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Comparison between LDG-network and GERESS-array with respect to regional detection and location results

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Abstract
The design of a global seismic system to monitor compliance with a ban on underground nuclear testing considerably deviates from previous concepts of international seismic data exchange. The new concept relies on centralized processing of continuous data from a fixed station network («alpha» stations) which provides the primary detection and location capability. This alpha station network is augmented by additional stations («beta» stations) which send data on request to refine the hypocentres of events which were detected by the alpha network. To test this concept we have used the GERESS array in Germany as a prototype alpha station and investigated its regional detection and location capability for events in France and surrounding areas. For this region, data from the national French network operated by LDG provide an excellent reference data base. Within a 5 degree distance, GERESS showed an excellent performance in terms of detection and location down to magnitude $M(\mathrm{LDG}) = 3$. Between a 5 degree and 10 degree distance, the detection capability is still high but very often it is not sufficient to locate events below $M(\mathrm{LDG}) = 4$. Generalizing these results, we can conclude that either the maximum distance between alpha stations should be 10 degrees or the contribution of beta stations has to play a significant role in a future monitoring system.

Key words *locations – array – seismic monitoring – alpha stations*

1. Introduction

The technical concept for a future global system of international seismic data exchange includes a two-tiered network. The first tier, the alpha network, is formed by 50 to 60 globally distributed stations, mostly arrays, and provides the primary detection and location capability. It is augmented by 200 to 250 beta stations which help to refine the hypocenters of events which were detected by the alpha network. The current siting plan for the alpha network shows station spacings which vary between 10 degrees and more than 20 degrees. Taking these station distances into account, the alpha network must be regarded as a teleseismic network, *i.e.* its detection and location capabilities (at least 2-4 stations must detect an event) are limited to events at distances larger than 25-30 degrees. On the other hand, each single alpha station is very sensitive and detects very small events in its neighbourhood, *i.e.* at distances smaller than 25 degrees. This distance range is usually separated in two parts: the «local» distance range (about 5 degrees in Richter's original local magnitude scale) and the «regional» distance range which describes the interval between

5 degrees and 25 degrees. If an alpha station is a high-frequency array it provides independent location capability at local and regional distances. The single station location can be used to extract additional data from appropriately located beta stations to confirm and refine the initial hypocentre. During the warm-up phase of GSETT-3, we have used the GERESS-array – a 25-element high-frequency array – in Germany as a candidate alpha station and investigated its detection and location capability at regional distances for events in France and surrounding areas. For this region, data from the national French network operated by LDG provide an excellent reference data base.

2. The data

In an area limited by 40°N and 52°N in latitude and 12°W and 14°E in longitude, the LDG bulletin contains 500 events for the time period from 1 January 1991 to 15 June 1993 (fig. 1). Only events with magnitude $M(\mathrm{LDG}) \geq 3$ were considered. The map reflects the well-known seismicity pattern of the area where the seismic activity is concentrated in Northern and Central Italy and in the Swiss and Austrian Alps. There are also numerous events along the French/German border, in Northwestern France and along the Pyrenees. As a peculiarity, the Roermond earthquake (the strongest event in Northern Europe in this century) and its aftershocks occurred during the investigated time period at the Dutch/German border. The circles around GERESS are drawn at multiples of 5 degrees. For comparison the GERESS detection and location bulletin was used which is automatically produced in near real-time. It was found that for areas like Italy, Germany, and the Austrian Alps which are close to GERESS and outside the LDG-network, a comparison of the two bulletins was difficult without an independent reference (for example the ING-bulletin for events in Italy). The analysis was therefore restricted to an area west of 8°E longitude because this region is mainly inside the LDG-network.

For association we scanned all GERESS detections within a backazimuth range between 200 and 300 degrees and a time window of 420 s after the origin time determined by LDG. Mislocation vectors were calculated for all events west of 8°E with a difference in origin time

$$\mathrm{OT(LDG)} - \mathrm{OT(GERESS)} \leq 120 \text{ s.}$$

Figure 2 shows a map of the remaining 368 LDG-events which are separated as not detected by GERESS (crosses), as associated with a single phase GERESS detection (circles), or as events located by GERESS (stars) relative to the LDG-location (squares). Altogether 140 events were detected and 53 events of these were automatically located by GERESS.

3. Detection results

Although the total percentage (38%) of LDG-events which were detected by GERESS in the area under investigation seems to be rather low, the magnitude range and epicentral distance have to be taken into account.

In fig. 3 the data set has been plotted as a function of magnitude (LDG) and distance from GERESS. It can be seen that GERESS detected all events with magnitude $M(\mathrm{LDG}) > 4.0$ at all distances. Only 10% of all undetected events occurred in the magnitude range $M(\mathrm{LDG}) > 3.5$ whereas below this level the detection probability sharply decreases. This variation of detection threshold is obviously dependent on distance. Within a 5 degree distance, GERESS detected all LDG-events, within a 10 degree distance there is still a high detection probability. Beyond 10 degree distance, very few events were

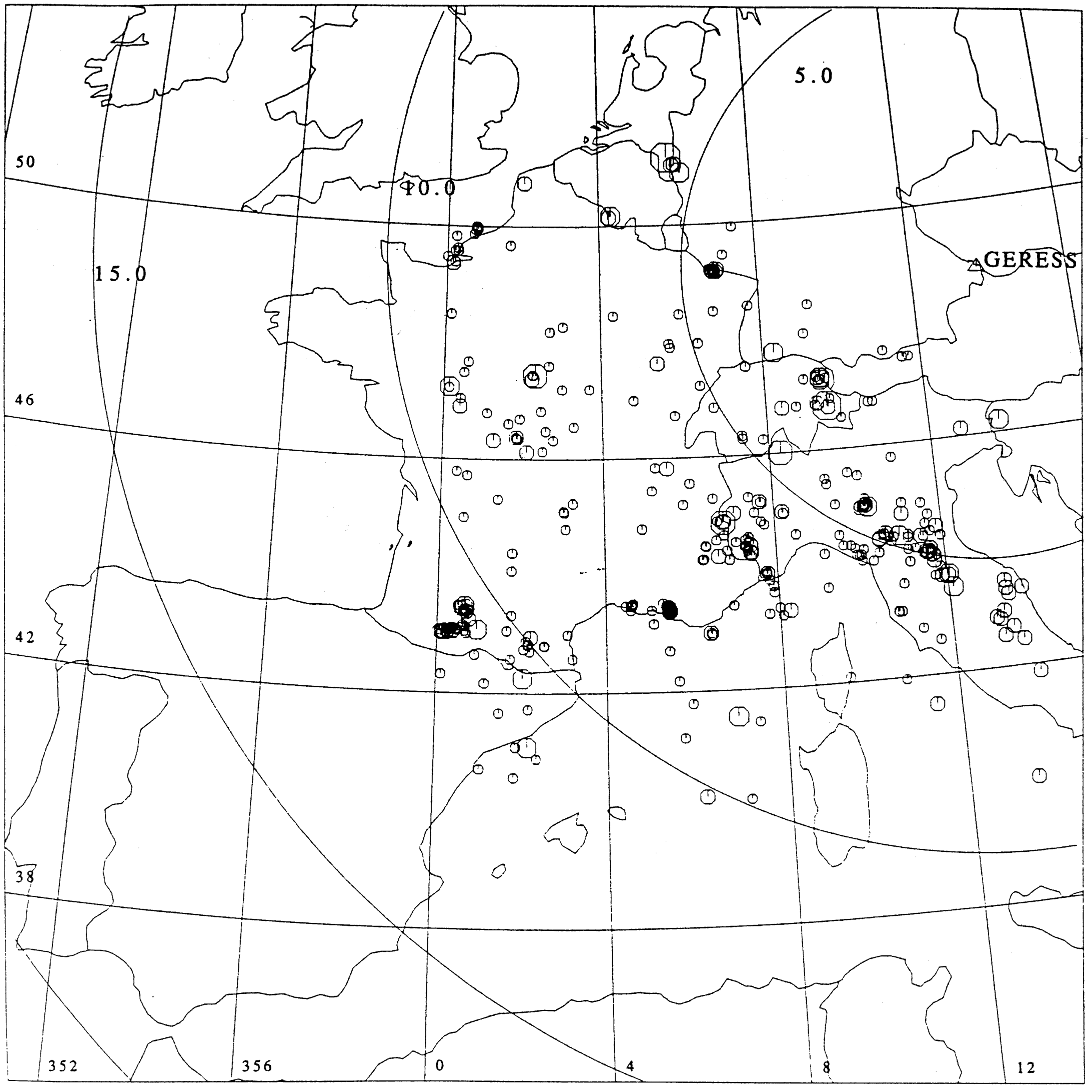

Fig. 1. All events located by LDG 1.1.1991 - 15.6.1993, M_L(LDG) > = 3.0. ○: M_L(LDG) < = 3.5; ○: 3.5 < = M_L(LDG) < 4.0; ○: 4.0 < = M_L(LDG) < 4.5; ○: 4.5 < = M_L (LDG) < 5.0; ○: 5.0 < = M_L (LDG).

detected by GERESS but those are mainly small events with magnitudes M(LDG) < 3.5. If we compare the epicentres of the missed events in fig. 2, it is found that they are either offshore the west coast of France in the Atlantic Ocean or in the Pyrenees/Spain. In all cases the seismic waves of crustal phases have to cross major geological boundaries on their way to GERESS which will generally decrease the amplitudes and increase the detection threshold.

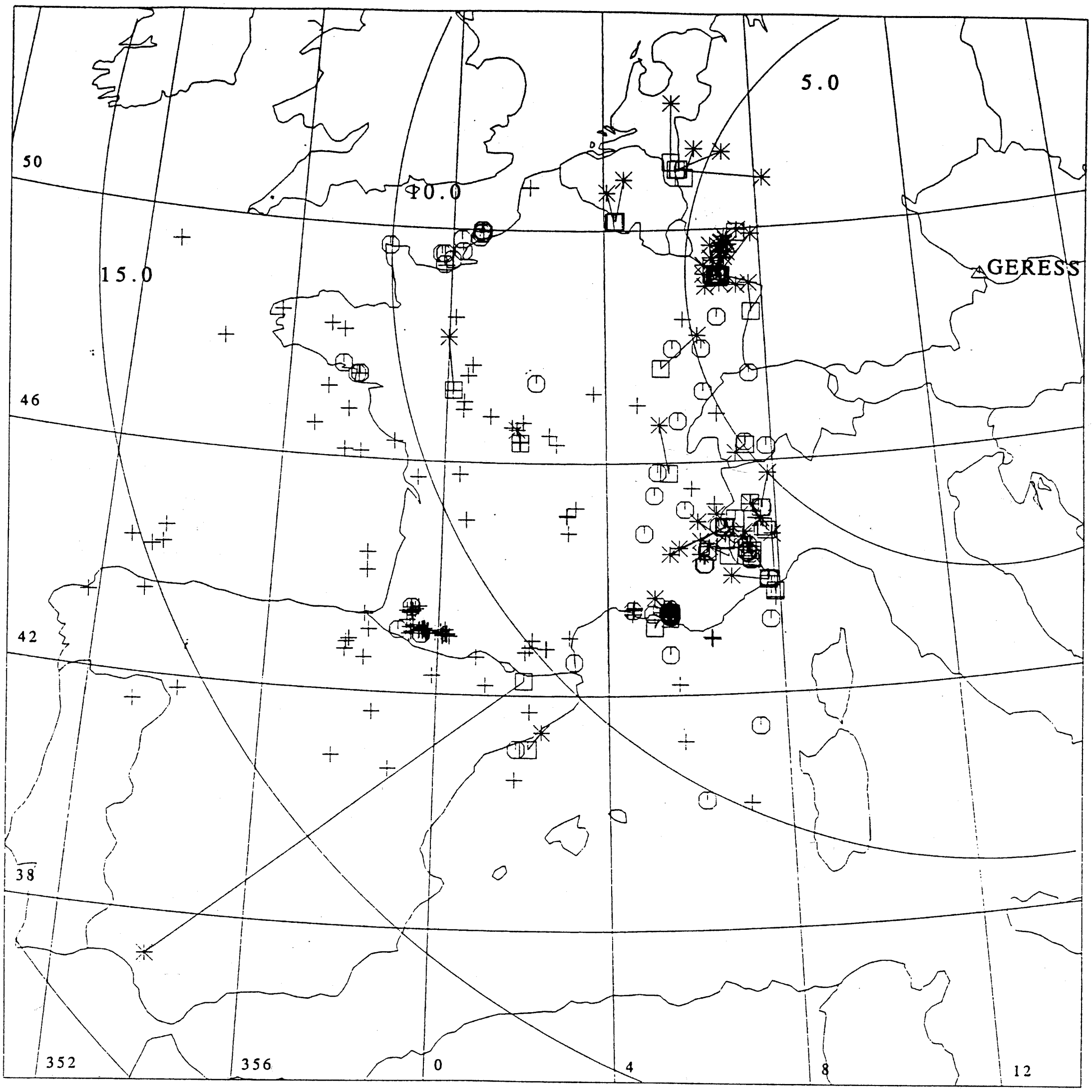

Fig. 2. Association of LDG locations to GERESS locations and detections. All events located by LDG 1.1.1991 - 15.6.1993, lon < = 8.0, M_L > = 3.0. □: LDG-location, event located by GERESS; ○: LDG-location, single phase detection by GERESS; +: LDG-location, no detection by GERESS; *: GERESS-location of □ with mislocation to LDG.

4. Location results

Those LDG-events which were also located by GERESS, are marked by a star symbol in fig. 2 and 3. It can be seen from fig. 3 that almost all events within 5 degree distance from GERESS were located. Again a clear correlation between location probability and epicentral distance can be seen. For magnitudes M(LGD) > 4, only

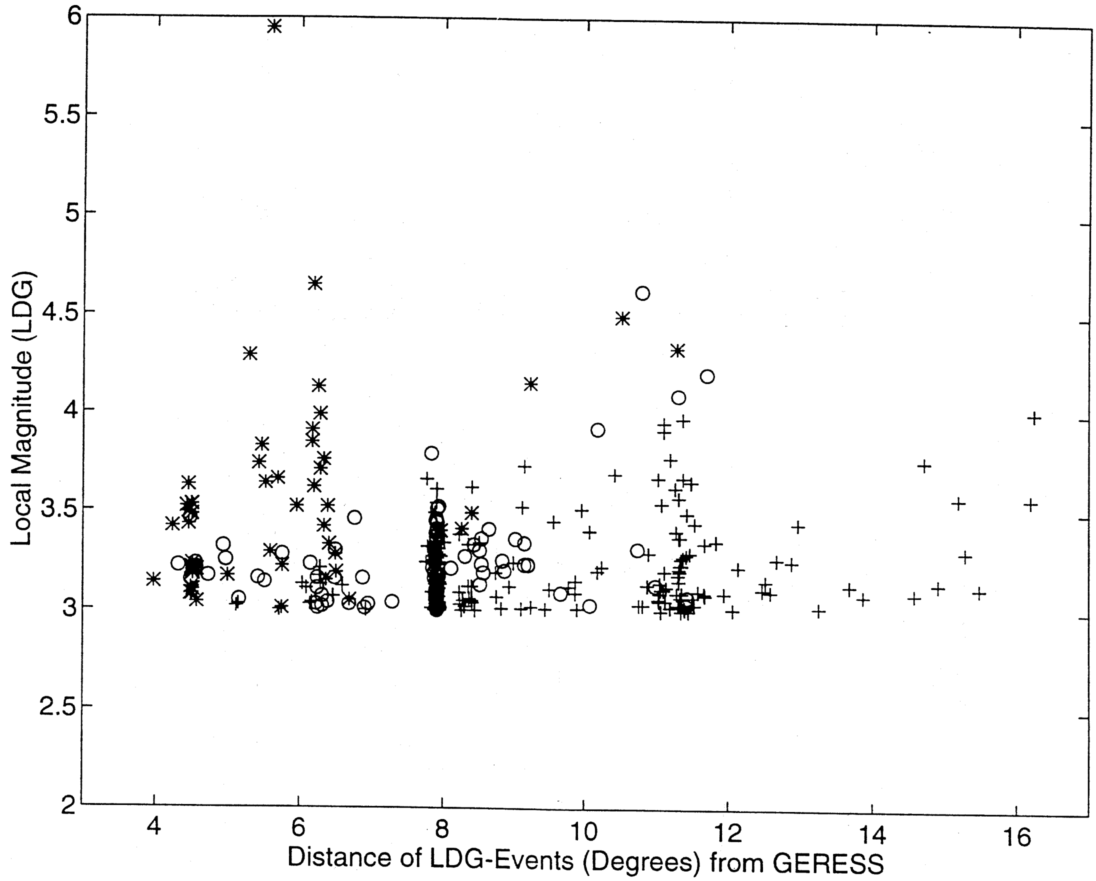

Fig. 3. Distance dependence of GERESS detection and location capability. ∗: automatic location by GERESS; ○: automatic detection and single phase association by GERESS; +: no detection by GERESS.

three events were not located although they had been detected. The automatic location process needs a *P*-phase and an *S*-phase within a common azimuth window to define an event location. The criteria for event definition are very critical for regional arrays like GERESS. As an example we investigated the largest detected but not located event in our data set in detail. Figure 4 shows the GERESS recording of this event which was an earthquake in the French Bretagne (*M*(LGD) = 4.6). By inspection one clearly recognizes the main regional phases, *i.e. Pn*, *Sn*, and *Lg*. GERESS automatically detected *Pn* (with SNR = 33) and *Lg*(*Sg*).

The difference in arrival time for these two phases was larger than 200 s which was the allowed time window in the location procedure. As a result, the automatic location process dismissed the event. Increasing the time window would have worked perfectly for this event but it would also increase the probability of «mixed event» situations and thereby mislocations in many other cases. At this point the alpha/beta-station concept could play a significant role to improve the situation. Triggered by the

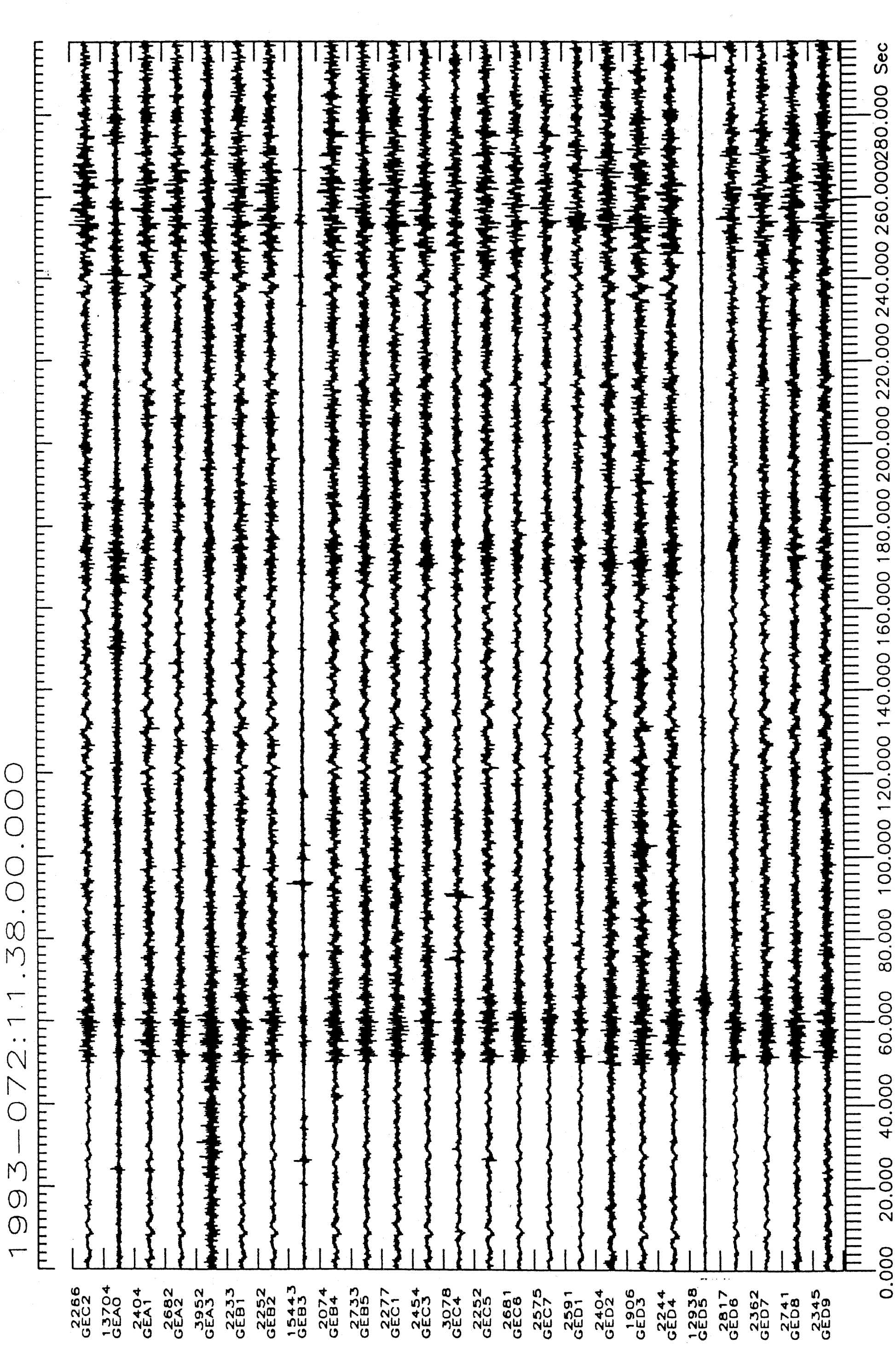

Fig. 4. Bretagne earthquake (M(LDG) = 4.6) which was missed by the GERESS automatic location procedure.

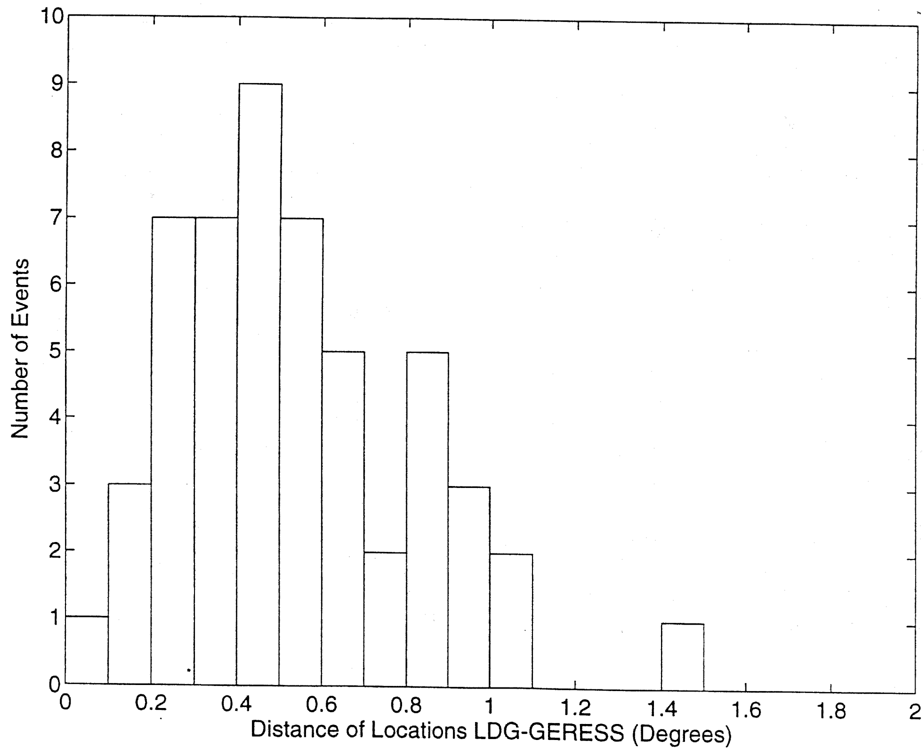

Fig. 5. Histogram of GERESS mislocations.

Pn-detection – regarding GERESS as an alpha-station which also provides slowness and azimuth information – one or two beta stations in Western Europe would have been sufficient to locate the event.

Figure 5 shows a histogram of the differences between LDG and GERESS epicentres for all 53 events which were automatically located by GERESS in the test area. Taking the LDG locations as a reference, the mean (median) of the GERESS mislocation is 54 km. With few exceptions, all GERESS locations roughly lie within 1 degree distance to the associated LDG epicentres.

It can be seen from fig. 2 that one outlier which is not included in the histogram of mislocations (fig. 5), was an earthquake in the Pyrenees which was mislocated by the automatic GERESS procedure by almost 8 degrees due to a «mixed event» situation, *i.e.* a *Pg*-phase of a different event in a similar direction arrived just before the *Lg*-phase of the Pyrenees earthquake.

Although mislocations of this type seem to be unavoidable in an automatic realtime location process, our study shows that epicentre determinations of an alpha station like GERESS are generally excellent starting solutions which then can be refined by additional data from beta stations.

5. Conclusions

We have compared the automatic detection and location results of the GERESS array for events at local and regional distances with a reference bulletin from the national LDG-network in France. Within

5 degree distance, GERESS showed excellent performance in terms of detection and location capability down to magnitude M(LGD) = 3. Between a 5 degree and 10 degree distance, the detection capability is still high but very often it is not sufficient to locate events in the magnitude range 3 < M(LDG) < 4. Beyond a distance of 10 degree in this azimuthal direction, the detection capability of GERESS is poor for events below magnitude M(LGD) < 4. This may be related to a very complex crust and upper mantle for wave paths from the Pyrenees or Western France to GERESS. The mean location error was 54 km for events which commonly occurred in the GERESS and LDG bulletin taking LDG as a reference.

In this paper we have used the local magnitude (M(LDG)) as a reference which is well established by correlation with magnitude determinations from a global network (NEIC). It should be mentioned that GERESS amplitudes are rather low and yield a significant station magnitude bias. This observation has been confirmed by teleseismic events (for comparison see Harjes *et al.*, «Preliminary calibration of candidate alpha stations in the GSETT-3 network», this volume). This problem needs further study.

A prototype alpha station like GERESS can easily achieve a detection capability down to magnitude 3 and a location accuracy of 50 km within a distance range of 5 degrees. If these were design criteria for the global network they would require a maximum distance of 10 degrees for alpha stations. In the current concept, the average distance between alpha stations is much larger and therefore the contribution of beta stations will play an important role to achieve the objectives of the global seismic monitoring system.