British Geological Survey
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Seismological Calibration of Arrays

Seismology and Geomagnetism Programme
Internal Report IR/04/056

BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT IR/04/056

Seismological Calibration of Arrays

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Key words

Station corrections, automatic phase picking, analysis of variance

Bibliographical reference

A. O'MONGAIN. 2004 Seismological Calibration of Arrays, 2004 *British Geological Survey Internal Report,* IR/04/056. 1pp.

Keyworth, Nottingham British Geological Survey 2004

BRITISH GEOLOGICAL SURVEY

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Contents

1 Abstract

The UK is responsible for the seismological calibration of the array station EKA which contributes data to the International Monitoring System (IMS) of the Comprehensive Test Ban Treaty Organisation (CTBTO). Such calibration includes the provision of seismic travel time corrections for the array station to allow for local velocity variations on the propagation path from seismic events at different distances and azimuths. The EC ARI Framework funded a two-part investigation into techniques for facilitating seismological calibration of seismic arrays. In the first part, analysis of variance was applied to manually picked arrival times at EKA from local events. Four bins of event data at different distances and azimuths were examined and for most the station correction time terms were found to be smaller than the sample rate of the instruments (0.05 seconds). Travel time residuals from each source-station pair were also examined and some distance and azimuth dependency was found. Slowness and azimuth values were recalculated once the station correction terms were applied to the data. Large discrepancies were found between the observed slowness values and those of the standard earth model IASPEI91, indicating significant differences between the local velocity structure and the IASPEI model. The second part of the work examined automatic arrival time pickers in order to expedite the calibration procedure and extend the study to more bins of data. Analysis of variance was used to investigate the picking accuracy and two methods (a cross correlation method and an Auto-Regressive Akaike Information Criterion method (ARAIC)) were tested. The results showed that in most cases the cross correlation method proves to be even more accurate than manual picking (having a variance of less than $0.001s^2$ in most cases) while the ARAIC method is not as successful on this data set.

2 Introduction

This report describes work which was performed by the author at NORSAR and funded by an Access to Research Infrastructures (ARI) grant from the European Commission. The ARI project proposal was related to the calibration of the EKA seismological array. As a Comprehensive Test Ban Treaty (CTBT) signatory the UK is responsible for carrying out a seismological calibration of the EKA array and one of the requirements is to provide enough information on P and S travel times in the vicinity of EKA to allow the IDC to construct tables of times from any hypocentre to the station for any phase, and apply slowness and azimuth corrections. To do this, I determine time residuals and station corrections for EKA. The time residuals discussed in this report are the observed P arrival times minus the theoretical times (obtained using local velocity models) for each source-receiver pair. The station correction, is the average correction calculated from the time residuals for each element using all events in a bin. These station correction terms can be applied to the observed arrival times to correct for local velocity variations.

On the basis of the requirement outlined above, an ARI project was proposed with two parts. In the first part various bins of local event data recorded on the array are checked for azimuth and distance dependency, to determine if different station time corrections need to be applied for different distances and azimuths. The second part of the proposal investigates the use of an automatic picking algorithm on the recordings of local events at EKA in order to expedite the calibration work, as the manual picking of the events proved to be far too time consuming. The proposal was accepted by NORSAR's ARI selection pannel and performed during March and April 2003.

3 Data

The EKA array is located at Eskdalemuir in the Scottish Borders. It is a 20 element 'L' shaped short period array and its layout is shown in Figure 1.

The data used so far in the calibration of the array has been from four 1° by 1° bins, namely, Cumbria (18 events), Stoke (15 events), North Yorkshire (12 events) and Strathclyde (20 events). The events are shown in Figure 2 along with the position of the EKA array. Most of the events are small earthquakes with local magnitudes between 1.7 and 4.0 with an average local magnitude of about 2.2. There are also some explosions, mainly underwater explosions in the Strathclyde bin of events with magnitudes of around 1.8.

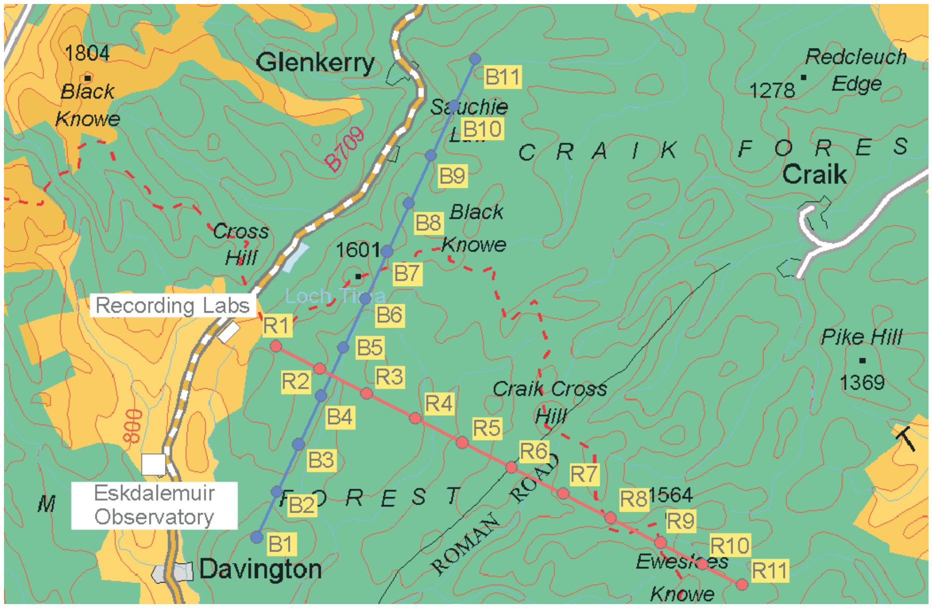

Figure 1: Layout of EKA array. The height contours are in feet. R11 and B11 are not in use.

None of the events have been accurately timed, so they cannot be used as calibration events of high accuracy. In this study we take the P-wave onset times at each element of the array and form time residuals which are defined as the difference between the observed time and the theoretical arrival time for the defined source and station locations. Analysis of variance is then performed on the time residuals.

4 Analysis of Variance

The onset time picks from each element of the array for each event are made manually for each bin of events. Section 6 will describe later how these picks were also made by two different automatic picking routines. These two routines are a cross correlation method, and the Auto-Regressive Akaike Information Criterion (ARAIC) method for automatic picking. The aim is compare the accuracy of all the picks by performing analysis of variance.

For each bin of events and for each set of time picks, an analysis of variance is performed which allows us to separate the various effects that contribute to station timing residuals such as reading errors and path effects. This is done by assuming that for the P arrival from the i th event recorded at the j th station, $\Delta \mathrm{T}_{ij}$ can be written

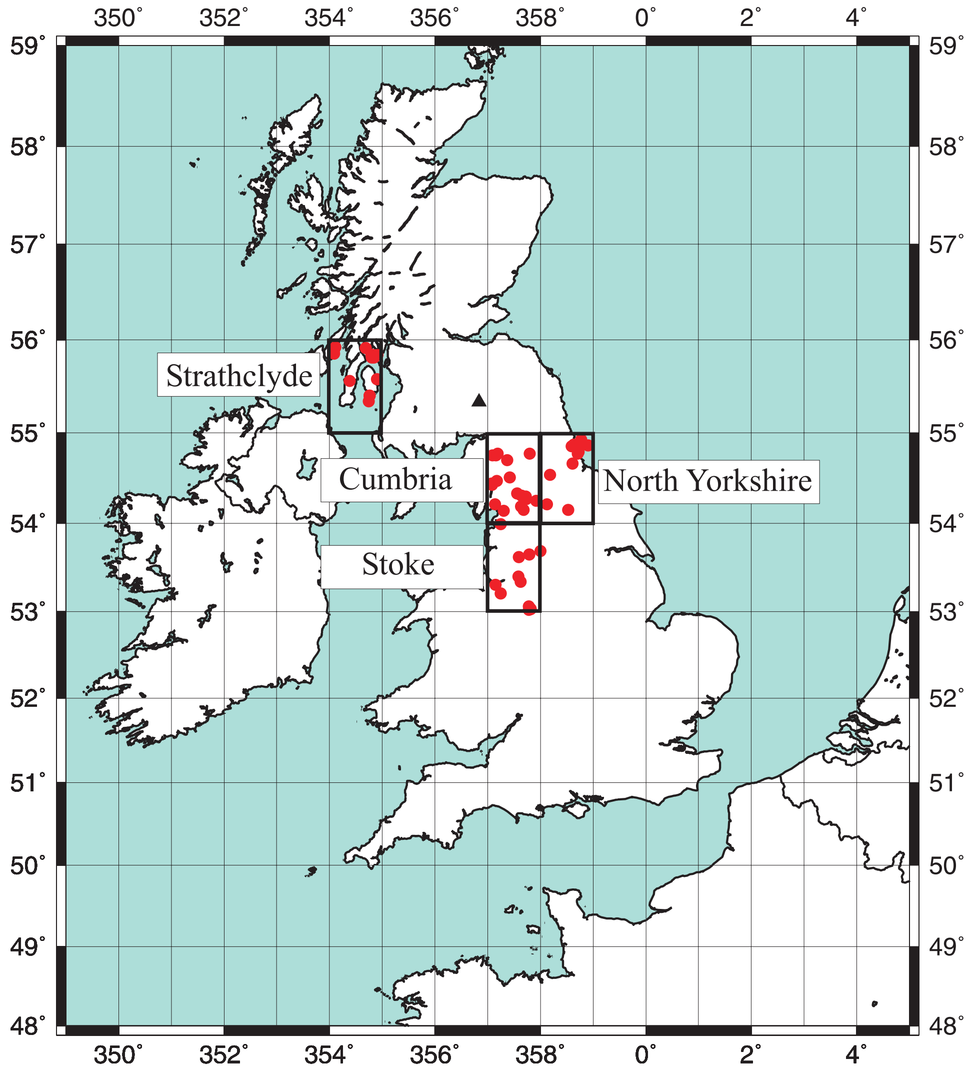

Figure 2: Events used to test the calibration procedures. 4 bins of events, Strathclyde, Stoke, North Yorkshire, Cumbria. EKA is marked with a black triangle.

as:

$$\Delta T_{ij} = E_i + S_j + \overline{T} + \epsilon_{ij} \qquad (1)$$

where ΔT_{ij} is the observed arrival time pick (measured from the seismic records) minus the theoretical arrival time (calculated by taking the event locations in the BGS bulletins and using appropriate local velocity models for each bin). E_i is an event term which will depend on path-dependent effects on the travel time and S_j is a station term which depends on local velocity variations influencing the onset time of the P-wave arrival at station j. ϵ_{ij} is the residual error which includes the picking/reading error and $\overline{T}$ is a constant. E_i, S_j , $\overline{T}$ can be estimated by least squares with the assumption that $\sum E_i = \sum S_j = 0$.

Estimates of the sample variance due to the event and station effects are also obtained and these variances can be examined to investigate pick accuracy and any anomalous paths to the array. It is expected that in comparing the three methods of picking, the path effects should be similar for all three while the pick effects will vary.

5 Manual Picks

Time picks on each element of the array were made on the first P arrival for every event in the four bins. These picks were usually made on optimal filtered (Douglas, 1997) data or on unfiltered data where the signal to noise ratio was good. For each bin of events the picks are analysed using analysis of variance to determine the average station corrections for each element of the array for that bin of data. The variance of the residual error (ϵ_{ij}) and the event (E_i) and station (S_j) effects are also computed. Using this analysis we investigate the following questions:

- What size are the station corrections (S_j) and how do they compare between the four bins of data?
- Is there azimuth or distance dependency in E_i?
- Are the effects of the elevation differences between the stations within the array obvious in the station corrections?
- Is the bin size appropriate?

S_j terms in seconds					
	Cumbria	North Yorkshire	Strathclyde	Stoke	Mean
R1	0.006 ±0.015	-0.009 ±0.020	-0.009 ±0.016	-0.010 ±0.016	-0.005 ±0.017
R2	0.004 ±0.015	-0.011 ±0.019	0.002 ±0.015	-0.011 ±0.016	-0.003 ±0.016
R3	0.001 ±0.015	0.001 ±0.019	0.004 ±0.015	0.002 ±0.016	0.002 ±0.016
R4	0.006 ±0.015	0.000 ±0.019	0.003 ±0.017	0.012 ±0.016	0.006 ±0.016
R5	-0.004 ±0.015	-0.018 ±0.020	-0.004 ±0.017	0.009 ±0.016	-0.002 ±0.017
R6	0.007 ±0.015	0.011 ±0.019	0.007 ±0.018	0.019 ±0.016	0.011 ±0.017
R7	0.001 ±0.015	-0.004 ±0.019	0.007 ±0.017	0.005 ±0.016	0.003 ±0.016
R8	0.009 ±0.015	0.016 ±0.019	0.006 ±0.018	0.010 ±0.017	0.009 ±0.017
R9	0.001 ±0.015	-0.002 ±0.023	0.009 ±0.016	-0.004 ±0.017	0.001 ±0.018
R10	-0.022 ±0.016	-0.014 ±0.020	-0.021 ±0.015	-0.021 ±0.017	-0.020 ±0.017
B1	0.002 ±0.015	-0.027 ±0.022	-0.009 ±0.015	-0.006 ±0.019	-0.007 ±0.017
B2	0.005 ±0.015	-0.022 ±0.020	0.007 ±0.015	-0.009 ±0.016	-0.003 ±0.017
B3	0.011 ±0.015	-0.019 ±0.019	-0.006 ±0.015	0.000 ±0.016	-0.001 ±0.016
B4	0.003 ±0.015	-0.007 ±0.019	0.001 ±0.015	-0.009 ±0.016	-0.003 ±0.016
B5	-0.003 ±0.015	-0.006 ±0.019	0.000 ±0.015	0.000 ±0.016	-0.002 ±0.016
B6	0.000 ±0.016	-0.006 ±0.020	0.008 ±0.016	0.002 ±0.016	0.002 ±0.017
B7	0.000 ±0.015	0.021 ±0.019	0.018 ±0.017	0.003 ±0.016	0.008 ±0.017
B8	-0.012 ±0.017	0.025 ±0.020	-0.009 ±0.018	0.003 ±0.017	-0.001 ±0.018
B9	-0.008 ±0.017	0.044 ±0.020	-0.002 ±0.015	0.005 ±0.016	0.006 ±0.017
B10	-0.006 ±0.016	0.029 ±0.020	-0.013 ±0.016	-0.001 ±0.016	-0.001 ±0.017

Table 1: Table showing the station corrections (S_j) and their associated errors for each of the four bins of data. The weighted mean station terms are also given.

- Once the station corrections are applied to the pick times, do the slowness and azimuth values change?

5.1 Station Corrections

For each bin of events the station corrections (S_j in Equation 1) are calculated independently so that we obtain the average station correction for each element of the array for each bin of data. These station corrections are given in Table 1 and shown in Figure 3 where it is seen that most of the corrections and their error bars lie within the dashed lines marking +0.02 and -0.02 seconds. The bin of events from North Yorkshire show slightly larger station corrections for the elements B8-B10.

If we examine the variance values in Table 2 which were obtained from analysis of variance on the individual bins of events, we see that for three of the bins the local path effect (S_j) variance is bigger than the pick effect (ϵ_{ij}) variance. However, performing Snedecor's F-test we see that it is only significantly larger at above the 95% level for the North Yorkshire bin. The Cumbria bin shows a slightly higher pick effect variance than local path effect variance.

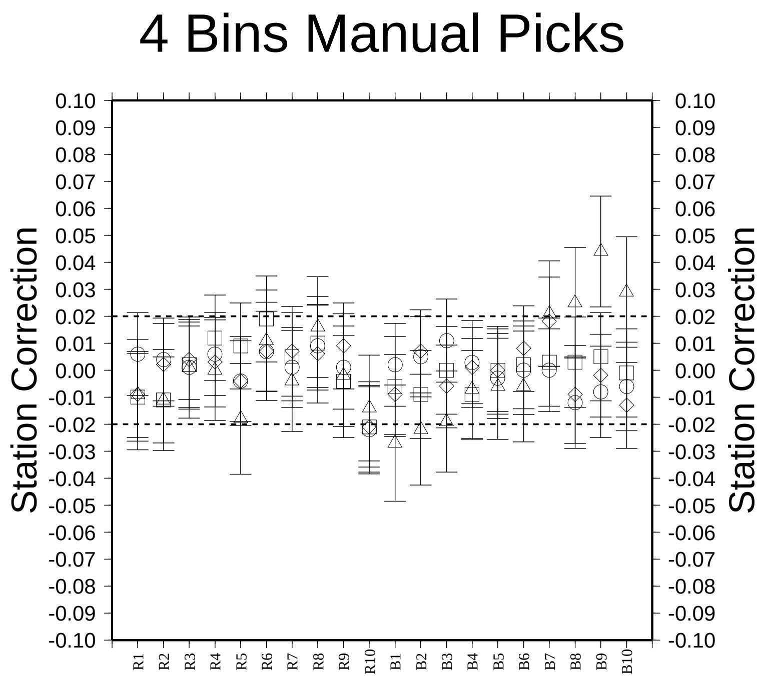

Figure 3: Station corrections in seconds for the manual picks on all four bins of events, Cumbria (circles), North Yorkshire (triangles), Strathclyde (squares) and Stoke (diamonds).

Analysis of variance results for manual picks				
	Cumbria	North Yorkshire	Strathclyde	Stoke
pick variance	0.001093	0.001134	0.001307	0.000887
DOF	296	185	318	226
local path variance	0.000895	0.003566	0.001547	0.001112
DOF	19	19	19	19
F-test pick/path sig%	68.4% ↑	100.0% ↓	73.1% ↓	78.4% ↓

Table 2: Table showing the variance (s^2) results from analysis of variance on the manual picks on all four bins of events. DOF is degrees of freedom and F-test sig% is the significance between the local path effect (S_j) variance and the pick effect (ϵ_{ij}) variance.

5.2 Time Residuals

In order to check for distance and azimuth dependency, we examine E_i from Equation 1. To compare all bins, the time picks for all four bins are combined and analysis of variance calculated for all four bins together using appropriate local velocity models to obtain the observed minus calculated (O-C) residuals. The residuals for the Strathclyde bin were calculated using the BGS velocity model for Lownet and general UK (Simpson 2001); residuals for the other bins were calculated using the BGS velocity model for the Borders region (Simpson 2001).

We obtain one E_i value for each event and can examine these to determine if events from one region have significantly larger E_i effects than another. If we didn't combine all the bins for this part of the study and looked at E_i for each analysis of variance study on the individual bins then $\overline{T}$ would be different for each bin and the E_i values would not be comparable between bins.

A polar plot (Figure 4) is generated to display the E_i values for all events. This plot is centered on EKA and azimuth is shown in degrees from north. Radial distance corresponds to epicentral distance from EKA in degrees. E_i for each event is plotted at the appropriate distance and azimuth according to the colour-coded scale in seconds.

In Figure 4, the Cumbria and North Yorkshire bins are close together (with azimuths between about 100 to 180 degrees) while the Stoke bin is at a similar azimuth but slightly further away. The E_i values for the Strathclyde bin are at azimuths between about 270 and 300 degrees.

By examining Figure 4 we see that all of the E_i values lie between -2 and +2 seconds. For the North Yorkshire and Stoke bins the majority of values are negative (Stoke 91% negative, North Yorkshire 81% negative). On the other hand the Cumbria and Strathclyde bins of events have mostly postive E_i values (Cumbria 82% positive, Strathclyde 89% positive).

Events from Stoke and North Yorkshire arrive earlier than theoretically predicted which suggests that the true average velocity in these areas is faster than theoretically predicted by the local models. The positive E_i values for the Cumbria and Strathclyde areas suggests that a lower velocity than predicted by the local velocity models might be responsible for the late arrivals.

The local velocity models minimise the residuals but some lateral heterogeneity is obvious since we observe some variation in E_i values with azimuth between events at

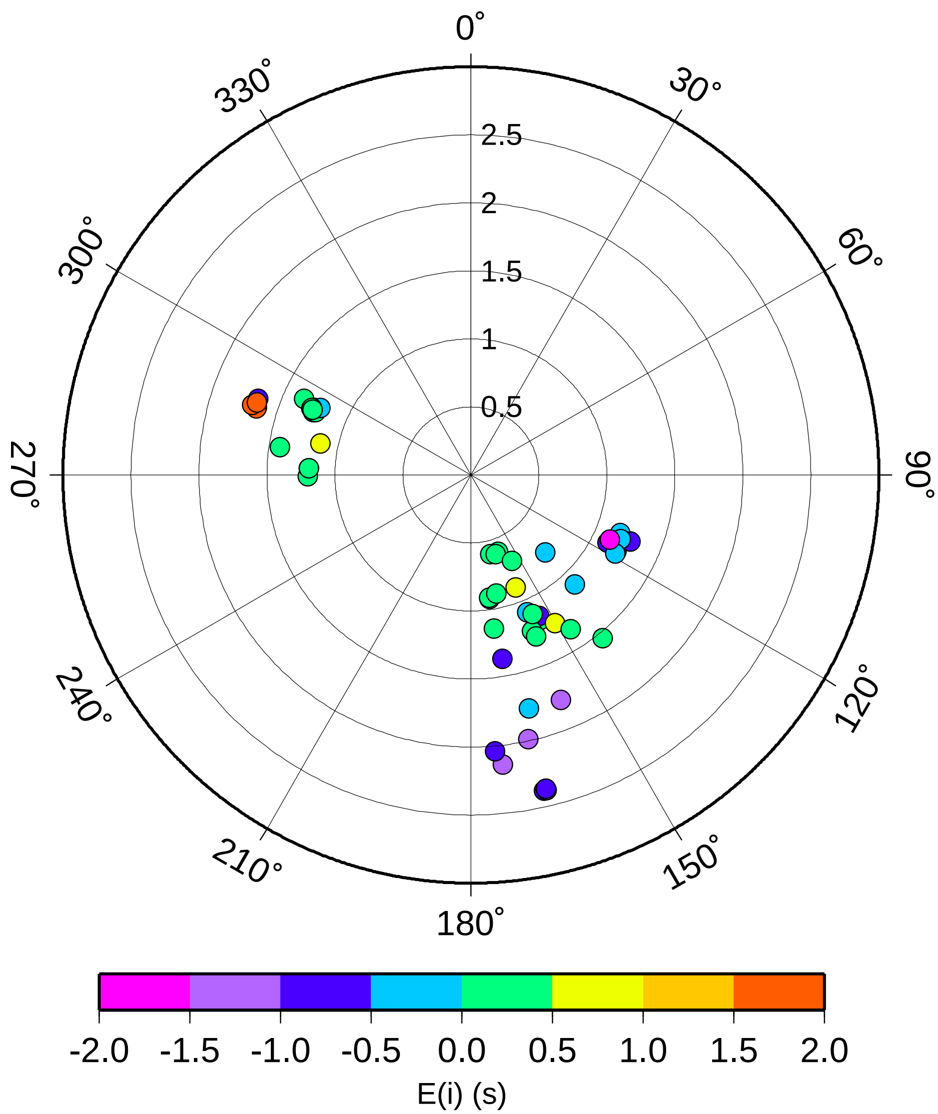

Figure 4: Polar plot showing E_i values for a combined analysis of variance on all four bins of data. The plot is centered on EKA, azimuth is given in degrees clockwise from north, and the radius corresponds to distance from EKA in degrees.

similar distances. The group of large positive residuals in the Strathclyde bin can be attributed to poorer location accuracy in this region because these events are on the outskirts of the UK seismic network. The polarity of the E_i values tells us that, with respect to the input models, the Stoke and North Yorkshire times are faster and the Strathclyde and Cumbria arrival times are slower than predicted by the input models.

5.3 Elevation Effects

In order to investigate the effect of the elevation differences between each site of the array, the data from all the individual analysis of variance runs on each bin were combined. For each array element, the weighted mean station correction was calculated using the station corrections from each of the four bins and the associated weighted mean errors were also calculated (Table 1). These mean station correction values are plotted in Figure 5. In order to examine the effect that elevation could have on the time residuals, we assume a local velocity of 5km/s, a maximum Pn velocity of 8.55km/s and a minimum Pg velocity of 5.85km/s. The maximum variation in elevation across the array is 160.4m. Using these values, the maximum effect in the times for Pn is 0.0260s or ±0.0130s and for Pg it is 0.0167s or ±0.0083s. The local velocity assumed is conservative and the wave velocities used are extreme values so these time error values represent the worst case.

Figure 5 shows, along with the mean station corrections and their errors for each element of the array, the values of the Pg (blue triangle) time effects from the elevation differences and Pn (green squares) time effects due to the elevation differences. These values mark the maximum effect that the elevation should have on this investigation. The relative elevations of each element of the array are also shown in this Figure.

It is obvious from Figure 5 that any elevation effects on the Pn and Pg times are far less significant than the errors in the station correction values. There does seem to be some correlation between relative elevations and calculated station corrections, particularly for the Blue line but a few stations (e.g. R10), are clearly uncorrelated. In order to check the significance of the height effects, the analysis of variance needs to be recalculated by firstly correcting the observations for height. Then, if the station terms were predicted exactly from the heights then the local path effect should be reduced significantly.

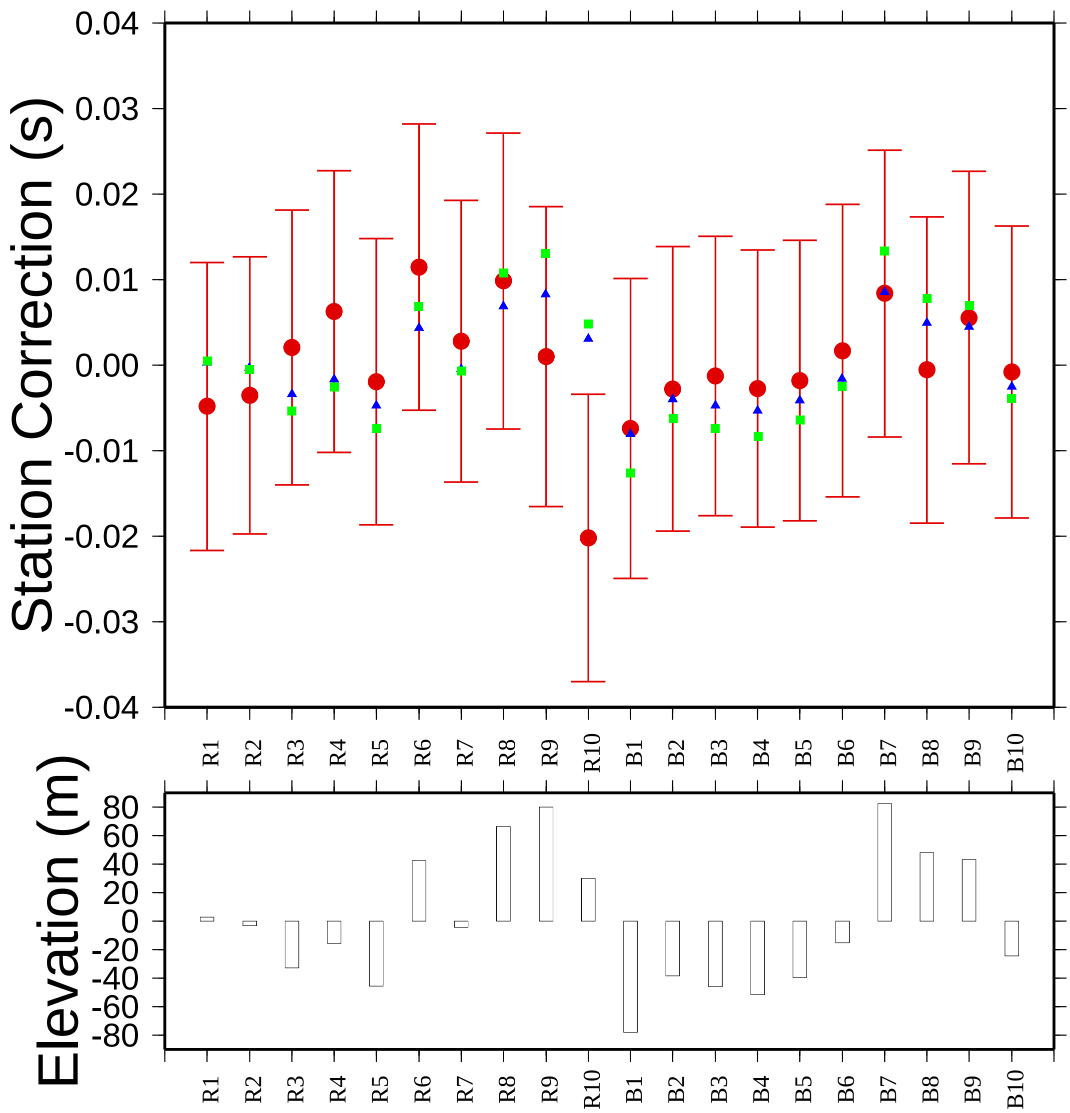

Figure 5: The weighted mean station corrections (red circles) and their associated errors for all four bins of data. The lower plot shows the relative elevations of each element of the array. The top plot also shows the maximum effect that the maximum elevation difference would have on Pn (green square) and Pg (blue triangle).

Analysis of Variance results for manual picks on two UK bins and the combined bin			
	Cumbria	North York	Cumbria + North York
pick variance	0.001093	0.001134	0.001173
dof	296	185	500
local path variance	0.000895	0.003566	0.001969
dof	19	19	19
F-test pick sig%			Cumbria=74.85%, NY=60.20%
F-test path sig%			Cumbria=95.30%, NY=89.77%

Table 3: Table showing the variance (s^2) results from the analysis of variance for the Cumbria and North Yorkshire bins and the combined Cumbria and North Yorkshire bin. The path variance is the local path effect (S_j) variance and the pick variance is the variance of ϵ_{ij}.

5.4 Combining Bins

At present the bin size is 1° by 1°. It is desirable to examine the effect of bin size by combining bins and determining if this makes the results of analysis of variance significantly worse. The two closest bins are Cumbria and North Yorkshire, so these were chosen for this examination. The times for both bins were combined and then analysis of variance performed as if they were one bin. Table 3 and Figure 6 show the results from the individual bins and the combined bin. The pick(ϵ_{ij}) and local path (S_j) variances are slightly lower for the Cumbria bin of data than the North Yorkshire bin and when combined the local path effect variance lies between the two. Significance tests (i.e. Snedecor's F-test) prove that the pick effects are unaffected by combining the data whilst the path effect is significantly worse at the 95% level for the comparison between the Cumbria bin and the combined bin. This implies that it is best to keep the bin size of 1° by 1° for the calibration procedure.

5.5 Slowness and Azimuth

Now that the station corrections have been estimated we can see what effect they have on the slowness and azimuth values once they are applied to the times. We would not expect to see much of a difference in the values as the station corrections themselves are very small. Figure 7 shows the slowness values calculated from the arrival times, those calculated using FK analysis, and also those after the station correction terms have been applied to the arrival times. We can see that for all four bins the slowness values are spread over a large range. The Cumbria bin has values which tend to be similar to Pg slownesses (upper dashed line) while the Stoke bin is similar to Pn (lower dashed line).

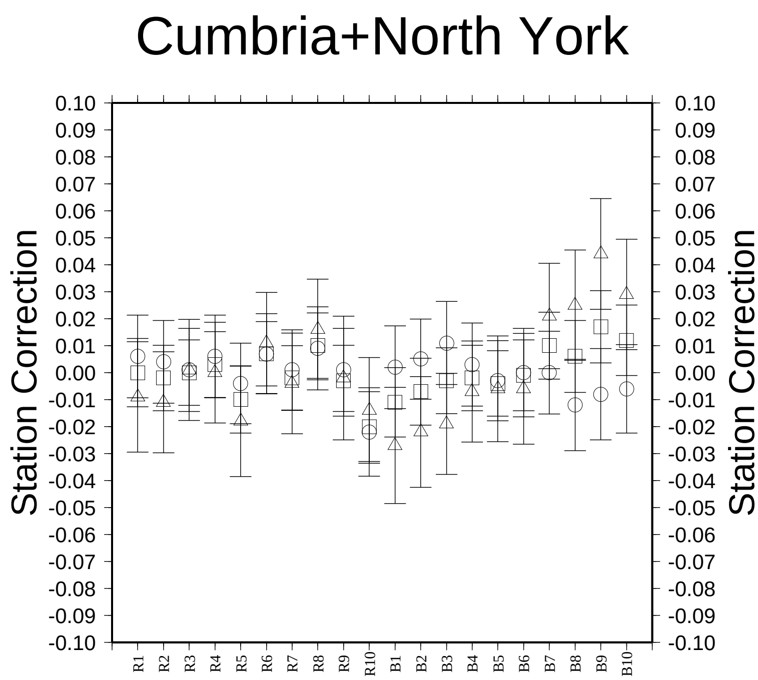

Figure 6: Station corrections for the manual picks on the Cumbria bin (circles), the North York bin (triangles) and the combined Cumbria and North York bin of events (squares).

Figure 7 shows that applying the station corrections to the times and then calculating the slowness has little effect. Doing so does not move them significantly closer to the theoretical values suggesting that the velocity structure in this region must be significantly different to the IASPEI model.

The azimuths calculated from the times agree well with the theoretical values and are not shown here.

6 Automatic Pickers

In order to further this calibration work it is necessary to increase the number of bins of data and especially to examine events to the East and North East. Continuing with manual picking of P-wave onset times for more bins is far too time consuming, so an accurate automatic picker needs to be found and employed. Time differences between the elements of the array are of the order of 0.1 seconds so the picking accuracy of the automatic picker must at least be better than that. The sample rate of the instruments is 20 Hz or 0.05 sec period. Three automatic pickers were chosen, a Neural Network picker (Dai and MacBeth, 1997), a Cross Correlation picker (Schweitzer, pers comm 2003) and an AR-AIC (Auto-regressive Akaike Information Criterion, Kvaerna 1995) picker. The Neural Network picker was briefly tested but was found to be significantly worse than the others on this data set so it was not tested any further.

6.1 Cross Correlation Method

Waveforms are generally coherent across the EKA array, so the cross correlation method which relies on waveform similarities should work well. The necessary pre-processing stages are as follows:

- Optimal filter all channels using the same filter that was used for the manual picking
- Form the beam using the slowness and azimuth obtained from FK analysis
- Select the time window on the beam trace that will be cross-correlated with the other traces (usually about 2 seconds)
- Select the time window over which the cross correlation shall be made on the individual traces (usually about 4.5 seconds)

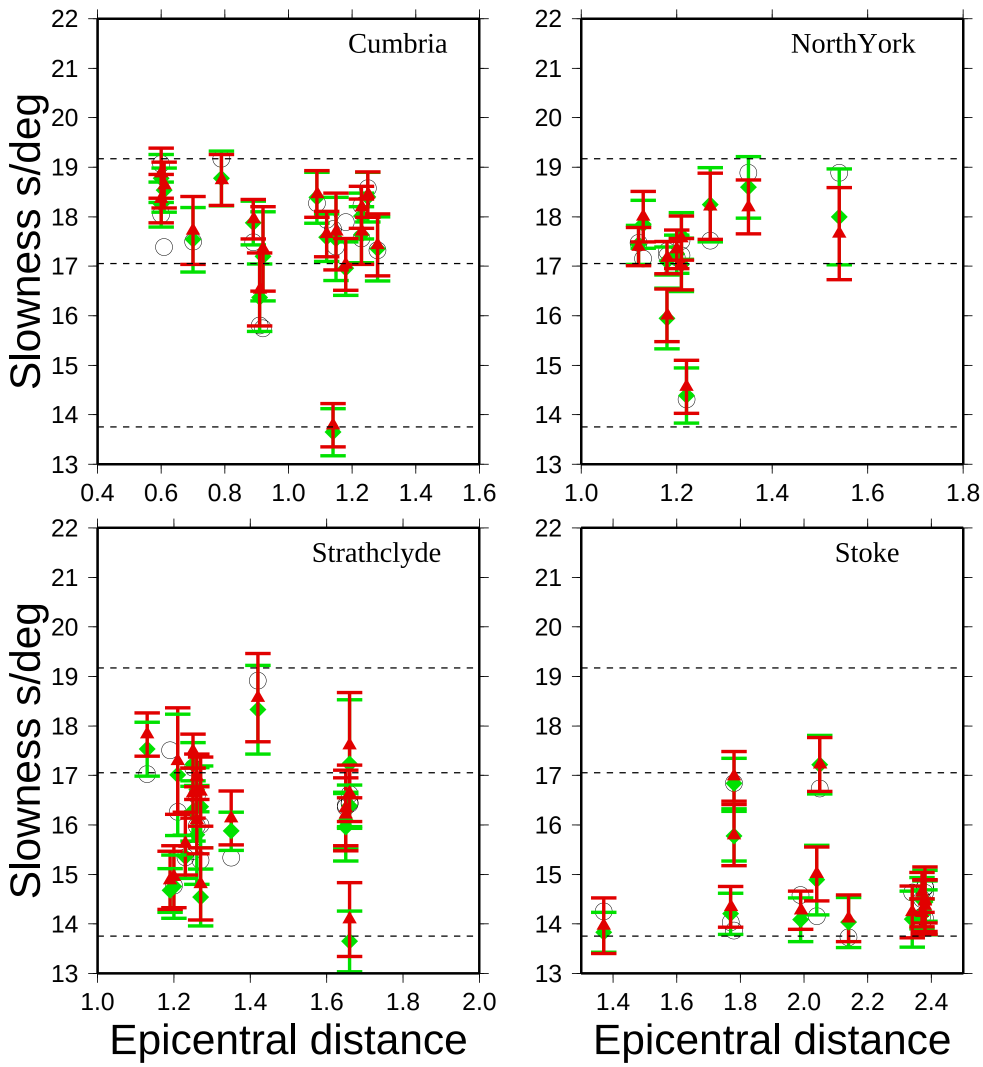

Figure 7: Slowness values calculated from the arrival times at the array are shown as green diamonds. The slowness values calculated by correcting these times using the station correction terms are shown as red triangles and the FK slowness values are shown as unfilled circles. IASPEI theoretical slownesses are shown as dashed lines, Pg at approximately 19 s/deg, Pb at 17 s/deg and Pn between 13 and 14 s/deg.

- Resample the traces by 5 so that the sample rate is now 0.01 seconds

Once the cross-correlator has been run on the data, the time window sizes may be adjusted to obtain better picks. This is worth doing and every event needs to be checked to see how good the picks are. It is clear there is still a need for some analyst intervention but first impressions are very good.

6.2 ARAIC Method

The Autoregressive Akaike Information Criterion (ARAIC) method estimates the arrival time by distinguishing the properties of a segment of waveform data presumed to be ambient noise from an adjacent segment of waveform data containing both signal and noise. The arrival time is estimated to be the time for which the properties of the immediately proceeding waveform segment are maximally different (using the AIC test statistic) from the properties of the immediately following waveform segment. More details of this method can be found in Kvaerna (1995).

The pre-processing stages are as follows:

- Optimal filter all channels using the same filter that was used for the manual picking
- Select the noise segment of the trace by using an estimate of the onset pick
- Select the time window on the trace which contains both signal and noise

7 Manual Versus Automatic Comparison

As for the manual picks, the automatic picks were made on each element of the array for each bin of data. Bad picks were discarded, as they were for the manual picks. Analysis of variance was performed on the remaining picks in the same way as for the manual picks. F-tests were used to compare the variance results from analysis of variance to see if the automatic picks are significantly worse than the manual ones. Table 4 shows the results of analysis of variance and the F-test. Both automatic picking methods were used on the Cumbria and North Yorkshire bins but only the cross correlation method was used on the Strathclyde and Stoke bins. The arrows beside the F-test percentages in Table 4 display which method is favoured over the other (i.e. which is statistically better than the other). Up arrow indicates that the automatic method is significantly better than the manual while a sideways arrow shows that the manual is better then the automatic. No arrow means that they are not significantly different at the 95% level.

It is obvious from Table 4 that the pick (ϵ_{ij}) variances are very small for all three methods with the worst variance being 0.0077s^2. We expect to see little difference in the local path effect (S_j) variance but rather some changes in the pick effect variance which reflect the accuracy of the methods involved in the picking. Looking at the F-test results we see that for three out of four of the bins the cross correlation method is significantly better than the manual picks. For the other bin there isn't a significant difference between the manual and the cross correlation method. On the other hand, the comparison of the ARAIC method against the manual picks shows that in both cases the manual picks are significantly better. From these results we can deduce that the cross correlation method is at least as accurate as the manual picks while the ARAIC method is significantly worse on this data set.

The station correction terms calculated using the picks from the three picking methods can be compared by examining Figure 8. Once again for the Cumbria and North Yorkshire bins, all three methods are shown but for Strathclyde and Stoke only the results from using the cross correlation method and the manual picks are shown. Overall we see very good agreement between the station corrections from the manual and cross correlation picks but the ARAIC picks produce station correction terms with large errors and show little agreement with the other methods.

The comparison of the automatic and manual picks indicates that the cross correlation method is just as accurate if not even more accurate than the manual picks. The reason for this is probably because the data has been resampled by five before the cross correlation method was applied. For the ARAIC method the results are not good enough on this data set. Almost all station correction terms and their errors for the manual and cross correlation methods are less than the sample rate of the instruments (0.05 seconds).

Figure 9 to Figure 12 show some examples of the picks made by the ARAIC and cross correlation methods for two events from the Cumbria bin of data. Figure 9 and Figure 10 show that the picks are better for event 950130 using the cross correlation method rather than the ARAIC method, while Figure 11 and Figure 12 show that the ARAIC method does better for event 900521.

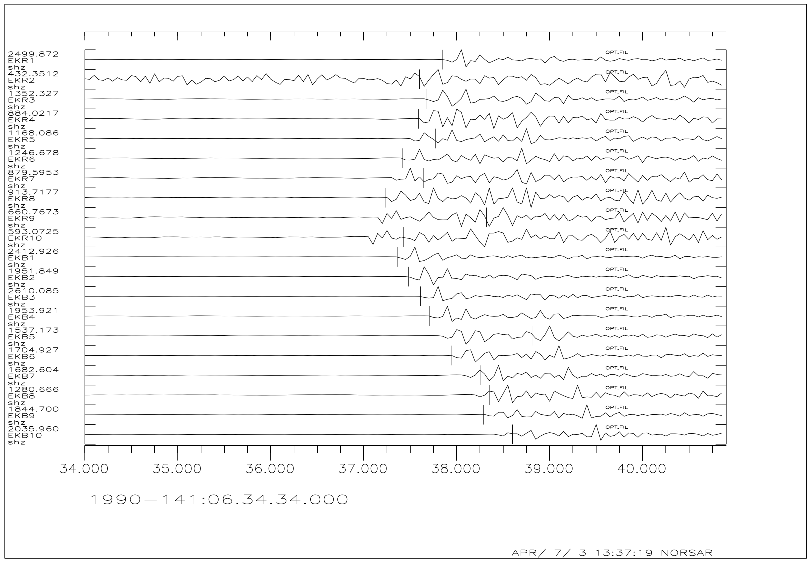

Figure 11: CC picks on Cumbria event 900521.

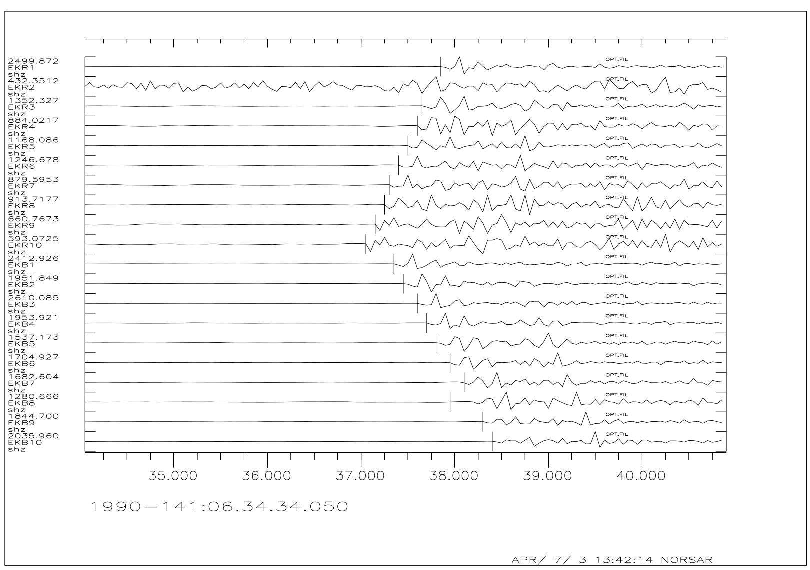

Figure 12: ARAIC picks on Cumbria event 900521.

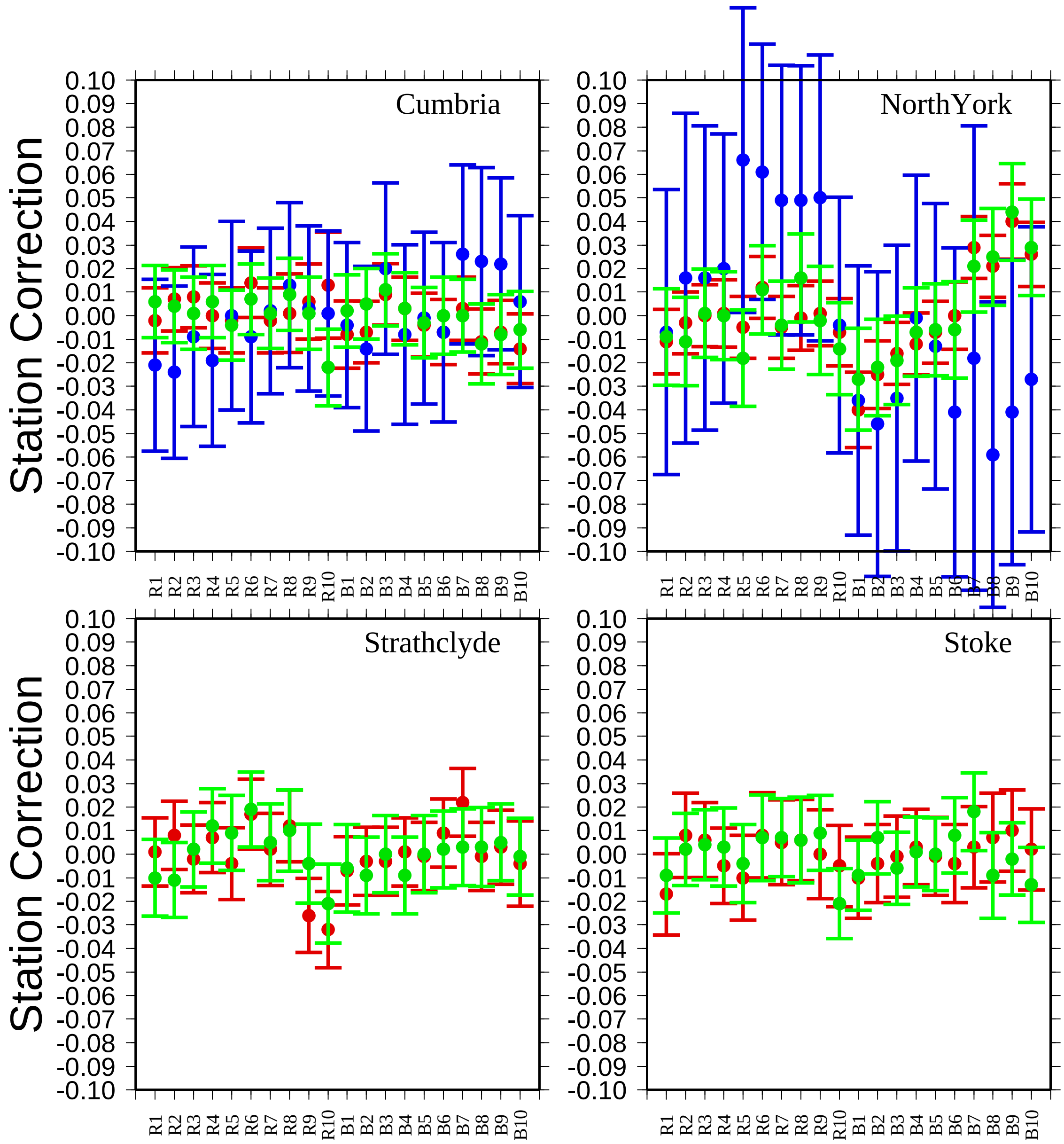

Figure 8: Station corrections for all four bins of events for the manual picks (green), CC picks (red) and ARAIC picks (blue).

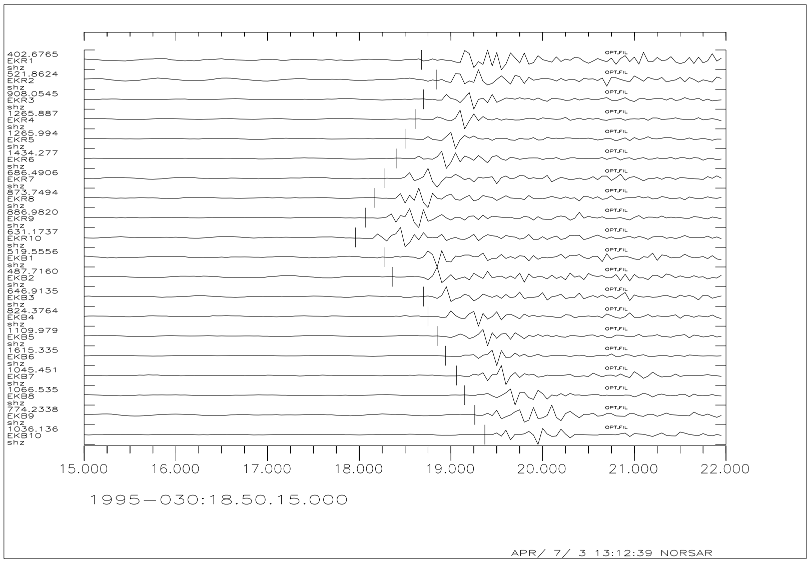

Figure 9: CC picks on Cumbria event 950130.

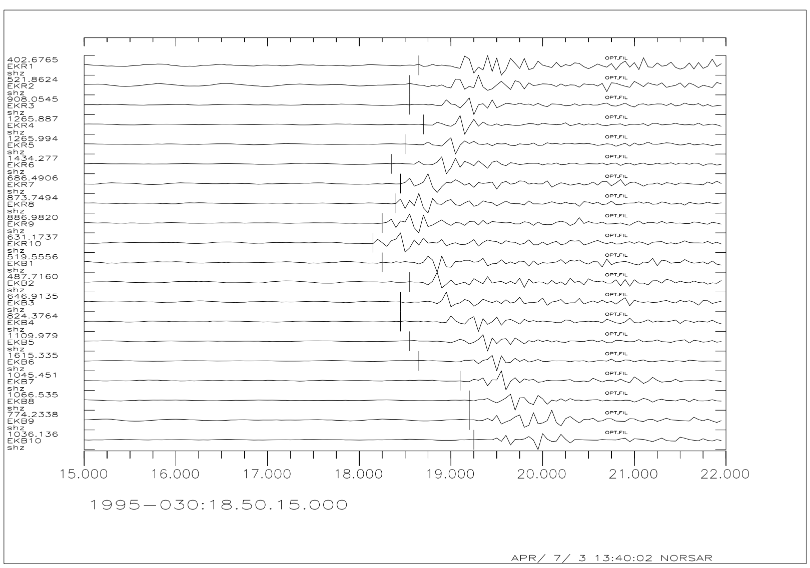

Figure 10: ARAIC picks on Cumbria event 950130.

8 Conclusions

The analysis of variance investigations of the manually picked onset times at the EKA array stations revealed that station correction values for 4 separate bins of event data at different distances and azimuths are very small (approx ± 0.02 seconds). We observed some lateral inhomogenity in the E_i values but overall the use of local velocity models in this part of the study minimises the residuals. The polarities of the E_i values suggests that events from the Stoke and North Yorkshire bins have a faster average velocity than predicted by the input local velocity models while events from the Strathclyde and Cumbria bins have slower velocities than predicted by the local velocity models. Considerable scatter was observed in the slowness values observed at the array and the values do not agree well with a standard earth model, IASPEI. This is not surprising as IASPEI is a global earth model while we are examining local event data. Applying the station corrections to the times and recalculating the slowness values does not move the slownesses any closer to the theoretical values, which confirms that local crustal and uppermost mantle velocities differ from the IASPEI model.

The implementation and testing of the automatic picking algorithms was highly successful. Two picking routines were tested, a cross correlation method and an ARAIC method. The picking variance results show that in most cases the cross correlation method is even more accurate than the manual picks, having a variance of less than 0.001 in most cases. The reason for this is thought to be because the data is resampled by five before the cross correlation picks are made. The ARAIC method proved not to be as accurate for this data set, and therefore the cross correlation method will be adopted for future work.

9 References

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Analysis of variance results for manual and automatic picks										
	Cumbria			Northyork			Strathclyde		Stoke	
	Manual	CC	ARAIC	Manual	CC	ARAIC	Manual	CC	Manual	CC
pick variance	0.001093	0.000830	0.004285	0.001134	0.000555	0.007719	0.001307	0.001085	0.000887	0.000956
dof	296	270	205	185	189	123	318	317	226	208
local path variance	0.000895	0.000848	0.002503	0.003566	0.003375	0.011855	0.001547	0.002545	0.001112	0.000603
dof	19	19	19	19	19	19	19	19	19	19
F-test pick sig%		98.93% ↑	100.00% ←		100.00% ↑	100.00% ←		95.11% ↑		70.98%
F-test path sig%		54.62%	98.49% ←		54.71%	99.40% ←		85.66%		90.43%

Table 4: Table showing the variance (s^2) results from analysis of variance on the various sets of picks on all four bins of events. DOF is degrees of freedom and F-test sig% is the significance between the manual and the cross correlation (CC) and the manual and the ARAIC picks. The path variance is the local path effect (S_j) varianc e and the pick variance is the variance of ϵ_{ij}.

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