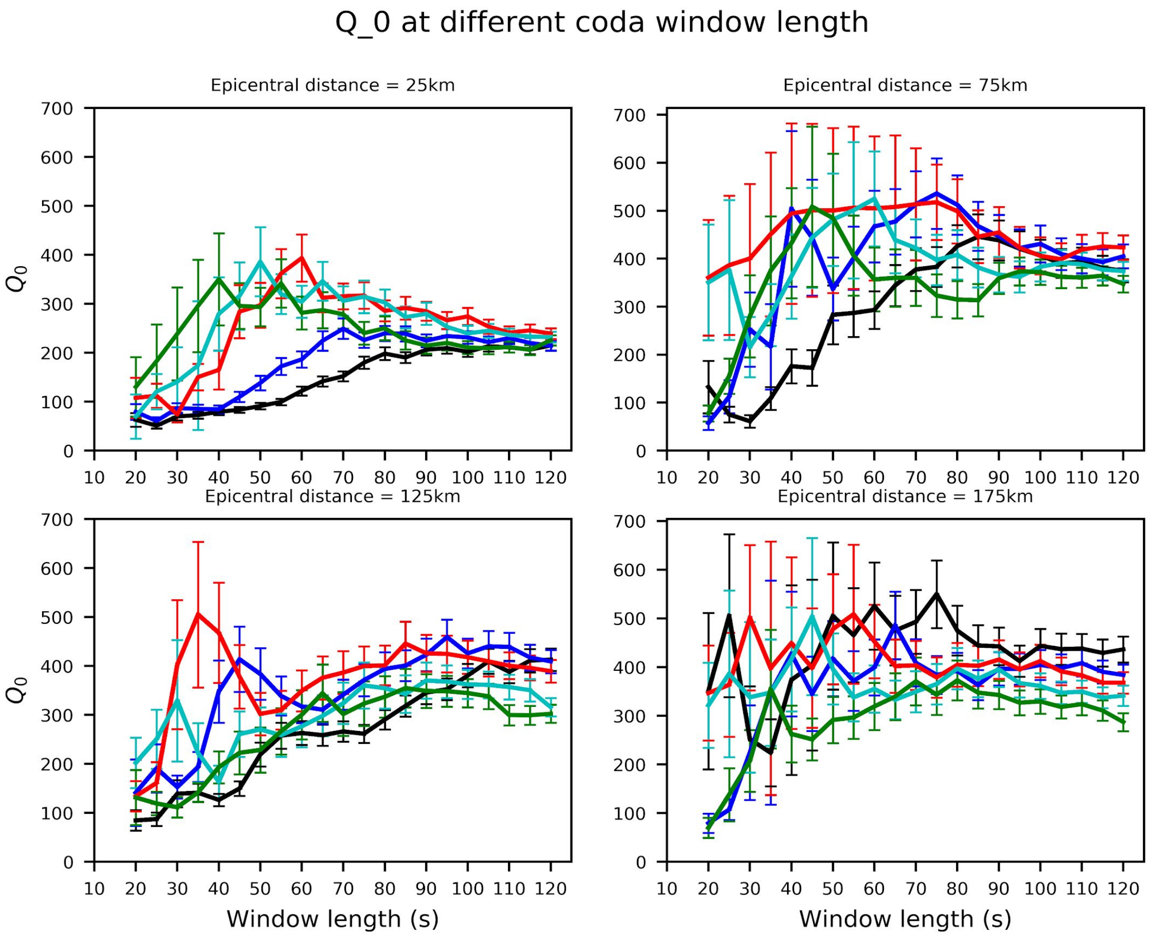
L_t

Black: 2ts Blue: 2t + 10s Red: 2t + 20s
Cyan: 2t + 30s Green: 2t + 40s

Here our goal is to choose a suitable C_W for 2ts L_t to plot the tomography. We have taken four waveforms having 25, 75, 125 and 175 km epicentral distance.

We gradually increase the L_t to decrease the effect of scattering attenuation and increase the effect of intrinsic attenuation and to finally reach the diffusive regime where we have dominant intrinsic attenuation.

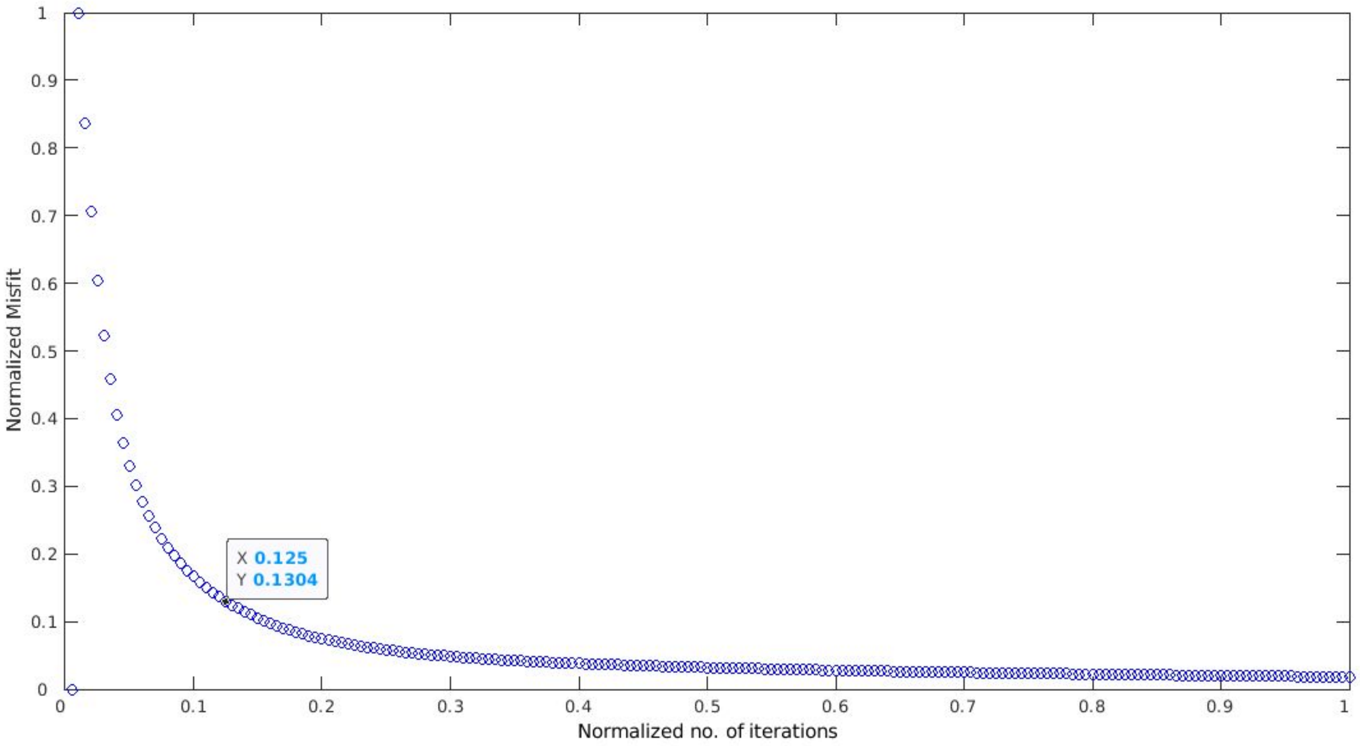
For all plots Q_0 is stabilizing at around 90s. So, we choose 90s to be the C_W along with 2ts L_t for tomography.



Choosing of No. of iteration: Normalized misfit vs Normalized no. of iteration

With continuous increase of iteration the misfit value will keep decreasing.
So to find out the the stopping point of iteration we plotted normalized misfit versus normalized no. of iteration for getting an optimum value of iteration where x=y in the plot.

Here the optimum value of iteration for tomography is coming **25**. So, we choose to do the tomography at 20, 25 and 30 iteration.

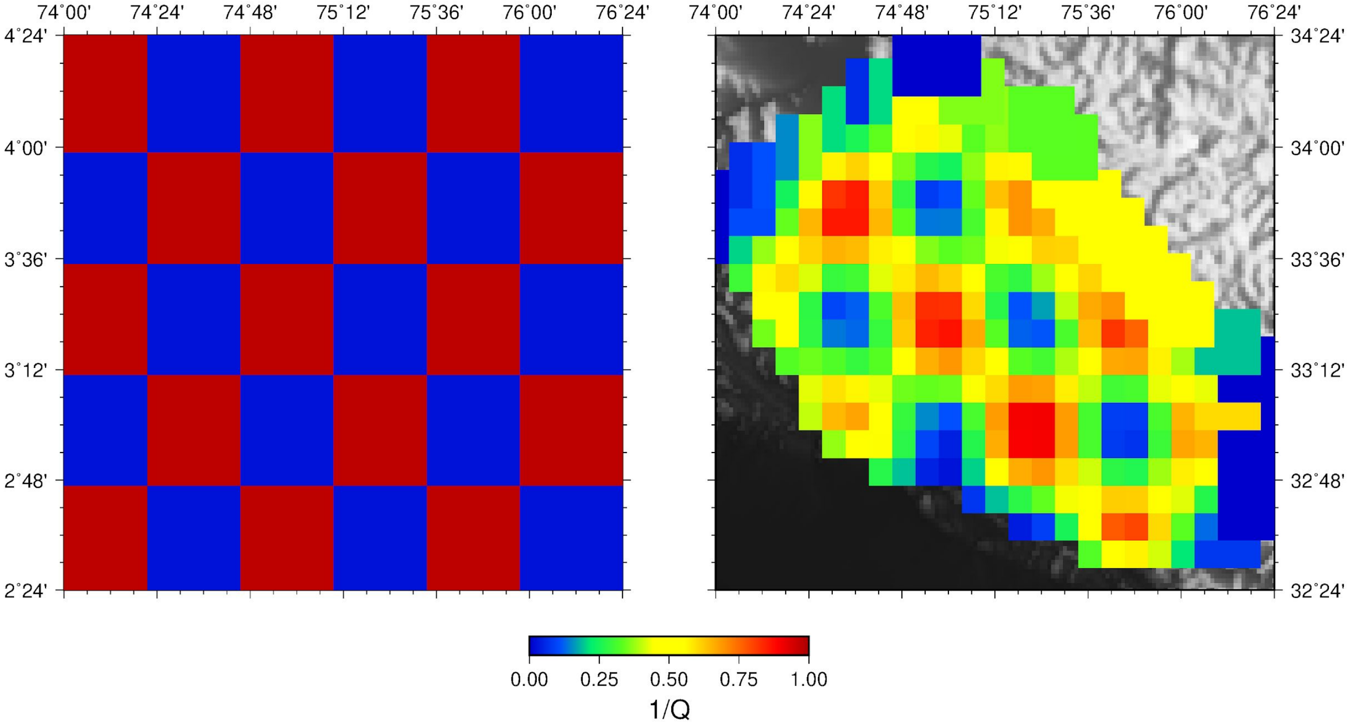


Other parameters: Grid dimension: 0.1° x 0.1° , Initial value of Q_0: mean value of Q_0 of all traces
Damping parameter: 1/total no. of raypaths, No. of raypaths within a grid: minimum 1

Standard Checkerboard resolution test

Left:
Checkerboard input model.

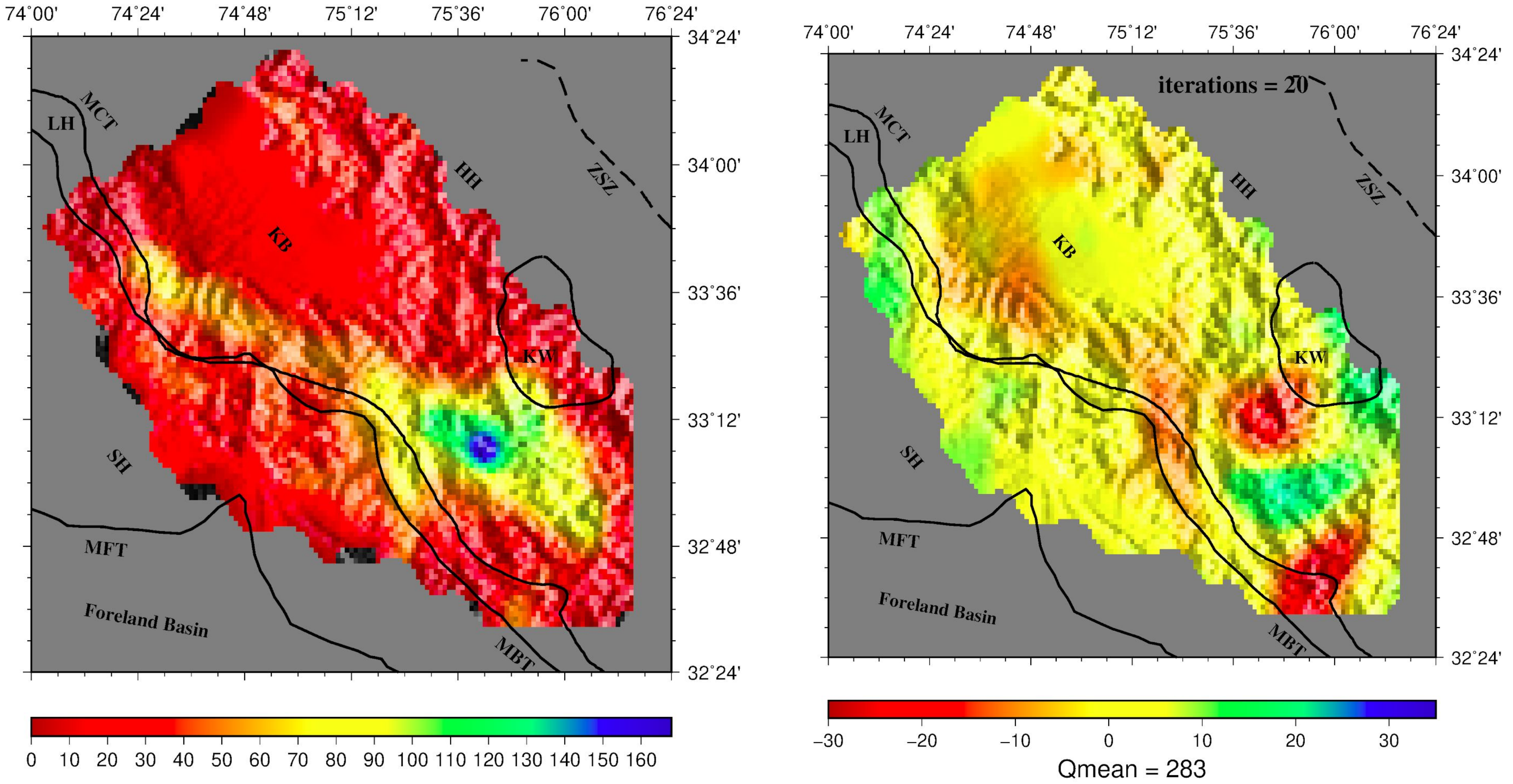
Right:
Output after the backprojection algorithm. Here grids with minimum 1 ray path are plotted only.



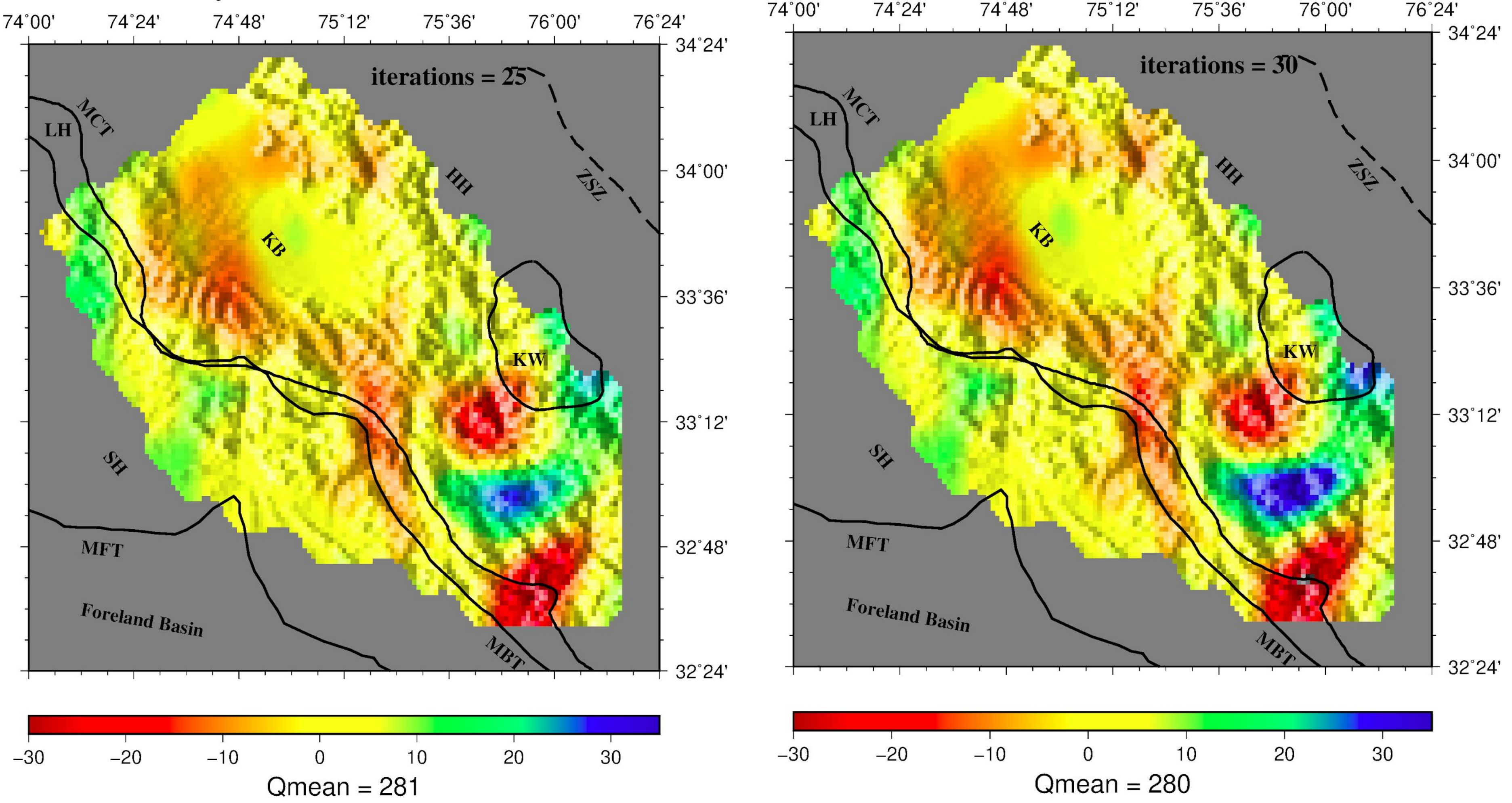
To understand the spatial resolution of 2D Q maps, we perform a standard checkerboard resolution test which ensure simultaneous recovery of Q perturbation. Perturbations are recovered using backprojection algorithm by constructing checker boards where each being parameterized as alternate high and low Q perturbation. From this we can conclude how good our tomography is.

Q_0 Tomography

Left: No. of Hits plotted in a tomography **Right:** Q_0 tomography (percentage of deviation from mean value)



Q$_0$ tomography (percentage of deviation from mean value) at 25 and 30 iteration



Discussion

- Kashmir basin (KB) is having low to medium Q_0 (230-260).
- Q_0 is medium to lower high in Shiwalik Himalaya (SH) (280-315)
- South-east of the Kishtwar window (KW) is having a lower high to high Q_0 value (310-340).
- South-west of the Kishtwar window (KW) is having very low Q_0 value (205-230).
- Whereas north of the Kishtwar window (KW) is having medium Q_0 value (270-300).
- Towards more south of the Kishtwar window (KW) in the Higher Himalaya (HH), Q_0 is very high (330-360).
- Far south of this window, a region consisting of both Lesser Himalaya (LH) and Higher Himalaya (HH) is having very low Q_0 (205-220).