Spiral Arm Seismic Arrays: Supplementary Materials

B.L.N. Kennett¹, J. Stipčević¹,³ and A. Gorbatov²

¹ Research School of Earth Sciences, The Australian National University, Canberra ACT 0200, Australia

(Brian.Kennett@anu.edu.au)

² Geoscience Australia, GPO Box 378 Canberra ACT 2601.

³ Department of Geophysics, Faculty of Science, University of Zagreb, Zagreb, Croatia.

SPIRAL-ARM AND CIRCULAR-RING ARRAYS

We illustrate the relation between the spiral-arm array design and the more conventional multi-ring circular arrays by comparing the geometry and response of the Arcess array in northern Norway with three-arm array configurations with many fewer stations. In Figure S1 we display the Arcess array with 25 stations, and two spiral-arm configurations with 13 and 10 stations that achieve comparable slowness resolution in the neighbourhood of the target.

The Arcess array was designed with the aim of achieving a very uniform azimuth response (e.g. Schweitzer et al., 2009), and does indeed produce a very symmetrical peak. The main ring side-lobe is displaced to 0.6 km\(^{-1}\) from the target slowness and so will rarely impeded the analysis of regional arrivals.

We compare this well established and effective array design, with two spiral-arm array concepts using fewer stations. The first version \(ar43\) has four rings as in Arcess, but now evenly spaced along the three arms, so there are 13 stations. The \(ar43\) response out to the 0.6 km\(^{-1}\) side-lobe ring is nearly as good as for the denser Arcess array, and indeed the threshold is a little lower. The symmetry of
Figure S1. Comparison of performance of array designs of equivalent aperture, with array geometry, the inter-station vectors, and the array energy response. The same linear scale for the array response is used as for figures 1,2 in the main paper. The upper panel shows the Arcess regional array in northern Norway, with four concentric rings and a total of 25 sensors, that achieves a well-defined central peak and a very low and uniform background. The middle panel shows a three-arm spiral design with four rings, and a total of 13 stations, for which the main lobe is comparable to Arcess though not quite as uniform in azimuthal response. The lower panel shows a configuration with just 10 stations that achieves a very low level of side lobes out to 0.5 km\(^{-1}\) from the target.
the spiral-arm pattern is reflected, as expected, in the outer pattern of array response side-lobes. The reduced number of sensors means that the sampling in inter-station space drops significantly, but a good distribution of inter-station vectors is still achieved.

It is even possible to drop the number of stations a little further by employing only three rings for a total of 10 stations. The second version $ar_{33}$ still has a well defined target peak, but now it is not quite as uniform with azimuth. More prominent side-lobes now appear with a separation of around 0.9 km$^{-1}$ from the target, which are unlikely to cause significant problems in analysis.

Although the spiral-arm arrays are insensitive to minor changes in sensor position, and even loss of sensors (see next section), we have found the 13 station configuration represents a good compromise between number of sensors and good array response. This design has therefore been used in multiple deployments of small arrays for surface characterisation studies on scales comparable to those displayed in Figure S1.

**INFLUENCE OF DESIGN PERTURBATIONS**

A good feature of the spiral arm design is that the array response is not very sensitive to the precise placing of the sensors. We illustrate this aspect in Figure S2 where we again show the 10 station array $ar_{33}$ in the upper panel, and two variants: $as_{33}$ with shifted stations, and $av_{33}$ with a missing station.

In practical deployments it is rare that logistical considerations allow sensors to be placed exactly at the design points. For the array $as_{33}$ (middle panel – Figure S2) we have introduced random perturbations of up to 50 m in each horizontal coordinate (i.e. up to 2% of the array aperture); these shifts are enough to be seen in the array configuration. The effect on both the array response and the pattern of inter-station vectors is small. The outer side-lobes are a little enhanced, but no discrimination capability is lost in the zone out to 0.5 km$^{-1}$ in slowness from the target.

If we drop a station as in array $av_{33}$ in the lower panel in Figure S2, the effect is more significant. Yet, we have not lost much, since the side lobes in the response in the slowness zone out to 0.5 km$^{-1}$ from the target remain quite small. The distribution of inter-station vectors is not as good as in the regular design and there are fewer pairs, but still enough to be useful.
**Figure S2.** Influence of changes to array configuration for a simple three-arm spiral array design (a) ar33: the 10-station configuration illustrated in Figure S1. (b) as33: array with random perturbations of up to 50 m in the horizontal offset. (c) av33: array with missing station. The array response stays stable under the influence of minor changes, but side-lobe energy rises a little when a station is lost.
As noted above we favour the use of 13 (or more stations) in temporary deployments of such arrays, since this gives additional resilience to the experimental design as implemented.

REFERENCES