Vol 2 (1998) Journal of International Academy of Physical Sciences pp.103-110

Scattering Response of P-Wave Beneath Gauribidanur Seismic Array

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(Received April 25, 1998)

Abstract : The amplitude and phase fluctuations of teleseismic *P*-waves across the Gauribidanur Seismic Array (GBA) may be considered due to the effect of scattering by random inhomogeneities which might be present beneath the array. The Chernov Theory has been applied for the analysis of 24 earthquakes recorded at GBA. The phase fluctuations information have been directly used for the analysis of slowness of time residual fluctuations. The extent of the structural inhomogeneities has been estimated beneath the array region. Correlation length of 18.13 km for the Gaussian correlation function has been derived. The estimated root mean square velocity fluctuation is around 1% under the array whereas the extension of the random medium is about 250 km.

Introduction

The observed irregular spatial variations of amplitude and travel time of seismic waves at the earth surface limit the accuracy of seismic probes, which is used for studing the earth's interior and source mechanism. Scattering of seismic waves is the cause of these variations. Thus, understanding of physical mechanism of scattering of the seismic waves will give clue to look into an accurate evaluation of the capability of seismic probe as well as the nature of inhomogeneities in the earth's crust and upper mantle.

The stochastic approach is desirable for obtaining the statistical proporties of the heterogeneities, when the medium beneath thr array has multi-scale and complex heterogeneities[1-5]. The first statistical study has been done for the data of the Large Seismic Array (LASA)[1]. Though, the variance of transverse correlation fluctuations of the phase and log-amplitude fluctuations of the direct *P*-arrivals were utilized by the earlier workers (Aki[1] for LASA; Berteussen *et al*[2] for NORSAR and LASA and Berteussen *et al.*[3] for GBA). The phase fluctuation information was either transormed into slowness fluctuations[6] or into time residuals[2,3]. An attempt has been made to use the phase fluctuation information directly by Tripathi and Ram.[7] Thus, structural heterogeneities can be statistically described by Chernov Theory[8] at specific location. The stochastic model of the heterogeneous media was assumed to be uniform isotropic random media with a Gaussian correlation function characterized by its relative velocity perturbations and average scale length scale length a.

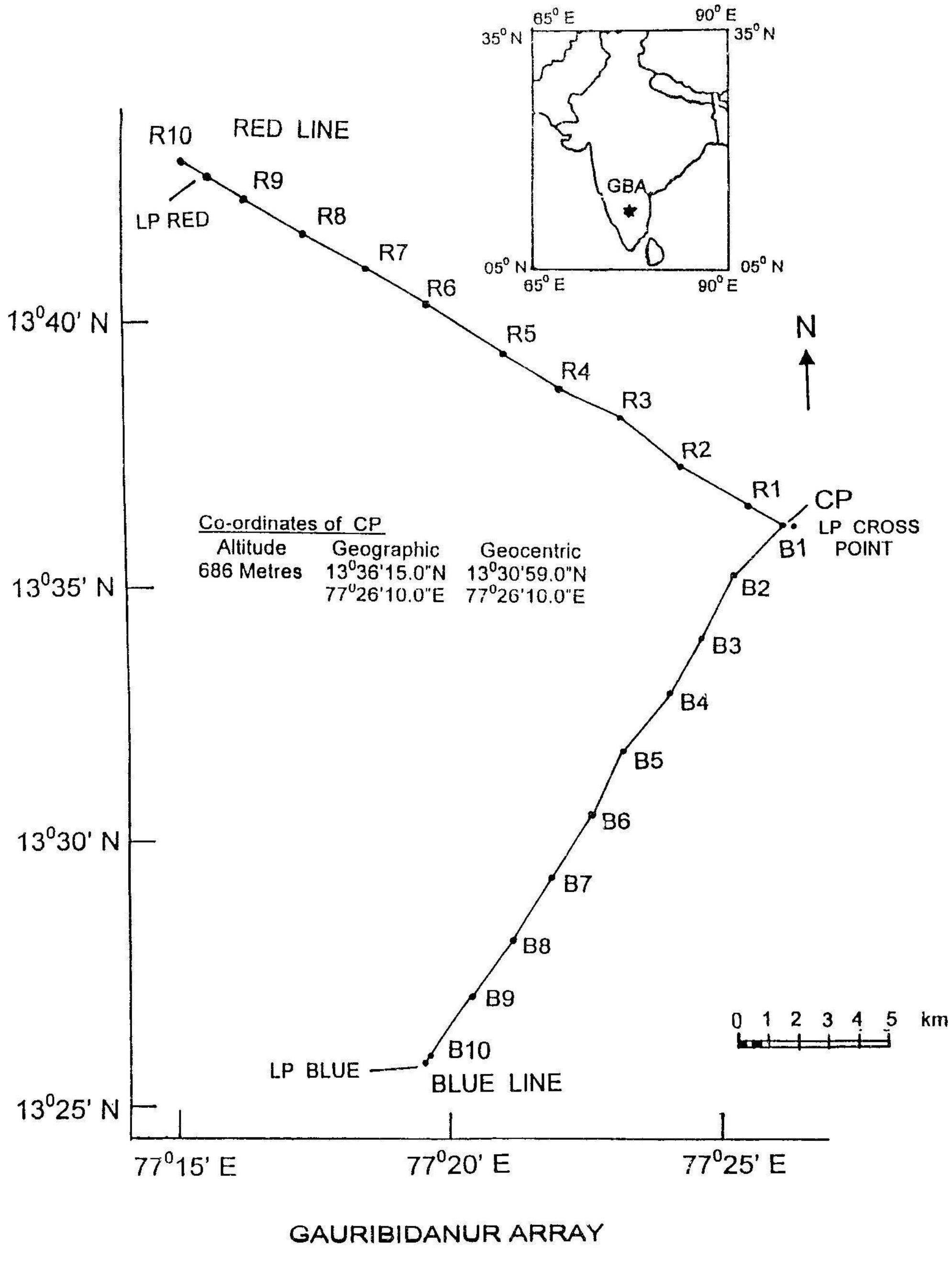

Fig. 1 :Location and configuration of the Gauribidanur medium aperture seismic array.

The Gauribidanur array, located in southern India (fig. 1), gives an opportunity to study the scattering mechanism for short period *P*-waves. Signal variations across the array are shown in the figure 2. The random media approch will be applied to estimate the root mean square (r.m.s.) velocity perturbations of the crust and upper mantle in the array siting area, the extent of the inhomogeneous medium and the correlation length. The correlation length is a measure on the wavelength of the structural anomalies. In this paper, phase fluctuation informations have been directly utilized for medium apperture array, instead of slowness or time residuals, for Chernov random media approach and estimated the extent of the structual inhomogeneities in the area of Gauribidanur seismic array (GBA). In this analysis 24 events, having a reasonable azimuthal coverage, were considered.

The Gauribidanur Seismic Array (GBA)

The array, which is located in southern India, was sponsored by the U.K. Atomic Energy Authority (UKAEA) in the early sixties with the cooperation of the Bhabha Atomic Research Centre (BARC), Government of India. The array became operational in October, 1965. The array is located about 90 km north of Bengalore. The array is *L*-shaped and each leg (called Blue and Red lines) contains 10 short-period (1s) vertical Willimore Mk II seismometers spaced at approximately 2.5 km. Resulting in overall length of each line 25 km. The vaults are set over Archean rocks unweathered gneisses ling within 2 meters of the surface over most of the region. The output of each of the instrument is carried by a telemetry system to a central recording laboratory. The rocks beneath the array are gneissic granite of Archean age, and their general foliation trends is NNW-SSE. A thin layer of soil varying in thickness from 1.5 to 4.5 meters overs the area. Basement is composed of highly-folded crystalline schists and Archean gneisses introded by granite gneiss with wide spread formation of gneous metamorphosed rocks. Exposed basement rocks in north-eastern and southern parts of the Indian peninsula make up two-thirds of the shield area, believed to be precambrian. Using the local earthquake data Arora[9] proposed a two layer crustal model in the vicinity of the array with top an upper granitic lalyer 16 km thick over a second layer 19 km thick, i.e. with the Moho at the 35 km depth. The *P*-wave velocities were found to be 5.7 and 6.5 km s^{-1} for these two layers above mantle of 8.0 km s^{-1}.

Data

The 24 earthquakes used in this analysis have been taken from the table 1 of Tripathi and Ram[7]. The selection was made on the basis of a best possible distance and azimuthal coverage. The corresponding *P*-wave records were characterized by good signal to noise ratios.

The Fourier amplitude and phase spectra have been computed for the frequencies 0.4 to 1.5 hz at an interval of 0.1 hz and also at 3 and 5 hz. Since the spectra at frequencies 0.1 hz apart are not independent, the frequencies more than 0.2 hz apart from other have been included. The final data consists of 192 sets, each set consisting of 20 amplitude and 20 phase delay measurements.

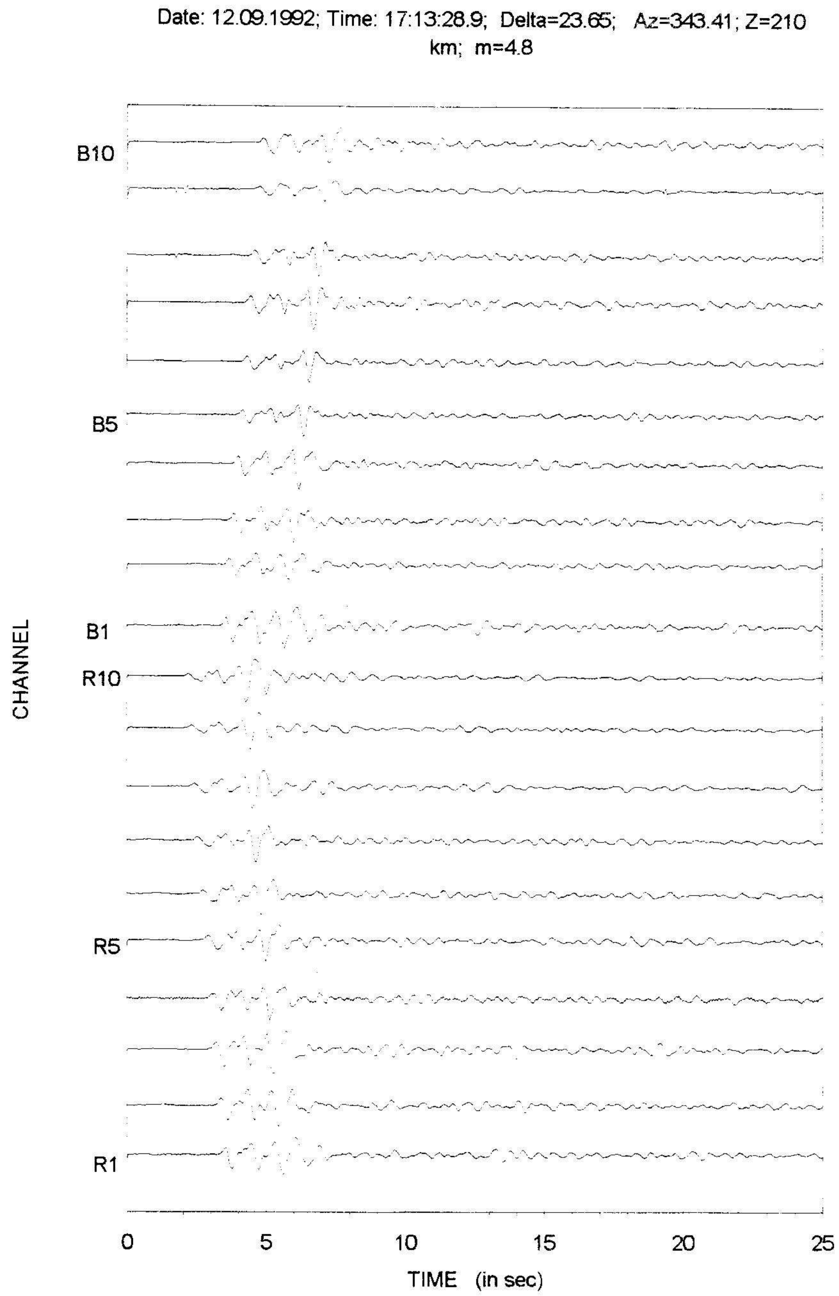

Fig. 2 (a) : Seismogram as recorded at the GBA for the events. Parameters of the events are given with the seismograms.

Date: 09.08.1993; Time: 11:38:31.7; Delta=23.61; Az=343.60; Z=215 km; m=5.7

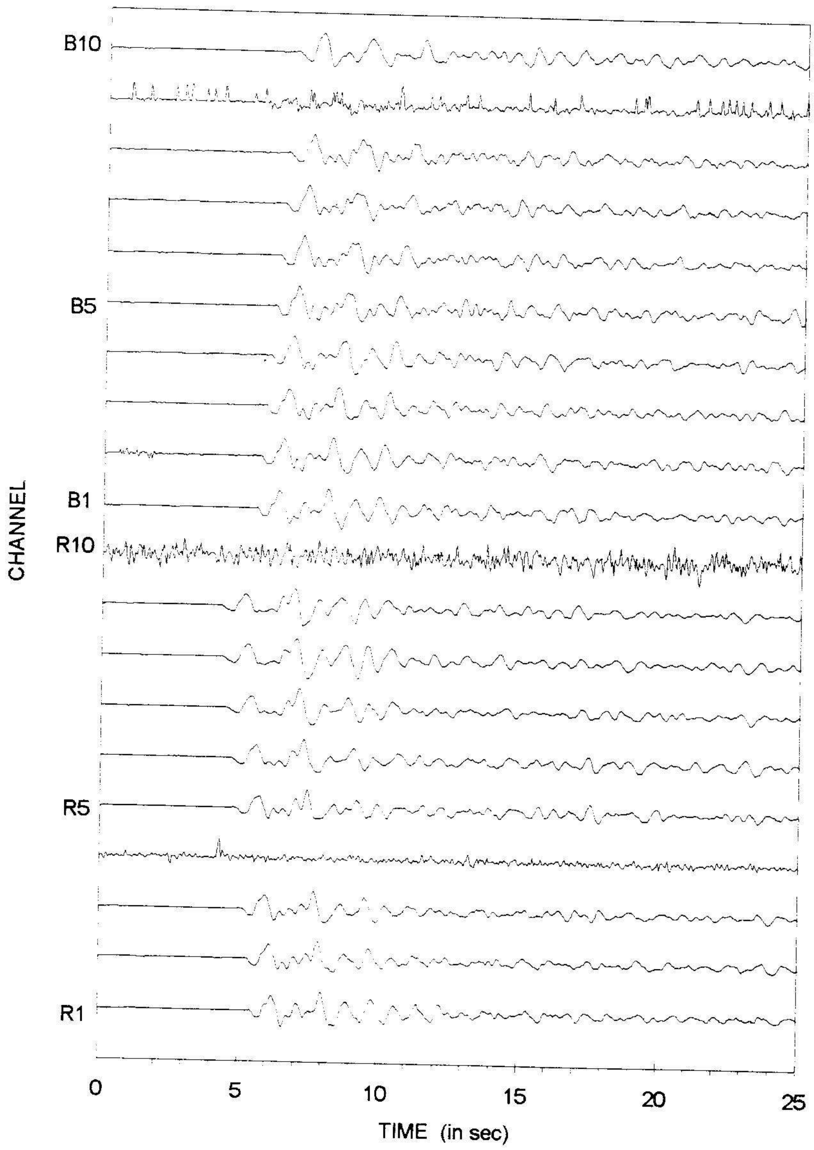

Fig. 2 (b) : Seismogram as recorded at the GBA for the events. Parameters of the events are given with the seismograms.

Statistical Properties of Amplitude and Phase Fluctuations

If it is assumed that the medium is uniform and isotropic random layer of thickness R with Gaussian correlation function[8], then the 'wave parameter' D can be given by following relation :

(1) $$D = 4R^2 / ka^2$$

where k is wave number and a is the correlation lenghth.

The parameter γ is given as :

(2) $$\gamma = \frac{\sigma_u}{\sigma_\phi} = \frac{(1 - (\tan^{-1} D)/D)^{1/2}}{(1 + (\tan^{-1} D)/D)^{1/2}}$$

where u = log-applitude (ln A), and ϕ is the phase. σ_u and σ_ϕ are standard deviation of u and ϕ, respectively.

The scale length a can be given as :

(3) $$a = \left[-X_T^2 / \log\left\{ 0.5\left(\rho_u + \rho_\phi + \left(\rho_u - \rho_\phi \right)\left(\tan^{-1} D \right) / D \right) \right\} \right]^{1/2}$$

where X_T is the spatial distance between two seismometers.

(4) $$\rho_u = \langle u_1 u_2 \rangle / \langle u^2 \rangle$$

and

(5) $$\rho_\phi = \langle \phi_1 \phi_2 \rangle / \langle \phi^2 \rangle$$

On the basis of Chernov Theory[8], the varianves of phase delay and the logarithmic of amplitude (ln A) have been calculated using Fast Fourier Transform algorithm and the correlation between them has been determined. The range of rms phase fluctuations is from 0.63 to 1.03 and that of log-amplitude fluctuations is 0.24 to 0.84. In Chernov Theory the ratio of standard deviation of log-amplitude to that of phase gives a clue to the physical mechanism of scattering. The observed ratio is always less than unity and all of the observed correlation coefficients (192 out of 192) are positive, as was predicted by Chernov theory.

The spatial correlation of amplitude and phase delay fluctuations is very important in the Chernov theory, because their correlation distances are directly related to the dimension of inhomogeneity of wave medium. The spatial autocorration for phase and log-amplitude was calculated for each and every possible array pairs. If all the 20 seisometers are active at the time of earthquake recording then the total number of array pairs will be 190. Thus with these 190 transverse autocorrelation coefficients for log-amplitudes and phase fluctuations one can find out 190 correlation lengths toget best possible result, which reduces the uncertainty affectivity. Statistical properties of amplitude and phase fluctuations have been discussed in detail by Chernov[8], Aki[1], Capon[6], Berteussen *et al.*[2], Tripathi and Ram[7].

Thus, ρ_u and ρ_ϕ have been determined from the log-amplitude and phase spectra. The ratio of the standard deviation of log-amplitude and phase gives the value of D. These value have been used for the determination of the value of the scale-length. Finally, the values of the R is determined and the rms velocity fluctuations is estimated.

Result and Discussions

Aki[1] has shown that the data satisfy both of the conditions, Born approximations as well as Fresnel approximations, very well at low frequencies. So, in this work data at frequency 0.5 hz have been taken for further calculation of D and a. The average D, wave parameter, has been estimated to be 20.1 and correlation length a, equal to 18.13 km. Though, the correlation length is slightly less than the 20 km observed at GBA by Berteussen *et al.*[3] but some what greater than the 10-16 km i.e. the correlation length for LASA and NORSAR observed for the subsets of instruments having same comparable aperture to GBA. The extension of the medium R, is about 250 km at 0.5 hz frequency. The average value of σ_ϕ is estimated as 0.935. Thus, the corresponding value of rms velocity fluctuation is obtained as 0.9%.

Table 1 : Summary of transmission fluctuation analysis by Chernov theory for single layer model.

		f (hz)	σ_ϕ	σ_t (sec)	σ_u
Aki (1973)	LASA	0.5	0.6	0.19	0.32
Capon (1974)	LASA	0.8	0.52	0.10	0.37
Berteussen et al (1975)	LASA	0.7	0.08-0.11	0.02-0.025	0.26-0.42
Berteussen et al (1975)	NORSAR	0.7	0.26-1.75	0.05-0.4	0.15-0.36
Berteussen et al (1977)	GBA			0.05-0.08	
Present Work	GBA	0.5	0.98	0.42	0.52

Table 1 *contd.*

		$\sigma_{u\phi}$	a (km)	Extent (km)	D	rms velocity perturbation
Aki (1973)	LASA	0.35	10	0-60	5	4%
Capon (1974)	LASA	0.23	12	0-136	6	1.9%
Berteussen et al (1975)	LASA		15	0-50		0.3-3%
Berteussen et al (1975)	NORSAR		15-60	0-100		0.5-2%
Berteussen et al (1977)	GBA		20	0-250		0.15-0.3%
Present Work	GBA	0.16	18	0.250	20	1%

Berteussen *et al.*[3] has also noted some complex time residuals. But they suggested an exceptionally homogeneous medium beneath the GBA. The result of this study reveal that the crust and upper mantle structure beneath the GBA is not homogeneous up to the extent as proposed by the Berteussen *et al.*[3] A summary of the transmission fluctuation analysis for the various single layer models is given in Table 1. The crustal/upper mantle scattering zone is also suggested by high semblance values for the Dharwar Cratons[10]. Anomalous time delays has also been observed for the telesiemic waves crossing beneath the Closepet granite and recorded at the GBA[11].

Thus, it is concluded that the heterogeneity of the medium beneath the GBA is characterized by a Gaussian correlation length of about 18 km with about 1% velocity perturbations and its extension is up to 250 km depth. The scattering coefficient, g for the values of rms velocity perturbations (= 1‰) and a (= 18.13 km) is obtained to be 5×10^{-4} km^{-1} at frequency 0.5 hz.

Acknowledgement

Author gratefully acknowledges the support of the GBA seismic array staff in providing the data used in this study. Author is also thankful to Prof. Avadh Ram, Department of Geophysics, B.H.U., Varanasi, for valuable suggestions, which has significantly improved the paper.

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