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VI.7 A new regional array in Norway: Design work

A prototype regional array will be installed in Norway during the summer of 1984. According to firm plans as of 1 June 1983, the array will comprise 25 short period elements, 4 out of which will be 3-component deployments with the remaining 21 elements consisting of vertical motion seismometers only. In addition, there will be a broad-band three-component system. Sampling rates will be 40 Hz for the short-period channels and 10 Hz for the broad-band system.

The on-line processing of data from the 25 vertical short-period channels will be based on an existing program package (Mykkeltveit et al, 1982; Mykkeltveit and Bungum, 1982). The subject of this contribution is the geometrical configuration of the 25-channel vertical array.

Design experiments

We have previously devised a method for array configuration optimization with respect to SNR gain by beamforming (Mykkeltveit et al, 1983). We have demonstrated optimized geometries leading to theoretical gains well in excess of the standard $\sqrt{N}$ gain, by utilizing negative minima in the observed noise correlation curves. Such optimum geometries, however, tended to be rather 'peaked' in their frequency response, i.e., a very high gain at one particular frequency was generally accompanied by low gains at other (relevant) frequencies. The optimized geometries were characterized by one particular intersensor spacing being represented as many times as possible in the geometry. This distance reflects the separation for which the noise correlation has its minimum, for a given frequency interval. For optimization taking several frequency bands into consideration (e.g., giving equal weight to each of five different frequency bands in the gain expression), again one single intermediate frequency 'dominated' the geometry. For on-line processing of regional events on the new array, signal frequencies in the range 1.5 to 5.0 Hz will be of importance. In this range the distance corresponding to the noise correlation minimum varies by as much as a factor of 3 and optimum geometries for different frequencies within this range would be vastly different. The configuration to be finally deployed must have many combinations of sensor pairs at optimum separation for any frequency within a fairly wide range.

From the foregoing discussion it follows that we have not been able to make much use of our optimization procedure during the more recent stages of planning for the new array. Rather, a design idea set forth by Followill and Harris of LLNL (Followill and Harris, 1983) has been pursued. They propose a geometry based on concentric rings spaced at log-periodic intervals in radius R, according to the formula:

$$R = R_{min} \cdot \alpha^n , \qquad n = 0,1,2,... \qquad (1)$$

Their design includes the deployment of an odd number of elements symmetrically distributed in azimuth, and it has the following attractive features:

- With an odd number of elements in each ring, the corresponding coarray (defined as the set of all intersensor separations, in vector space) pattern has no overlap among its points, i.e., it samples the wavefield in the best possible way, in this respect.
- Designs based on (1) comprise comprehensive subsets of sensors with very different typical intersensor separations, implying that both high-frequency and low-frequency phases could be well enhanced by appropriate subsets of the array.
- The beam patterns for the above designs are favorable, with a narrow main lobe yielding good resolution in phase velocity and azimuth and absence of cumbersome side lobes.

More specifically, the configuration in Fig. VI.7.1, OR13579, was proposed for the new array. It is the realization of (1), with R_{min} = 200 m, α = 2.25, n = 0,1,2,3 and with 3,5,7 and 9 elements in each ring, plus one in the center. This gives an array of aperture about 4.45 km. For high-frequency phases (3 Hz and above) the outer ring does not contribute to the gain and should be omitted during processing. This leaves an array of aperture 2 km. Similarly, the two inner rings should be masked while processing low-frequency phases.

SNR gains by beamforming for the OR13579 design and relevant subgeometries of it were checked using correlation curves for signals and noise based on recordings on the NORESS array. Signal and noise correlations were measured in the two bands 1-3 and 3-5 Hz and theoretical gains were computed (Mykkeltveit et al, 1983) for a range of values of R_{min} in (1). For each of the two frequency bands and corresponding full set/subset of sensors, the proposed value of R_{min} (200 m) gives gains close to optimum for this design.

The beam pattern of OR13579 is shown in Fig. VI.7.2a. The narrow main lobe is partly due to the large aperture of 4.45 km of this design. Standard beam pattern computations, however, assume identical signals. In order to evaluate the role of the aperture in a wavenumber resolution context, we compute response patterns incorporating realistic signal correlations, and one example of a resulting beam pattern is shown in Fig. VI.7.2b. As can be seen, the resolution capability of the array is degraded through the widening of the main lobe.

Because of the above concerns about actual resolution capability for a 4.45 km aperture array and several logistic constraints, the decision was made to plan for an aperture of about 3 km for the new array, but at the same time retain the basic ideas underlying the OR13579 design. The new proposed design, OR13579 1984, follows from (1) with R_{min} = 150 m and $\alpha = 2.15$, yielding an outer ring diameter of 2.985 km.

OR13579 1984 was checked with respect to theoretical gains in the same way as described above for OR13579. For this task, we used noise correlation curves for the frequency bands 1.5-2.5 and 3.5-4.5 Hz in conjunction with the previously derived signal correlation curves for the bands 1-3 and 3-5 Hz, thus making the noise correlation curves more representative for the center frequency in the signal bands.

(This amounts to partly compensating for the strong decay with frequency in the noise spectra.)

Gains for the OR13579 1984 geometry as a function of R_{min} are given in Fig. VI.7.3 for different weighting of frequency bands and different sensor masking schemes. It is found that for the proposed value of 150 m for R_{min} it does not pay to delete the outer ring of 9 elements for the higher frequencies. For the lower frequency range, however, gain improvement is achieved by masking the inner two rings. A general impression from this figure is that one should be able to improve the gain by a slight increase of R_{min} and a corresponding increase in the aperture to close to 4 km, but the net gain from this change would amount to less than 1 dB, which is of minor importance compared to the above considerations on array resolution and logistic implications.

Other geometricl patterns, both previous array realizations (CPO, UBO, LASA) and new concepts, have been investigated along the same lines as above. None of these, however, produced both a beam pattern, a coarray pattern and theoretical gains equal to or better than the Followill and Harris odd-ring designs.

<u>1983 temporary field installations</u>

There will be two experiments during the summer/fall of 1983 to evaluate our current ideas of array design. These experiments are:

1) Temporary deployment of five three-component sets. This experiment is designed to give us the background data for the decision of where to deploy the three-component stations in the 1984 array.
2) Deployment of OR13579 1984 with the exception of 4 instruments in the outer ring. This gives us the opportunity of experimental verification of the potentials of the OR13579 1984 design. There is an option for one reconfiguration of the 21 channels in August 1983.

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References

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Mykkeltveit, S., K. Åstebøl, D.J. Doornbos and E.S. Husebye (1983): Seismic array configuration optimization. Bull. Seism. Soc. Am. 73, 173-186.

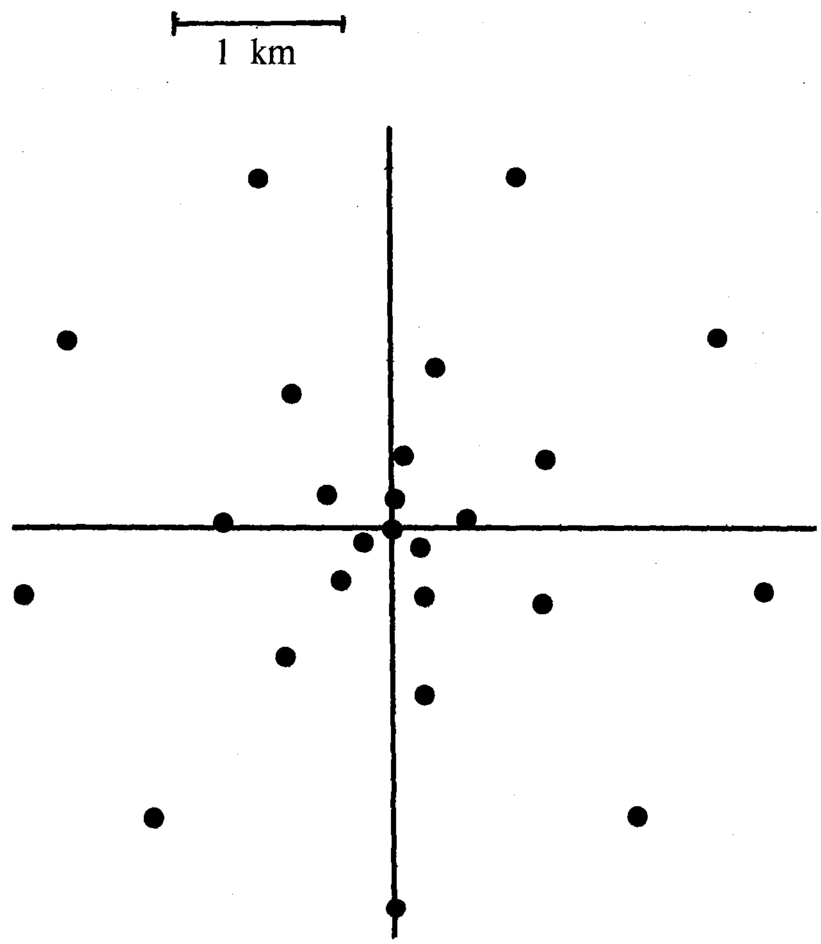

Fig. VI.7.1 Geometry of the OR13579 design by Followill and Harris (1983).

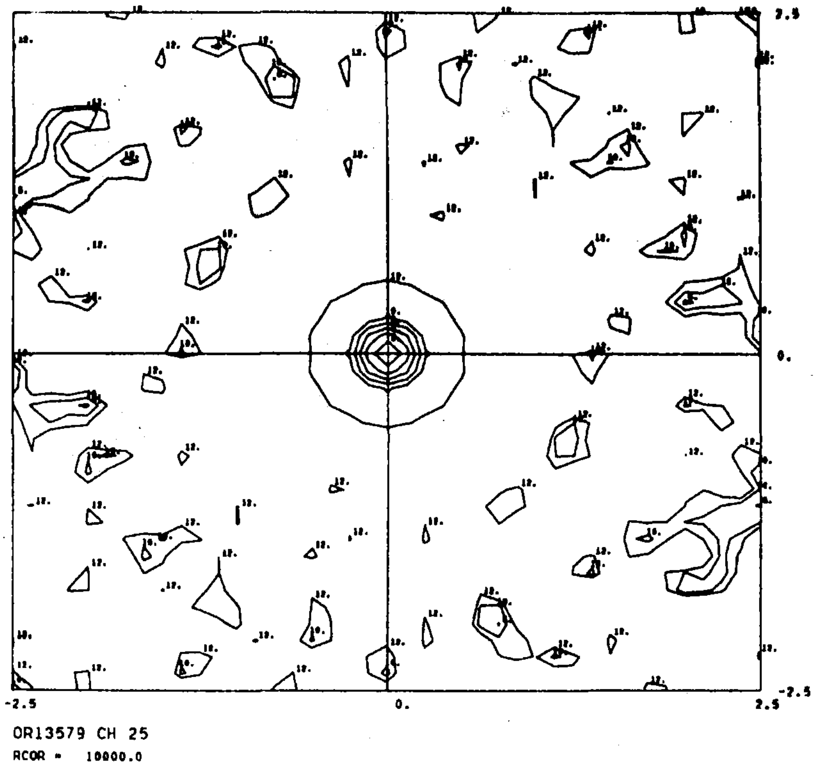

Fig. VI.7.2 (a) Standard beam pattern (impulse and response) for OR13579. This corresponds to signal correlation equal to 1 for all intersensor separations.

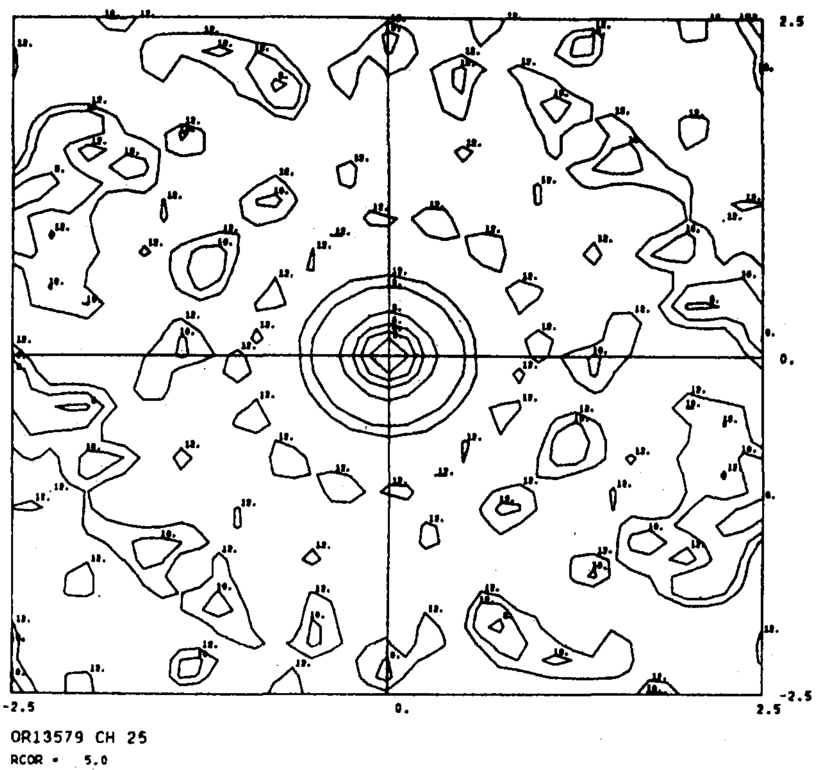

Fig. VI.7.2 (b) Array response for OR13579 for realistic signal correlations. Signal correlation is assumed to be linear and equal to 0 at 5 km intersensor separation. This value is typical of Lg and high-frequency (above ~ 4 Hz) Pn.

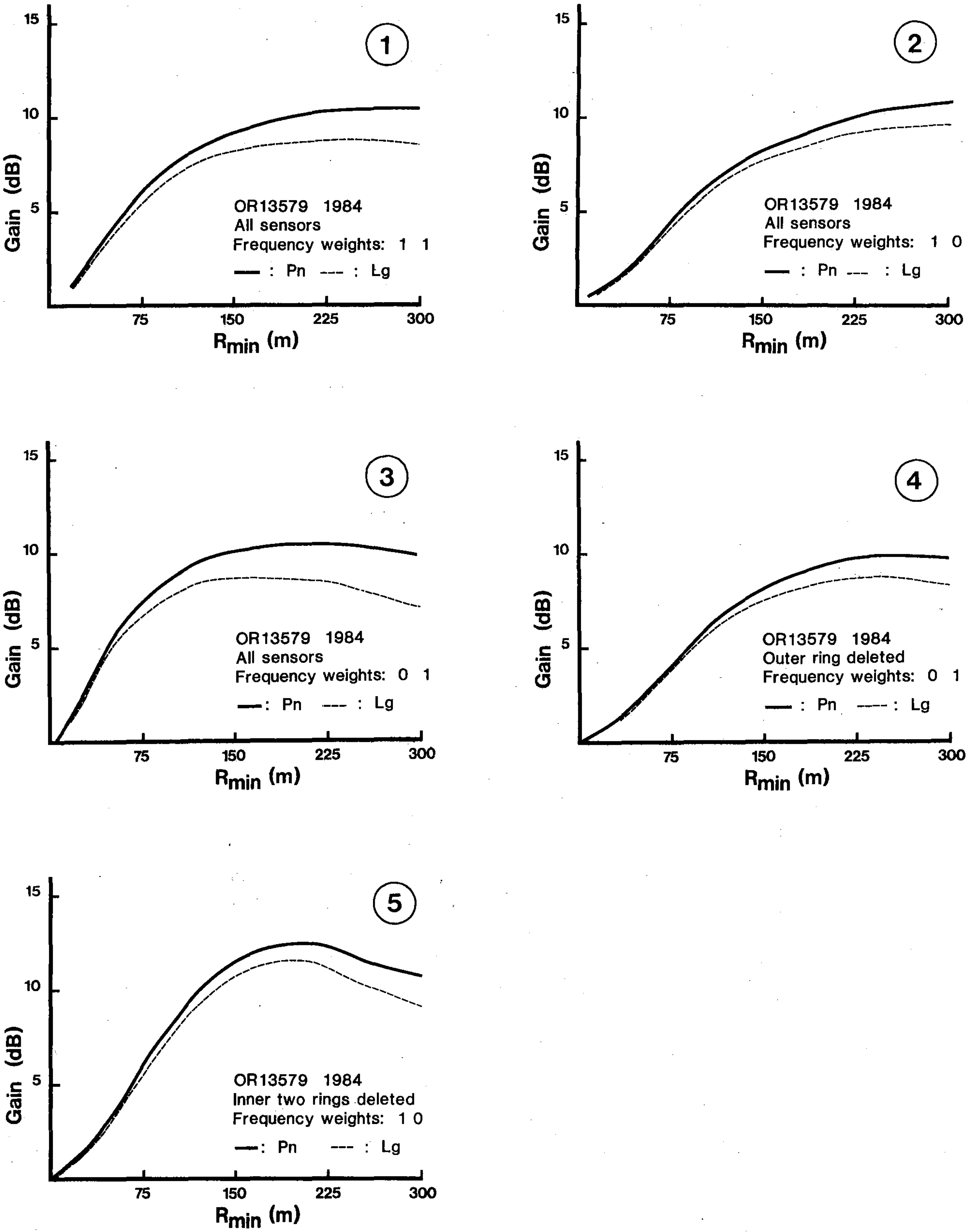

Fig. VI.7.3 Theoretical gains for the OR13579 1984 design and relevant subgeometries, as a function of R_{min}. 'Frequency weights 1 1' means that the low and high frequency bands (1-3 and 3-5 Hz, respectively) are given equal weight in the gain estimation, a.s.o.