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ANALYSIS OF P RESIDUALS FROM NEVADA EXPLOSIONS[1]

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Introduction

It is now well known that considerable regional variations exist in P and S wave velocities. Any standard set of travel time table or J-B tables, are thus affected by these variations. Total effect of regional variations on travel times at teleseismic distances can be split up into three components: (1) The effect of the upper mantle below the source (2) effect of the upper mantle below the stations and (3) effect of the lower mantle. Lower mantle is usually taken to be laterally homogeneous. However Hales et al. (1968), Chinnery & Toksoz (1967), Toksoz et al (1968), Julian & Sengupta (1972) and others have pointed out that regional variations can exist in lower mantle. Cinna Lomnitz (1971) has discussed errors in travel times in the laterally inhomogeneous earth. The effect of source and station bias on travel times, among others, has been discussed by Bolt & Nuttli (1966), Cleary and Hales (1966), Cleary (1967), Douglas (1967), Herrin & Taggart (1968). Any method of analysis based on standard set of travel times is affected by errors from two major sources (1) azimuthal clustering of stations and physical inhomogeneity of earth. Let A be a region of anomalous Seismic velocities in the mantle. The bundle of Seismic rays through A causes a shadow of anomalous arrivals at the earth surface. If v_A is low, the rays will either be trapped in low velocity channel, or they will arrive later than the diffracted rays around the low velocity inclusion. In either case arrival through A will be late. If v_A is high, energy partition favours high velocity region and there will be strong early arrivals through A.

Systematic errors tend to be self consistent within a given computational procedure. It has been found that J-B travel time tables predict Systematically late arrivals for all events. These effects of lateral inhomogeneity can be seperated from other Systematic errors. Gauss has pointed out that the optimality of an estimator depends on three assumption concerning the error. $\xi = X - x$, in our case ξ may be residuals

(a) X's are independently distributed random variables,

(b) Positive and negative values of ξ are equally likely and

(c) small values of ξ are more likely than large ones.

Here residuals satisfy all these conditions and thus using statistical techniques these errors can be removed.

In the present study of P residuals we have tried to find out lateral velocity variations by removing systematic errors. Methods of Station corrections has been used. Since the parameters of the explosions are correctly known, the effect of the upper mantle below the source can be removed. Since the explosions happen to be on the same site within $\pm$ 0.2° latitude and longitude a good set of azimuth dependent observations for different stations were expected. The aim is to study lateral variations from azimuthal variations of the residuals.

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Station correction have been calculated by Cleary & Hales (1966) Herrin & Taggart (1968), Lilwall & Douglas (1970) and others. Herrin and Taggart calculated azimuthally dependent station corrections. Bolt & Nuttli (1966) in studying P wave residulas from 47 earthquakes observed at 13 stations found azimuthal dependence on travel times. We have tried to look the lateral variation by azimuthal variations statistically by taking large amount of data observed at 400 stations. In an earlier study we have also calculated station corrections using the same data as it is being used here.

Method of Analysis and Discussion

We considered the nuclear explosions from 1964 to 1972 P residuals from these explosions were sorted for each station. Each station received P arrivals from the same azimuth as expected, because all the explosions taken happened to be nearly on the same site. In calculating travel times of P waves from Nevada nuclear explosions, we applied method of uniform reduction (Jeffreys, 1936). We found that all residulas greater than 5.0 sec. in magnitude got zero weight. Hence we discarded all residuals greater than 5.0 sec. in magnitude in this study also. The means and standard deviations were calculated for each station. These means were used as station corrections. Then all the residuals were sorted in the cells of 5° and 5° Azimuth and got a 21×72 contingency table. Means and S.D. for eech cell was calculated. We found from the table that the region from 150° to 215° azimuth had information only in first cell i.e. upto 5°. In 90° to 150° azimuth range information was available only upto 85°. Hence we decided to devide the whole region into 3 azimuth ranges AZ_1, AZ_2, AZ_3 where as

0	AZ_1	90°
90°	AZ_2	150°
215°	AZ_3	360°

Region 150° to 215° azimuth was not taken into consideration because of the lack of observations.

Means and standard deviations were then calculated in the remaining groups for each 5° epicentral distances. Table I gives the mean of the residuals for the three azimuth groups. M_1, M_2, M_3 are the means of the azimuth groups AZ_1, AZ_2, AZ_3 respectively. M & MD are mean and mean deviations of M_1, M_2, M_3, MD gives a measure of the closeness of the fit of the azimuth groups.

To see whether or not there is a significant difference in the residuals for three groups we considered the mean residuals and applied t-test in pairs to the differences in the mean residuals in the three azimuth groups.

We compared the three azimuth groups for all degrees of freedom, leaving those intervals where no information is available in either of the group, we get

$t_{12} = 8.56$ (16 degree of freedom)

$t_{23} = 3.98$ (13 „ „ „)

$t_{13} = 5.92$ (17 „ „ „)

TABLE 1

Mean and Mean Deviation before Applying Station Correction
(Using I.S.C. Residuals)

deg	M_1	M_2	M_3	M	MD
2.5	−0.2547	−0.3210	−0.3167	−0.2957	0.0285
7.5	0.9848	−1.5837	0.3955	−0.1679	0.9456
12.5	−0.1103	1.6917	1.7311	1.1042	0.8096
17.5	−0.1771	−0.0769	1.6613	0.4691	0.7948
22.5	−1.1816	1.2586	0.6885	0.2538	0.9566
27.5	−1.7743	0.2842	—	−0.7451	1.0292
32.5	−2.0890	−0.3759	−0.4630	−0.9757	0.7422
37.5	−1.7035	−0.2667	−0.5429	−0.8377	0.5772
42.5	−1.2417	−2.2500	−1.1281	−1.5399	0.4734
47.5	−2.8318	−1.0015	—	−1.9167	0.9151
52.5	−2.8371	−1.1949	−1.8000	−1.9442	0.5957
57.5	−2.1299	−4.3394	−0.8071	−2.4255	1.2759
62.5	−1.5636	−0.8114	−0.6794	−1.0181	0.3636
67.5	−2.2977	−0.6922	—	−1.4949	0.8028
72.5	−2.3248	−1.6511	−1.9310	−1.7690	0.4786
77.5	−1.1515	0.1143	−1.4151	−0.8174	0.6212
82.5	−0.7435	−3.1026	−1.1440	−1.6634	0.9595
87.5	−0.9898	—	−1.5857	−1.2877	0.2980
92.5	−1.4500		−0.6853	−1.0677	0.3824
97.5	−1.5830		1.3000	−0.1425	1.4415
102.5	−2.2500		−1.6000	−0.9250	0.3250

These all values of t are higher than the table value at 5% level of significance at their corrosponding degree of freedom and shows that there are significant variation in three groups.

Though the above analysis shows significant variation in the three azimith groups even then we can not be sure whether the differences are due to lateral velocity variation or because of same other effects. As the initial parameters of the explosions are correctly known to us only station anomaly can effect the results and hence we intend to remove it. Bolt & Nuttli (1966) has shown P wave delay times (relative to Berkeley at twelve stations) depndence on azimuth of wave approach at some stations. Removal of this bias from the residuals is therefore expected to give small mean deviations. Since the explosions happen to be on the same site a good set of azimuthally dependent observations for different stations are expected. Hence we expect smaller mean deviation after applying azimuthally depent station corrections. Therefore we calculated station correction and applied to the three azimuth groups and after comparision we get the value of t statistic as follows :

t_{12} = 3.00 (16 degree of freedom)

t_{23} = 3.08 (13 „ „ „)

t_{13} = 4.57 (17 „ „ „)

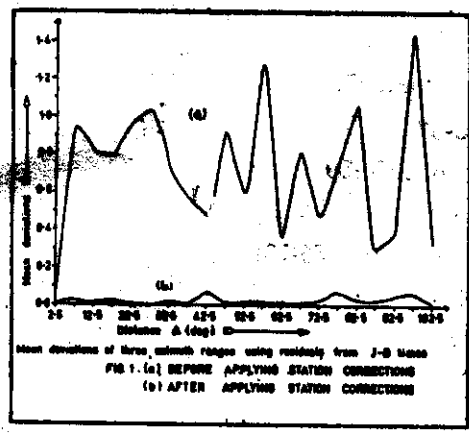
Means and mean deviations were very much reduced after applying station correction, but comparision, from taken value of t shows significant variations in three azimuth groups. Table II gives means and mean deviation for three groups. Figure 1 shows mean deviation before and after applying station corrections using residuals of I. S. C. Bulletins.

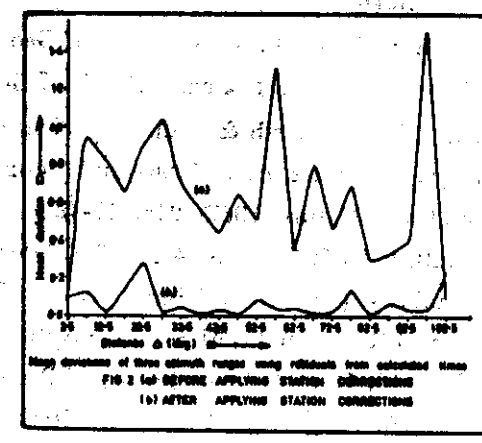
TABLE II

Mean and mean deviation after applying station corrections
(Using I.S.C. Residuals)

deg	M_1	M_2	M_3	M	MD
2.5	0.0249	0.0279	0.0083	0.0204	0.0080
7.5	−0.0251	0.0000	−0.0660	−0.0304	0.0238
12.5	−0.0022	0.0349	0.0274	0.0200	0.0148
17.5	0.0000	−0.0738	−0.0515	−0.0418	0.0278
22.5	0.0152	0.0280	0.0035	0.0156	0.0085
27.4	−0.0097	−0.0095	—	−0.0096	0.0001
32.5	−0.0194	−0.0180	0.0117	−0.0086	0.0135
37.5	0.0026	0.0000	0.9149	0.0058	0.0060
42.5	−0.0517	0.0000	−0.1839	−0.0785	0.0702
47.5	−0.0052	0.0045	—	−0.0004	0.0048
52.5	−0.0318	−0.0001	0 0000	−0.0106	0.0141
57.5	0.0268	−0.0003	0.0054	−0.0106	0.0108
62.5	−0.0264	−0.0014	0.0048	−0.0109	0.0104
67.5	0.0107	0.0156	—	0.0132	0.0024
72.5	0.0023	−0.0547	−0.0003	−0.0176	0.0248
77.5	−0.0067	0.1529	0.0068	0.0510	0.0679
82.5	−0.0039	0.0000	−0.0588	−0.0209	0.0153
87.5	0.0435	—	0.0800	0.0612	0.0188
92.5	−0.0281	—	0.0476	0.0098	0.0378
97.5	−0.1157	—	0.0000	−0.0578	0.0578
102.5	0.0000	—	−0.0028	−0.0014	0.0014

In an earlier study we calculated the travel time of P waves and station corrections by using the same set of nuclear explosions from Nevada. We used the residuals calculated from our calculated times so that effect of delay in J-B times may not affect the result. The means and mean deviations were calculated before and after applying station corrections. The mean deviation in both cases are shown in figure 2.





Comparision of the three azimuth groups were made and the values of the t statstic were found as follows :

(1) Before applying station correction

$t_{12} = 7.48$ (16 degrees of freedom)
$t_{13} = 3.50$ (13 ,, ,, ,,)
$t_{18} = 4.95$ (17 ,, ,, ,,)

and (2) after applying station correction

$t_{12} = 3.53$ (16 degrees of freedom)
$t_{23} = 3.60$ (13 ,, ,, ,,)
$t_{13} = 3.40$ (17 ,, ,, ,,)

Significance of t statistic in all cases at 5% level shows that the variations in the three groups are due to lateral velocity variations and not due to other effects. The other effects such as station anomaly intend to increase the value of t statistic and shows that azimuthally dependent station corrections give better result than mean station corrections.

Conclusion

P residuals from Nevada explosions have been studied and laterel velocity variations established. It is also found that azimuthal dependent station corrections give better results than mean station corrections.

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References

Bolt, B.A. & Nuttli, O.N. (1966) J. Geophysics R, 71, 5977-5985

Chinnery, M.A. & Toksoz, M.N., 1967 Bull seism. Soc. Am., 57, 199-226

Gleary, J. 1967 Earth & Planetary Science latters, 3, 29-37

Cleary, J & Hales, A.L. (1966) Bull. Seism. Soc. Am., 56, 467-489

Douglas, A Nature (1967), 215, 47-48

Lilwall, R.C. & Douglas, A., (1970) Geopys. J.R. Astr. Soc., 19, 165-181

Lominitz, C (1971) Bull Seism. Soc. Am 61, 1639-1654

Julian, B.R. Sengupta, M K., 1973 Nature 242, 443-447

Jeffreys, Sir Herold (1936) Theory of Probability Clearendom Press.

Herrin, E. Taggart, J (1968) Bull Seism. Soc. Am. 58, 1325-1337-1337, 1791-1996.