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VI.2 Signal and noise correlations and seismic array configuration optimalization

One of the subtasks under the NORSAR regional seismology research program is to devise an optimal sensor layout for a prototype regional seismic array. This contribution deals with initial attempts at array configuration optimalization based on observations of signal and noise correlations. More specifically, we outline a strategy for maximizing the gain funtion, which is expressible in terms of signal and noise correlations only. Possible constraints due to preferred lobe patterns are not dealt with in this study.

We define signal-to-noise ratio gain from beamforming by

$$G = \sum_{i,j} \rho_{ij} / \sum_{i,j} c_{ij} \qquad (1)$$

where ρ_{ij} is the signal correlation between sensors i and j and c_{ij} the noise correlation. The correlations ρ_{ij} and c_{ij} will, in general, be functions of relative positions of sensors and frequency. In addition, ρ_{ij} depends on the phase type considered.

In the following, we establish models for signal and noise correlations to be used in maximizing the gain in eq. (1).

Signal and noise correlation measurements

Measurements of signal and noise correlations are made from the 12-element NORESS array, described in previous semiannual technical summaries. Thus, predictions on optimum geometries of unimplemented arrays will be based on the correlation measurements made from the existing NORESS array.

From the five regional events in Table VI.2.1 we have identified Pn, Pg and Lg phases, which in turn have been subjected to correlation analysis. Since the original sampling rate is 20 Hz, a resampling at 100 Hz was necessary to achieve more accurate time shifts for the correlation computations. The shifts were performed with an optimum line-up of correlating peaks in the signals, and 2 sec of each phase were analyzed. The NORESS array with its 12 elements offers 66 different sensor combinations resulting in 66 cross-correlation values for separations ranging from 120 to 1950 m. Correlation values were averaged into separation intervals of 100 m. Also, averaging is performed over all available phases of the same kind. The results for the Pn phase are shown in Fig. VI.2.1 for the five frequency bands given in Table VI.2.2. Figs. VI.2.2 and VI.2.3 show correlation curves for the Pg and Lg phases, correspondingly.

The results for the Pn phase show increasing correlation with frequency. This is due to the high frequency content in the Pn signal; the Pn spectrum peaks at around 4 Hz. The Pg phase exhibits high correlation values throughout the range of both frequency and sensor separation. The Lg phase, on the other hand, correlates poorly for the higher frequencies.

Selected noise records have been subjected to the same kind of correlation analysis, but now with zero shifts. The noise is taken from five time windows, each consisting of 3 consecutive segments of 4 sec each, immediately preceding the first arrival onset time for the events in Table VI.2.1, so averaging is done over a total of 15 time windows. The results are given in Fig. VI.2.4.

The standard deviations associated with the curves in Fig. VI.2.4 are fairly modest, so we must consider the negative cross-correlation values a real entity. Also, it seems justified to consider the cross-correlations a function of interstation separations only, which is of course already implictly assumed in producing Fig. VI.2.4.

Array configuration optimalization

We are now in a position to contruct otpimal arrays by maximizing the gain expression given by eq. (1), utilizing the correlation functions derived from the measurements described above. We are thinking in terms of arrays with 15-20 elements, out of which an optimal subset should be used in the processing of a particular phase. In fact, the variation of cross-correlations (especially for the noise) with frequency is so strong that one would expect rather drastically different geometries to be optimal for different frequencies. So, realizing the extended range of signal frequencies encountered in regional seismic phases, the optimalization algorithm must be capable of coming up with a final geometry that comprises a broad variety of optimal subsets.

So far, the program for optimizing the gain handles one frequency or a 'weighted' combination of frequencies. Array configuration results based on signal correlations of the Lg wave and the noise are given in Fig. VI.2.5.

The array geometries in Fig. VI.2.5 are generated as follows: The observed correlation curves are represented by analytical functions which are pieced together so as to achieve continuous derivatives. Then a starting configuration is defined and a program which maximizes the gain function by a rapid descent method due to Fletcher and Powell (1963) finds an optimal configuration for the number of sensors in question. The suite of geometries in Fig. VI.2.5 are generated by repeated application of the Fletcher-Powell routine, where the starting geometry for N sensors is defined by the optimal geometry for N-1 sensors, with one sensor added at the point of gravity for the N-1 sensors.

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References

Fletcher, R. and M.J.D. Powell, 1963: A rapid descent method for minimization Computer Journal, 6, 163-168.

Wahlstrøm, R., 1978: Magnitude-scaling of earthquakes in Fennoscandia. Report No. 3-78, Seismological Institute, Uppsala, Sweden.

Date	Origin time	Location		Magnitude M_L
06 Nov 1980	14.53.02	59.5°N	10.7°E	2.1
25 Nov 1980	02.39.49	58.4°N	13.7°E	2.4
29 Nov 1980	20.42.16	51.2°N	18.5°E	3.5
26 Feb 1981	17.43.53	60.3°N	15.9°E	2.1
01 Mar 1981	05.08.16	62.8°N	6.2°E	2.7

Table VI.2.1

Local events used in this study. The local magnitude M_L is computed in accordance with Wahlström (1978).

Filter No.	Bandpass range (Hz)
1	0.8-2.8
2	1.2-3.2
3	1.6-4.0
4	2.0-4.8
5	2.4-4.8

Table VI.2.2

Butterworth bandpass filters (3rd order) used in this study.

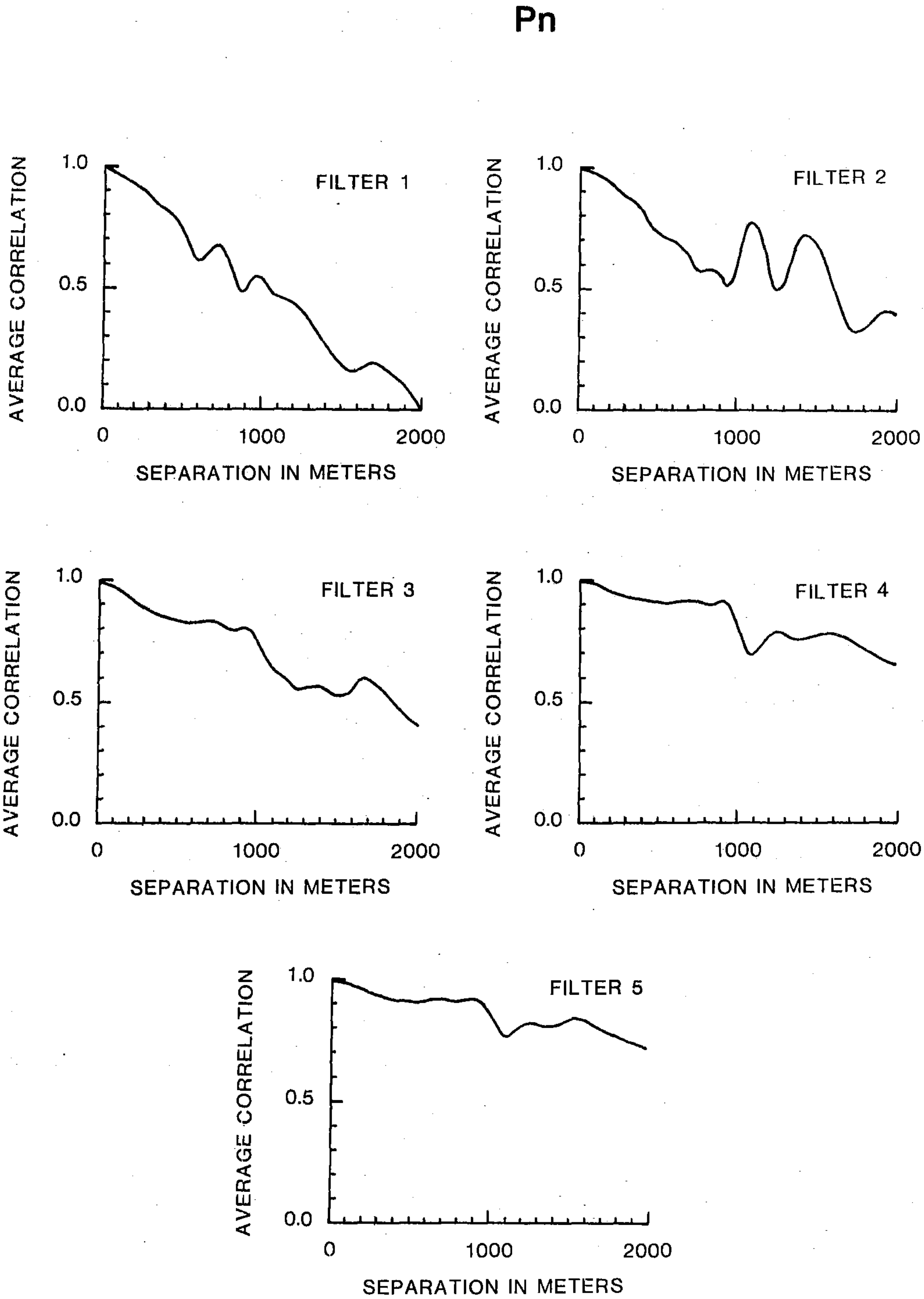

Fig. VI.2.1 Average signal correlations for the Pn phase. Each curve is based on measurements from 66 combinations of stations and averaging is performed within intervals of 100 m. The filters are defined in Table VI.2.2.

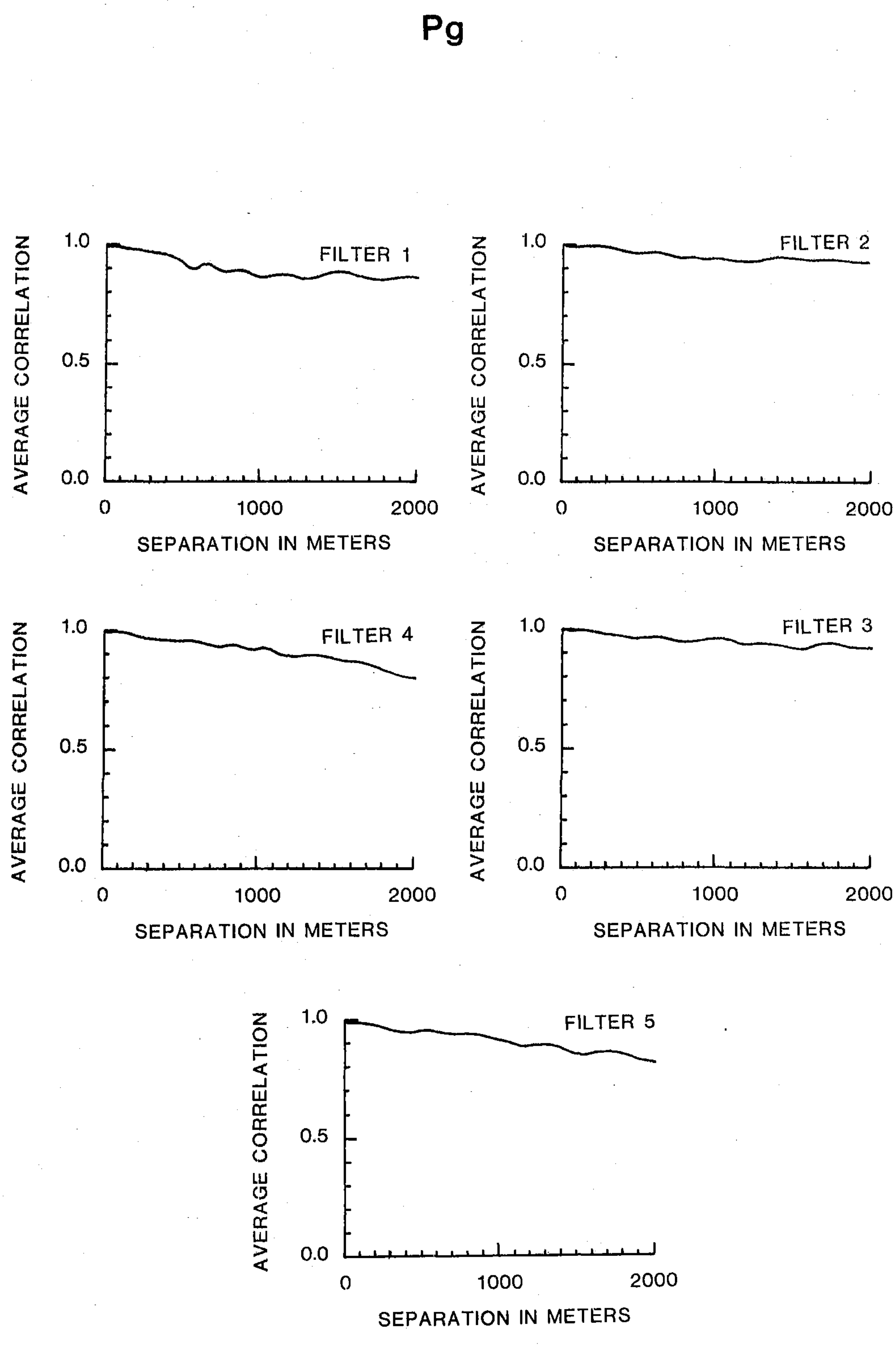

Fig. VI.2.2 Signal correlations for the Pg phase.

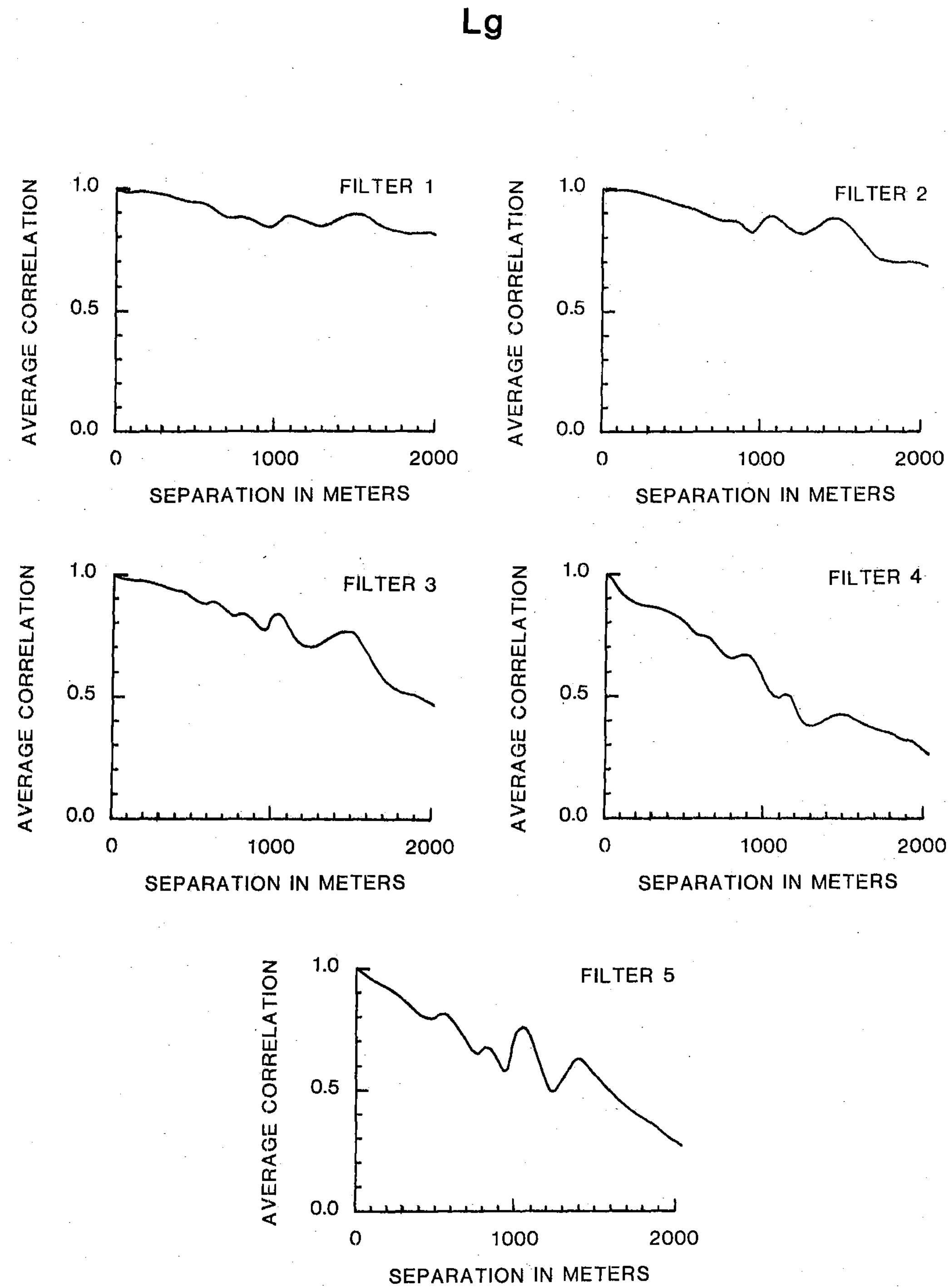

Fig. VI.2.3 Signal correlations for the Lg phase.

Noise

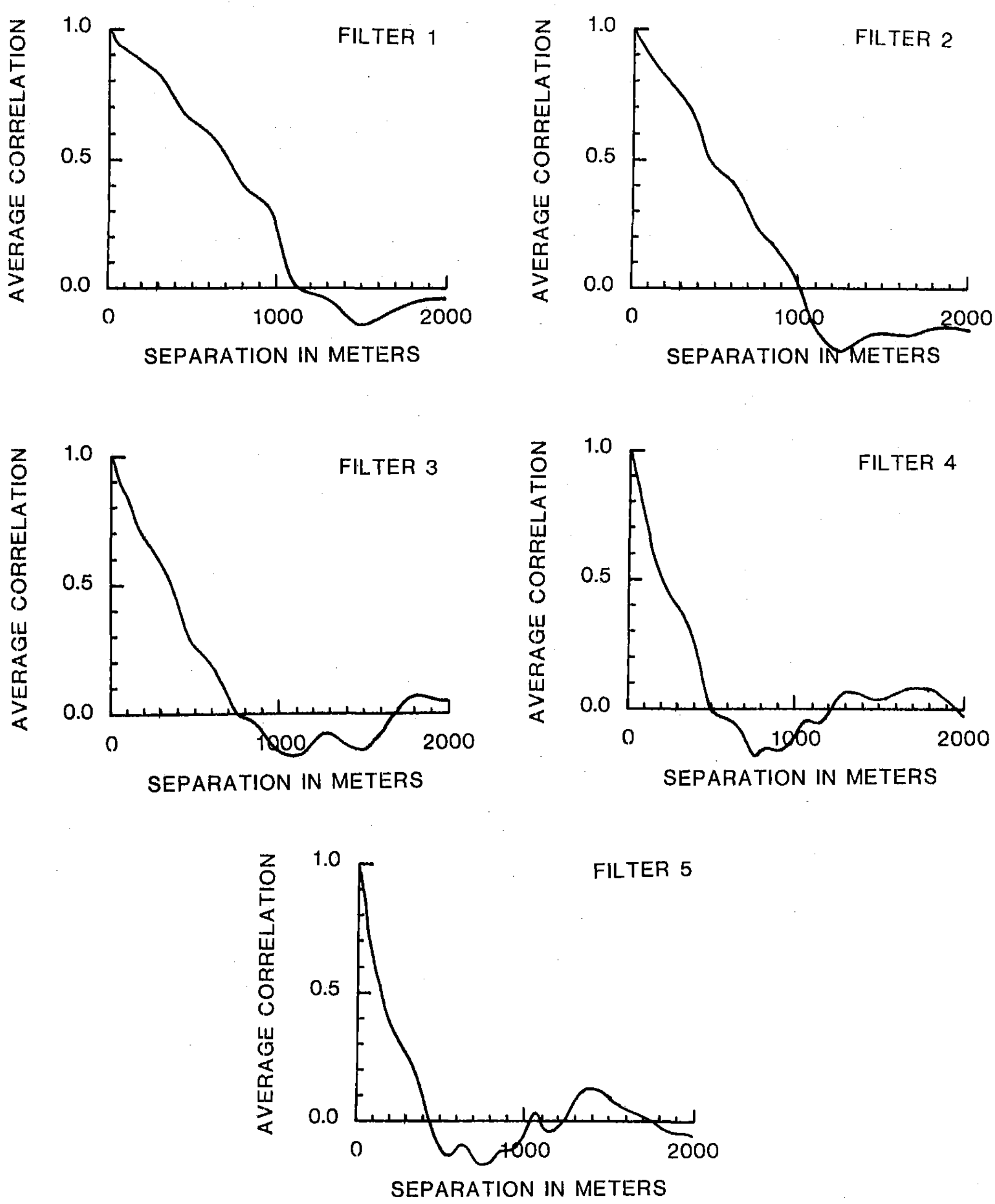

Fig. VI.2.4 Noise correlation results.

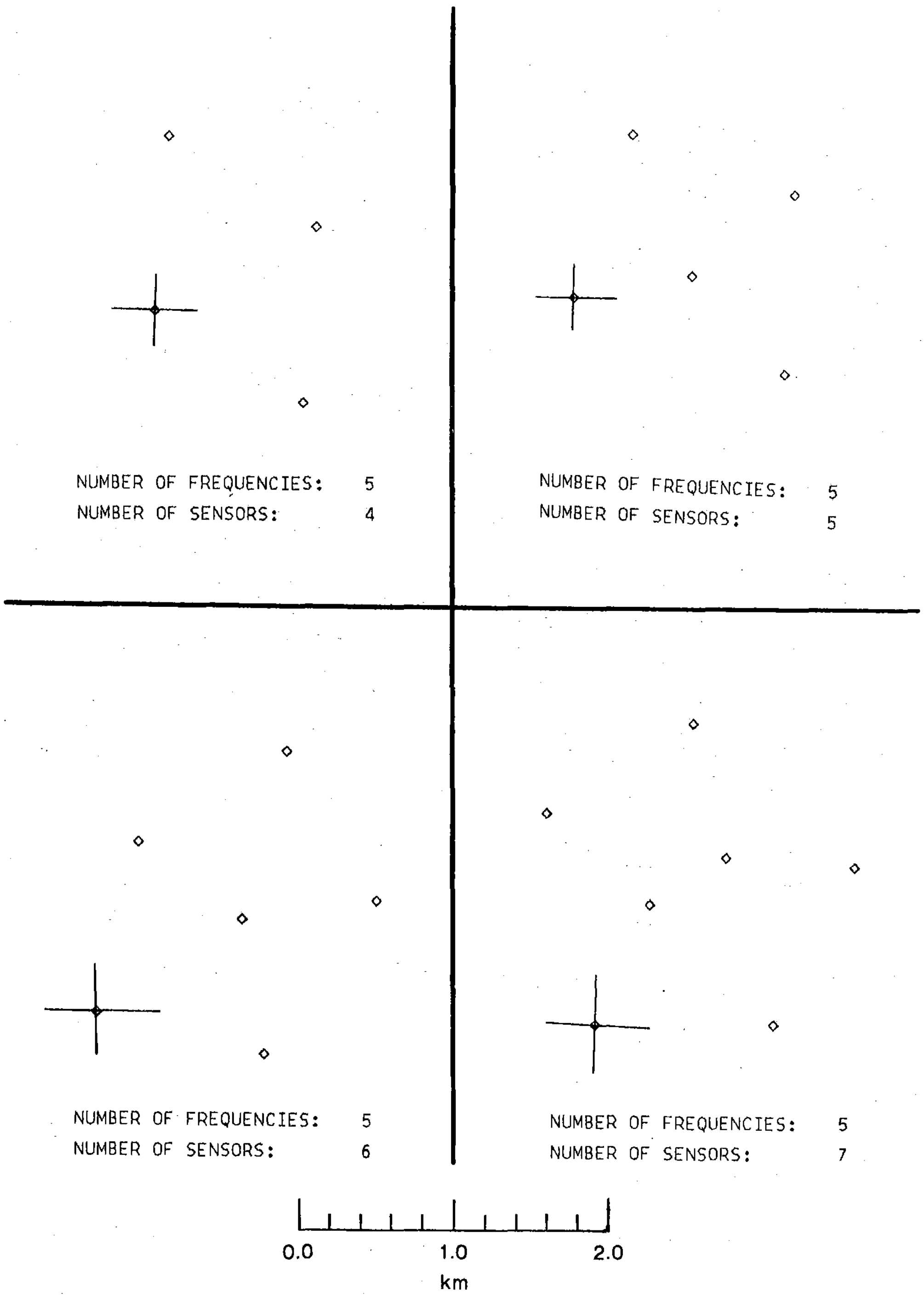

Fig. VI.2.5a Sensor geometries from maximizing the gain function. Equal weight is given to each of the five frequencies in Table VI.2.2. One position, appropriately marked, is kept fixed. This suite of frames shows optimal configurations for 4, 5, 6 and 7 sensors.

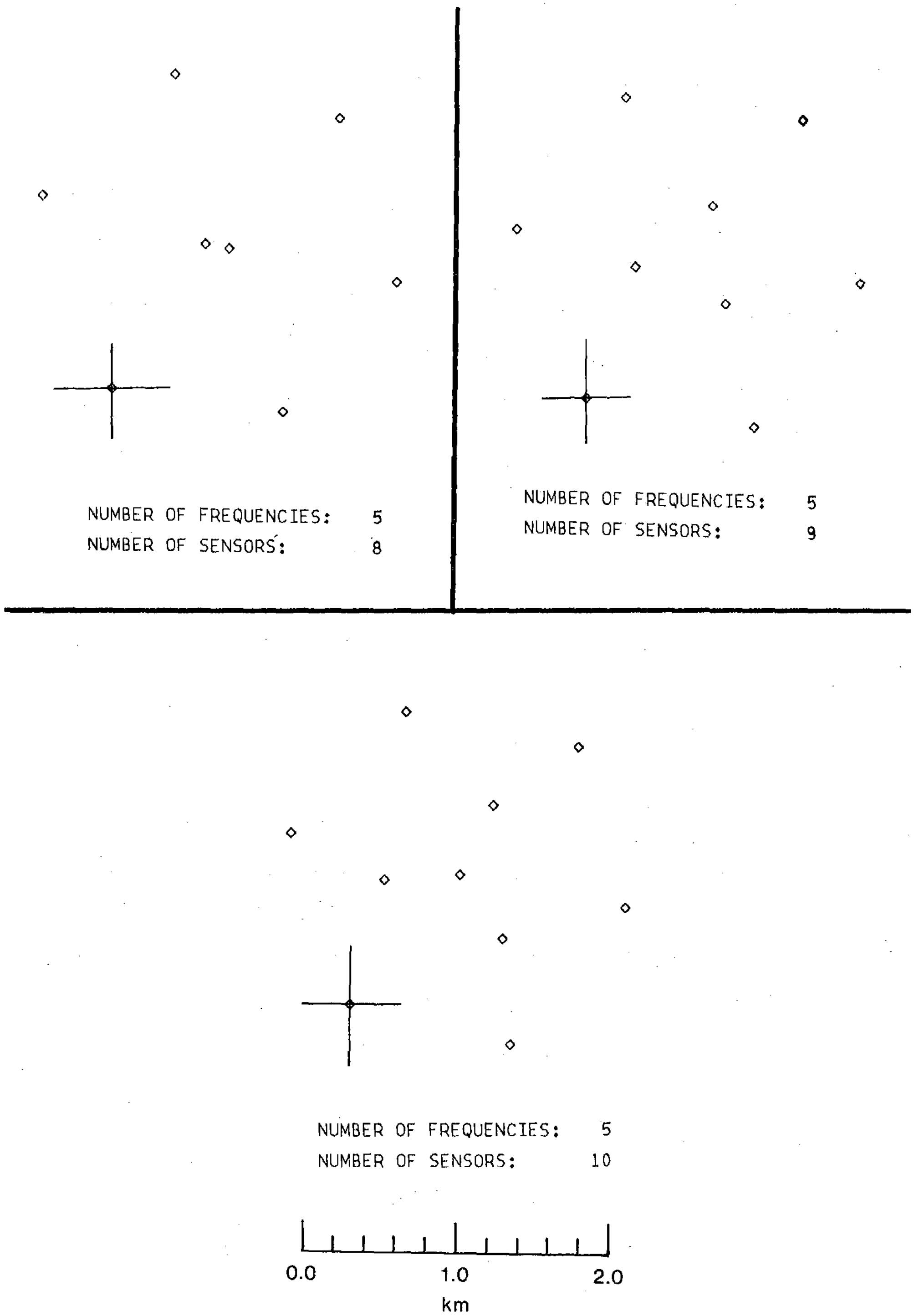

Fig. VI.2.5b Same as Fig. VI.2.5a, but now for 8, 9 and 10 sensors.

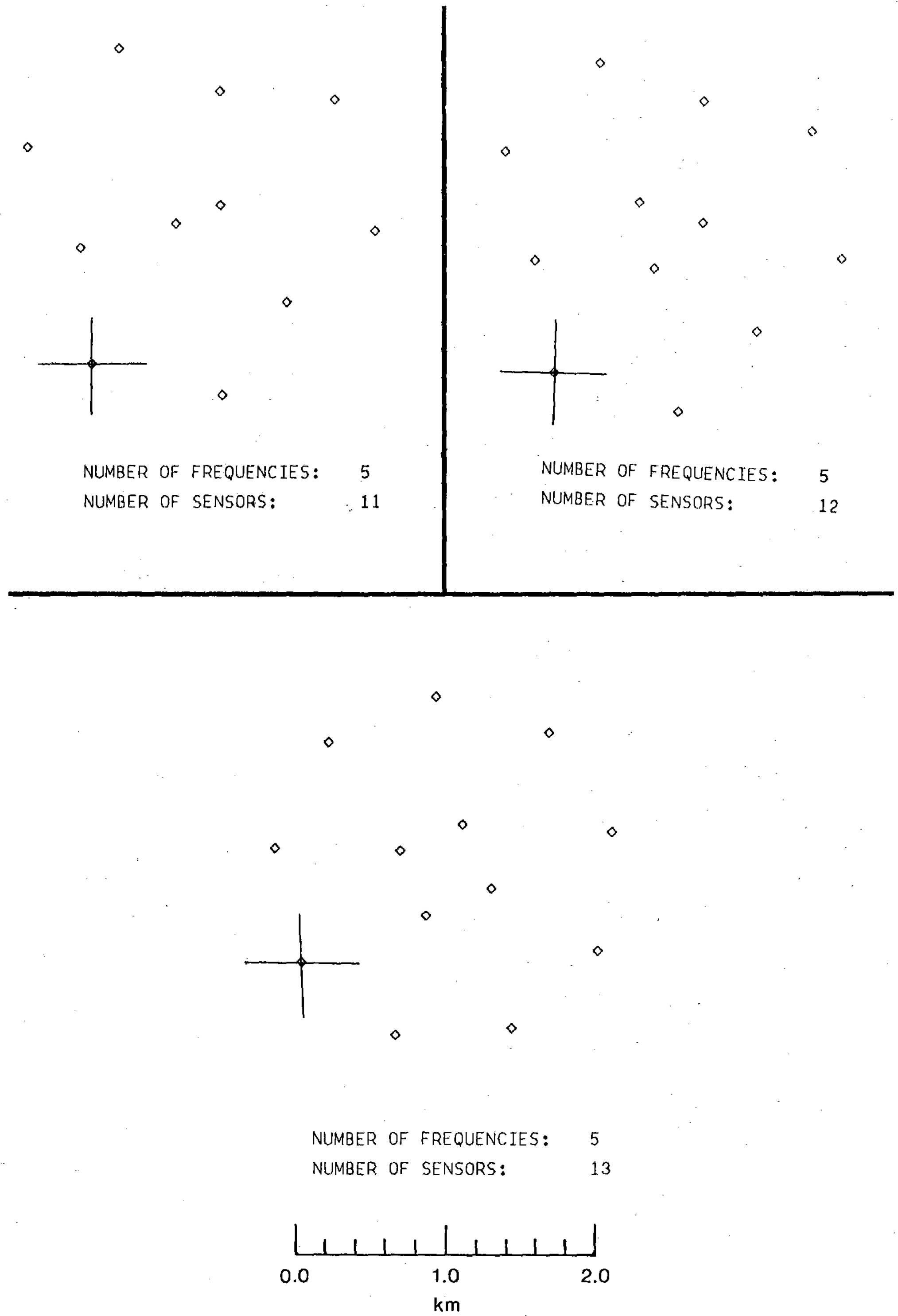

Fig. VI.2.5c Same as Fig. VI.2.5a, but now for 11, 12 and 13 sensors.