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7.3 On the use of regionalized wave propagation characteristics in automatic global phase association

The Generalized BeamForming (GBF) method for automatic phase association and event location (Ringdal and Kværna, 1989), uses the philosophy of matching the predicted phase arrivals from hypothetical events at a predefined set of target locations to the actual detections at each observing station. This approach gives us the opportunity of organizing and using knowledge on regionalized wave propagation characteristics in a simple and well-arranged way.

Examples of relevant questions are:

- Which seismic phases are observable/detectable at the different stations from an event at a given target location.
- What are the expected travel-times, slownesses, and azimuths of these phases, and the corresponding variability.
- What are the amplitude versus magnitude relations for the different phases, and the corresponding variability.

The quality of the GBF results as well as the false alarm rate are dependent on how well our predictions match the actual observations. As illustrated in Fig. 7.3.1, the detectable seismic phases may vary strongly from one region to another, as do the corresponding travel-times. The obvious way to obtain good predictions at a given station is to collect and analyze events from a wide range of epicentral regions. For these calibration events, independent bulletin information on hypocenter location, origin time and magnitude should be available.

Detailed mapping of the wave propagation characteristics attributed to a given station do, however, require significant amount of data and a substantial amount of work (Kværna and Mykkeltveit, 1985; Mykkeltveit et al., 1990; Gestermann, 1992; Sereno et al., 1992). The Intelligent Monitoring System (IMS) (Bache et al., 1990), currently operating a network of arrays in northern Europe, has a design that facilitates retrieval of this kind of knowledge, using a database management system (DBMS). During its 2-3 years of operation it has contributed significantly to improve the quality of the automatic processing results from this region of the world (Bratt et al., 1990).

The GSETT-2 database

Another interesting database is the waveforms and processing results from the GSETT-2 experiment conducted in 1991. During a period of six weeks (April 22 to June 2), 60 globally distributed stations (including single-component stations, three-component stations and arrays) reported phase readings and waveforms to a common database, see Fig. 7.3.2. At four different data centers, automatic analysis as well as analyst review were conducted to obtain precise event locations and magnitude estimates.

In the instructions for the conduct of the GSETT-2 experiment (GSE/CRP/Rev. 4, 1991), there are detailed instructions on which parameters to use for the preparation of the event bulletin. This includes the use of travel-times and slownesses derived from the Jeffreys-Bullen travel-time tables. There are also detailed instructions on which phases to consider, as well as their residual requirements on travel-time and slowness vector residuals for the different types of seismic stations.

A stepwise approach towards regionalization

When initiating phase association and event location with the GBF method on data from a new network like GSETT-2, the natural starting point is to use theoretically derived or globally averaged processing parameters like those described in the GSETT-2 instructions.

The GSETT-2 stations (see Fig. 7.3.2) are situated in very different geological provinces, and may experience systematic deviations from the globally averaged travel-times, slowness and azimuth estimates, especially for events within regional distances.

A first step towards regionalization would be to investigate if stations within the same geological province observe similar systematic anomalies with regard to, e.g., phase occurrence, travel-time, slowness or azimuth, and then accordingly introduce corrections to the parameters derived from the globally symmetric model.

Next, this can be refined by analyzing each station separately, and also, if possible, making corrections for source regions where the events exhibit anomalous behavior. For example, for seismic phases recorded at the GERESS array in Germany, both Gestermann (1992) and Sereno et al. (1992) have analyzed the characteristics of regional phases along different propagation paths.

Finally, for small areas with recurring events, such as mines, nuclear test sites and seismically very active regions, we can use the recorded events for calibration and obtain site-station specific processing parameters for use by the GBF method.

In the following, we will present samples from results we have obtained by searching the GSETT-2 database that are of relevance for improving the processing parameters for the GBF method. In this contribution we have used the event bulletin from the Washington Experimental International Data Center (EIDC) as the reference bulletin, also called WASCEL (WAShington Current Event List). This bulletin may not contain totally independent information because the phases we are to analyze have been used to produce the bulletin. However, for events with a sufficiently high number of associated phases, the bias due to this effect is considered negligible.

Phase occurrence

The optimum information on the occurrence of seismic phases at a given station would be to have a geographical map with indications on which phases may be observed from events in the different geographical areas. However, the derivation of such information requires a large number of recorded events, which can only be obtained for stations that have been operational over a long time period.

If we assume that the geology of the region surrounding a given station is rather uniform, the recording of seismic phases would primarily be distance- and magnitude- dependent (the effect of different source functions is ignored at this stage). The assumption of azimuthal symmetry will initially be made for the derivation of wave propagation characteristics from the GSETT-2 database. We will in the following use phase labels reported by the WASCEL as the reference.

As a first example we show a histogram of the occurrence of regional phases observed at the ARCESS array in Norway (ARA0) as reported in the WASCEL (Fig. 7.3.3.a). It is seen that certain distance ranges have more reported phases than others, corresponding to regions of high mining activity, like the Kola peninsula (3-4 degrees), the St. Petersburg region (8-9 degrees), and the Estonian region (10-11 degrees).

This data set indicates that beyond the critical distances, Pn and Sn can be expected to be seen for all regional distances, whereas Pg is not observed beyond 9 degrees. Lg is only observed within 12 degrees, and Rg only within 4 degrees.

It should be emphasized that this data set is sampled through a time period of only six weeks, and consequently only samples the lower part of the event magnitude distribution. It is therefore likely that phases from stronger events will be observable at larger distances than those found in this data. Such considerations have to be made when constraining the expected occurrence of seismic phases at a given station.

Fig. 7.3.4.a shows a histogram of the occurrence of teleseismic phases observed at ARCESS. The P and PKP phases generally follow the expected pattern of the global travel time curves. Some PcP phases are observed, probably corresponding to events in regions with favorable propagation paths and/or strong events.

In a similar way, such investigations can be conducted for each of the other GSETT-2 stations, but it should be noted that the GSETT-2 database probably contains too little data for a rigorous mapping of the occurrence of seismic phases.

Reported phase labels

Another interesting parameter that possibly can be utilized by the GBF algorithm is the phase labels given by the reporting stations. For direct comparison with the regional phase distribution of Fig. 7.3.3.a, we show in Fig. 7.3.3.b the same type of histogram, but based on phase labelling by the Norwegian National Data Center (NDC). From these figures it looks like there is good agreement with the final phase labels given in the WASCEL. On the other hand, from the histogram of NDC reported teleseismic phases of Fig. 7.3.4.b, we find that with very few exceptions, all phases were reported as P.

For the most frequently observed phases, the relation between the NDC reported phase labels and those reported in the WASCEL has been studied in more detail. The rows of Table 7.3.1 represent the ARCESS phase labels reported by the Norwegian NDC, and the columns represent the phase labels of the WASCEL. This matrix table thus gives an overview of the reliability of the NDC reported phase labels.

Phase labels reported in the WASCEL

NDC-reported phase labels	Pn	Pg	Sn	Sg	Lg	Rg	P	S	PP	PcP	PKP	pP	sP	UNK
Pn	**186**	4					4							1
Pg		**17**												1
Sn			**119**											2
Sg														
Lg		1	4		**113**									4
Rg						**6**								1
P	11	1					**534**		1	12	108	27	9	59
S														
PP									**1**					
PcP										**3**				
PKP							1				**5**			
pP												**37**		
sP													**9**	1
UNK													1	**11**

Table 7.3.1.

Let us consider phases reported as Pn by the Norwegian NDC:

186 of these phases were not renamed during global phase association, 4 were renamed to Pg,4 were renamed to P and 1 was renamed to be unknown. Similar statistics are seen for the other phase types. In the context of conducting event association by the GBF method, it is reasonable to introduce some general constraints on the use of NDC reported phases from the ARCESS array. For example, the following two constraints are quite apparent from the table:

- A phase reported to be of P-type (P, Pn, Pg, PKP,...) should not be associated with a hypothetical arrival of S-type. Out of 1032 P-type phases in this data set, none was renamed to an S-type phase.
- A phase reported to be of S-type (S, Sn, Lg, Rg) should not be associated with a hypothetical arrival of P-type. In this data set, out of 250 S-type reports (Sn, Lg, Rg), only one phase was changed to a P-type phase by WASCEL.

Many other constraints of more limited application can also be inferred from the table. For example, a phase reported as Pn should only be allowed to be renamed P or Pg (or retained as Pn). On the other hand, a phase reported as P could be renamed to either Pn, Pg, PP, PcP, PKP, pP, sP or, of course, retained as P. It is possible that some more refinements may be made by taking into consideration the difference in the slowness estimates between core phases and P-phases, but this will be the topic of a separate investigation.

Without going into detail, it is clear that a database of the GSETT-2 type can provide a number of useful rules to constrain the reinterpretation of phases reported by an NDC. This in turn will reduce the probability of false associations in the global event definition process.

Reported event locations

During the GSETT-2 experiment, the National Data Centers (NDCs) were encouraged to provide information on location parameters of events detected at their participating stations.

These location parameters provide useful information to the automatic phase association procedure. Depending on the expected accuracy of the reported NDC location, a phase associated to an event by an NDC, can during the global phase association process be restricted to stem from events in target regions close to the NDC reported event location.

One-station event locations are usually found by associating a P- and an S-phase to a common event, getting a distance estimate from the S-P travel-time difference and source direction from the azimuth estimates of the phases. One-station event locations are thereby most commonly obtained for regional events, where clear P- and S-phases are frequently observed. Reliable azimuth estimates of both P- and S-phases are obtained by arrays, whereas three-component stations have the ability to estimate the azimuth of P-phases.

To investigate the reliability of the NDC locations provided by the regional arrays, ARCESS, FINESA, NORESS and GERESS, we have in Fig. 7.3.5 plotted the station-to-event distances of the NDC locations against the station-to-event distances of the corresponding locations of the WASCEL. As seen from the plots, there are, with few exceptions, good correspondence between these distance estimates.

A few phases associated to local or regional events by the NDC have, however, been associated to teleseismic events in the WASCEL. Incidentally, this is a violation of the rules outlined in GSE/CRP/Rev. 4 (1991) (Appendix B.3.2 (ii): "Observations of phases reported as originating from local or regional distances may be used only within local and/or regional distances").

Conclusions

We have in this paper outlined a strategy for retrieving and organizing information on regionalized wave propagation characteristics for use by the GBF method algorithm. Different types of relevant information derived from the GSETT-2 database have been shown in several examples. These examples illustrated features like the distance dependent occurrence of seismic phases, the reliability of reported phase labels and the accuracy of one-station event locations. In future work we plan to examine the GSETT-2 as well as other data bases in more detail, in order to develop an optimum framework for application of the GBF method to a global network.

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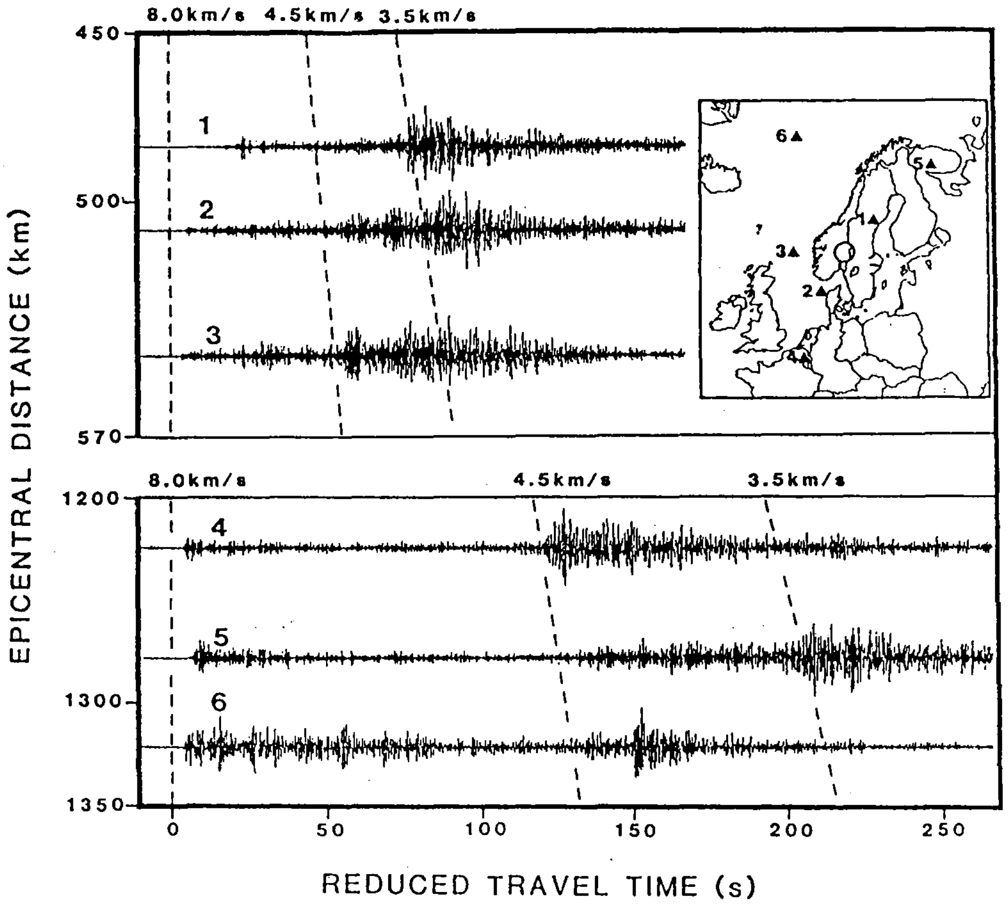

Fig. 7.3.1. Illustration of variation of relative importance of the phases Sn and Lg for six events with locations as indicated in the map. The standard group velocities of 4.5 and 3.5 km/sec, commonly assigned to Sn and Lg, respectively, are marked by dashed lines. The upper three traces cover the distance interval from 480 to 550 km, while the lower three traces correspond to epicentral distances in the range from 1,225 to 1,320 km. The location of the NORSAR array is denoted by a ring on the map, and the traces are from NORSAR seismometer 02B01. The data are bandpass-filtered 1 to 5 Hz. The reduction velocity is 8.0 km/sec. From Mykkeltveit et al (1990).

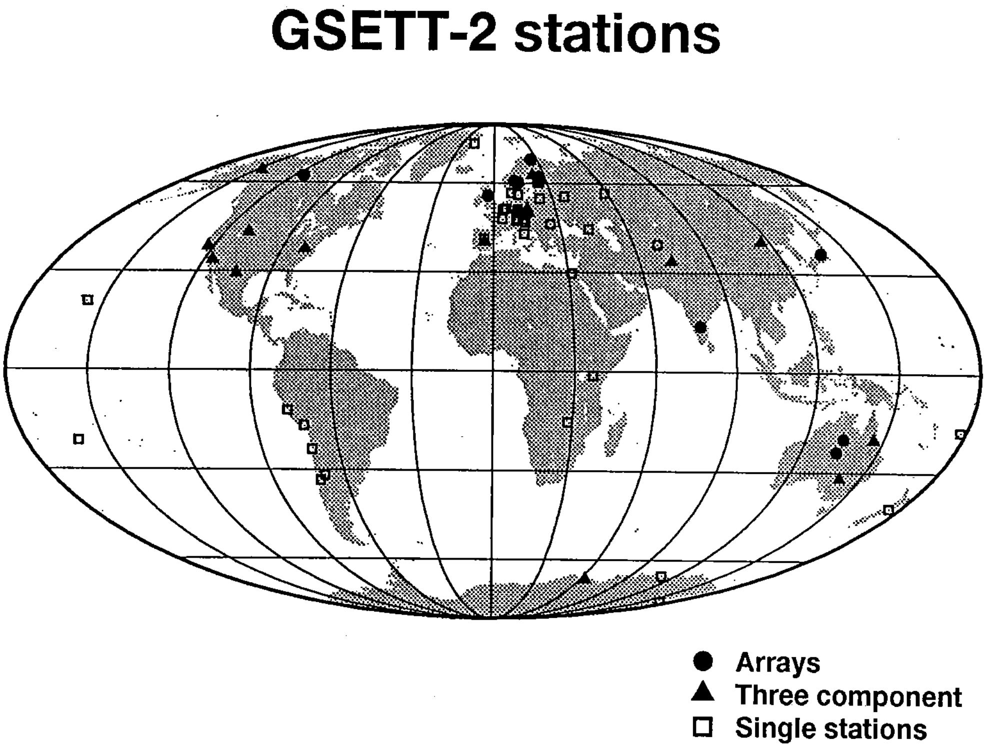
GSETT-2 stations

Fig. 7.3.2. Map showing the location of the stations participating in the GSETT-2 experiment.

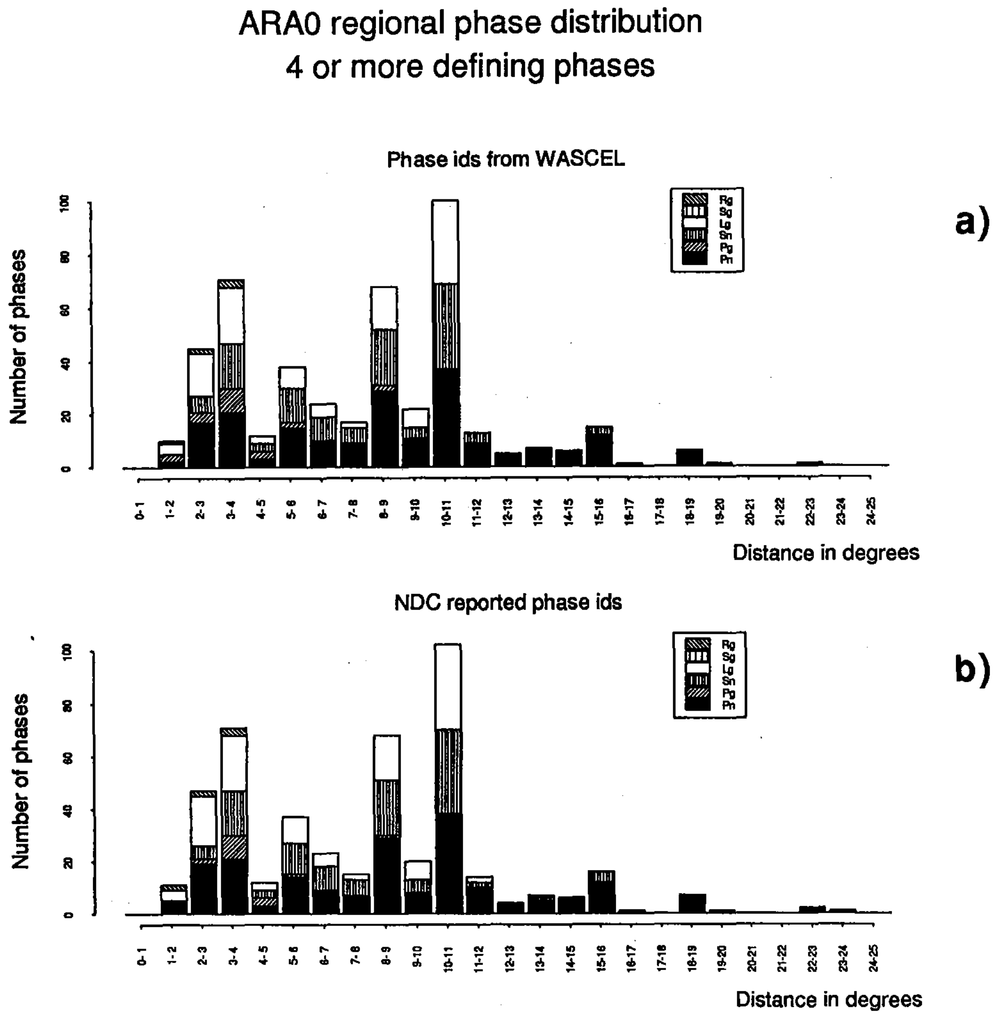

Fig. 7.3.3.

a) Histogram showing the distance dependent occurrence of regional phases observed at the ARCESS array in Norway (ARA0). Event to station distances and phase labels are both taken from the WAShington Current Event List (WASCEL).

b) Histogram showing the ARCESS regional phase labels reported by the Norwegian National Data Center (NDC). Event to station distances are taken from the WAShington Current Event List (WASCEL).

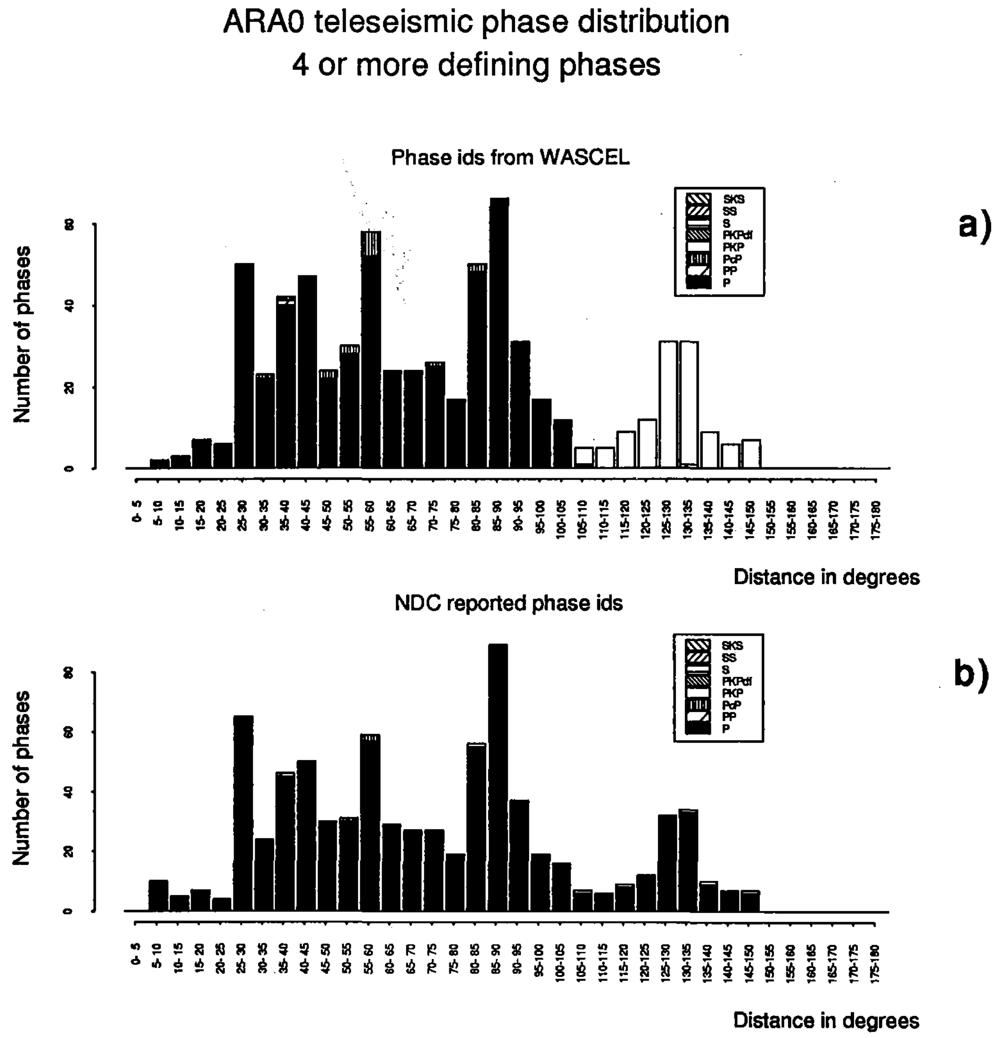

Fig. 7.3.4.

a) Histogram showing the distance dependent occurrence of teleseismic phases observed at the ARCESS array in Norway (ARA0). Event to station distances and phase labels are both taken from the WAShington Current Event List (WASCEL).

b) Histogram showing the ARCESS teleseismic phase labels reported by the Norwegian National Data Center (NDC). Event to station distances are taken from the WAShington Current Event List (WASCEL).

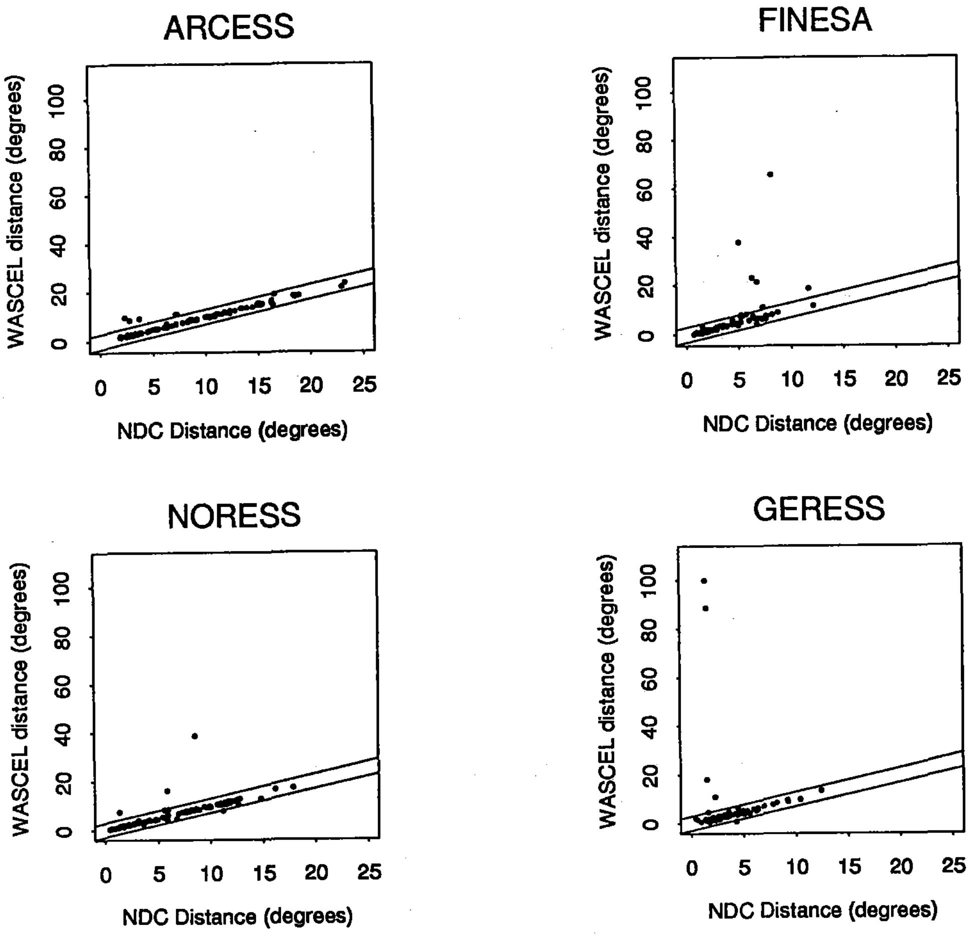

Fig. 7.3.5. Plots showing the relation between NDC reported event locations and those given in the WASCEL, obtained after global phase association, for the regional arrays ARCESS, FINESA, NORESS and GERESS. Two lines with deviations of ±3 degrees, respectively, are shown on each plot.