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VI.4 Further RONAPP developments

The RONAPP - Regional On-Line Array Processing Package - has now been developed further, and with two main changes:

1. To analyze the data from the new 21-channel test array in the NORESS siting area (see Section VI.3)
2. To include beam forming in the detector.

The first of these tasks was a trivial software job, but the second was not. To summarize what has been reported on previously (Mykkeltveit et al, 1982; Mykkeltveit and Bungum, 1983), the basic logic of RONAPP is as follows:

1) Initialize program, parameters, etc.
2) Event Detection Procedure: Enter a Detection Processor and stay there until a detection is found
3) Event Detection Analysis: When a detection is found, analyze the wave train causing the detection, essentially with the purpose of finding arrival azimuth and phase velocity
4) Event Location Procedure: If the wave train can be identified as an S (or Lg) phase, check with previous detections for a matching P phase, and perform an event location if possible
5) Return to 2) and continue.

Up to now, most of the RONAPP tests have been performed with data from a 6-channel test array, and an effort at that stage to include beam forming in the detector was not particularly successful because of beam space instabilities and associated problems with detection reductions. Because of this effect of a poor array configuration, most of the initial RONAPP analysis was based on detections from only one vertical beam.

The more recent changes in RONAPP can be described as follows:

1) The detection processor (DP) is initialized with any number of beams, each one specified in terms of azimuth, inverse velocity, filter, and individual channel weights. Time delays are then computed once and for all, and it will be easy at a later stage to include possible time delay corrections. The filter is normally the same for all beams

because of the beam space instabilities that otherwise would occur. The use of several filters would require equally many independent DP partitions, and this would only be a question of computer time.

2) The STA computations are now based on averaging absolute instead of squared amplitudes, in order to avoid precision problems in the computer and to save computer time. The corresponding loss in SNR is negligible.
3) For each beam, there is one STA/LTA threshold for declaring a detection (provided that P out of Q successive samples exceeds the threshold) and another (and lower) threshold for closing the detection.
4) The DP is defined to be in detection state if a detection is declared for at least one beam. To leave the detection state (i.e., to allow a new detection to occur), two criteria must be fulfilled:
   - All but a specified number of beams must be out of their (individual) detection state. (That number has so far mostly been set to zero.)
   - A certain time must have elapsed since the last beam closed its detection.
5) To process a detection (i.e., to enter Event Detection Analysis), a certain time must have elapsed since the previous processed detection.
6) Before a detection is processed, the beam with maximum STA is found and used as a basis for determination of refined arrival time, dominant frequency, f-k analysis prefilter, and f-k analysis time window.
7) Following each f-k analysis, the RONAPP procedure is unchanged, i.e., a phase association and event location procedure is entered if the last detection has been identified as an S-type phase. So far, our data base is too small for development of possible regional corrections in locations (systematic azimuth and phase velocity deviations), but with the present program structure the inclusion of such corrections should be quite straightforward software-wise.

This version of the RONAPP package has been tested on a number of selected events, as well as on real-time data. The performance with respect to an event (explosion) in western Norway is demonstrated in the following, with the seismic data shown in Fig. VI.4.1, and detections indicated by arrows.

We have previously had some problems with too many coda detections, a situation which now has been significantly improved with the availability of data from the new 21-channel array and with the new detection reduction procedures discussed above. The point with the coda detections is of course that they should be reduced in number without losing the detections that we are interested in.

The results for each detection are shown in the detection report on top of Table VI.4.1, and at the bottom of that table the results from phase association and location are given. It is seen there that the first location is based on the Sn phase combined with the Pn phase, a location which is recomputed upon the arrival of the stronger Lg phase. This is exactly the way we want the processing package to perform.

In Table VI.4.2 the results tied to one particular detection, namely, the Lg phase, are demonstrated. There are 13 beams (1 is vertical, 2-7 are P beams, 8-13 are Lg beams) which all have detected, but it is interesting to note that the best beam (no. 12) has an SNR of 140 while many of the others have around 30. This gives a ratio of about 4.7 which corresponds almost exactly to the beamforming gain that should be expected under ideal signal and noise conditions. It is seen further down in Table VI.4.2 that beam 12 is located (in slowness space) very close to where the f-k analysis finds maximum power.

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S. Mykkeltveit

References

Mykkeltveit, S. and H. Bungum, 1983: On-line event detection and location based on NORESS data. NORSAR Semiannual Tech. Summary 1 April - 30 September 1982.

Mykkeltveit, S., H. Bungum and F. Ringdal, 1982: A processing package for on-line analysis of data from small-aperture arrays. NORSAR Semiannual Tech. Summary 1 October 1981 - 31 March 1982.

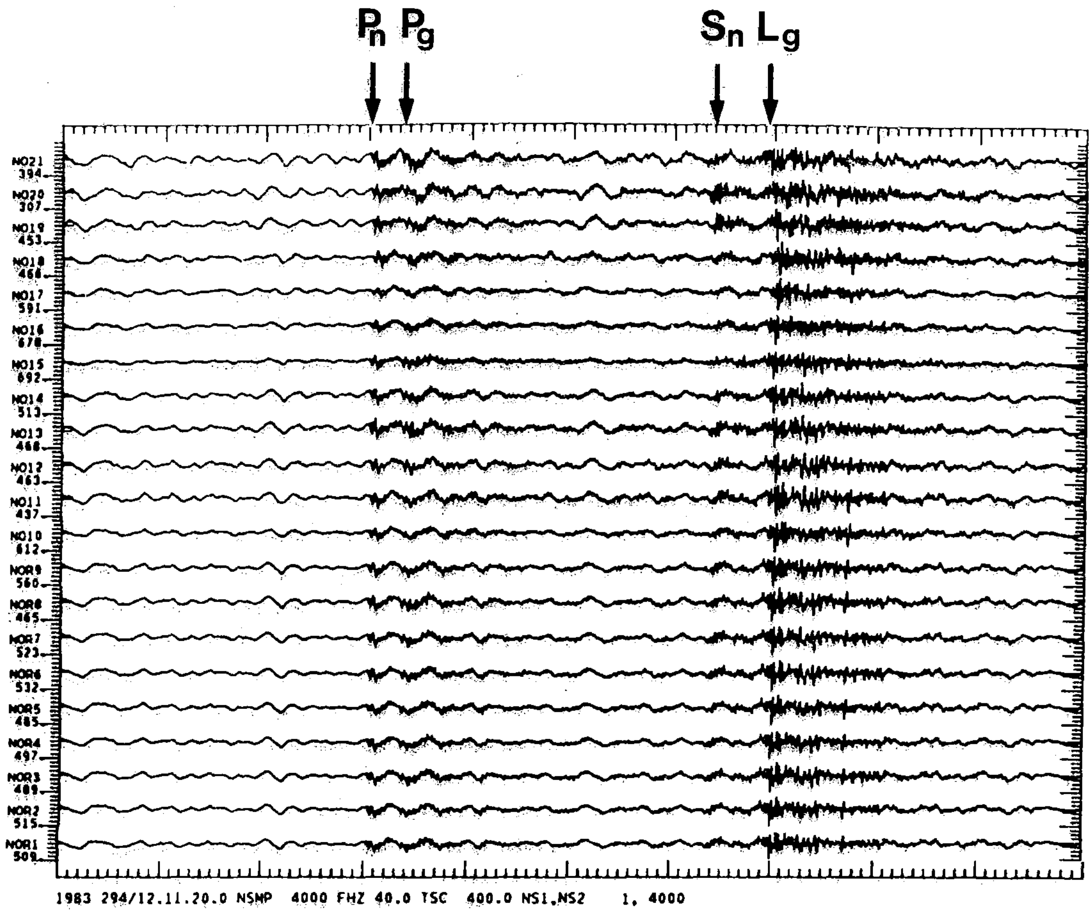

Fig. VI.4.1 Test event for RONAPP. The four phases indicated by arrows were detected, and only those. For each detection, the f-k results are displayed in Fig. VI.4.2.

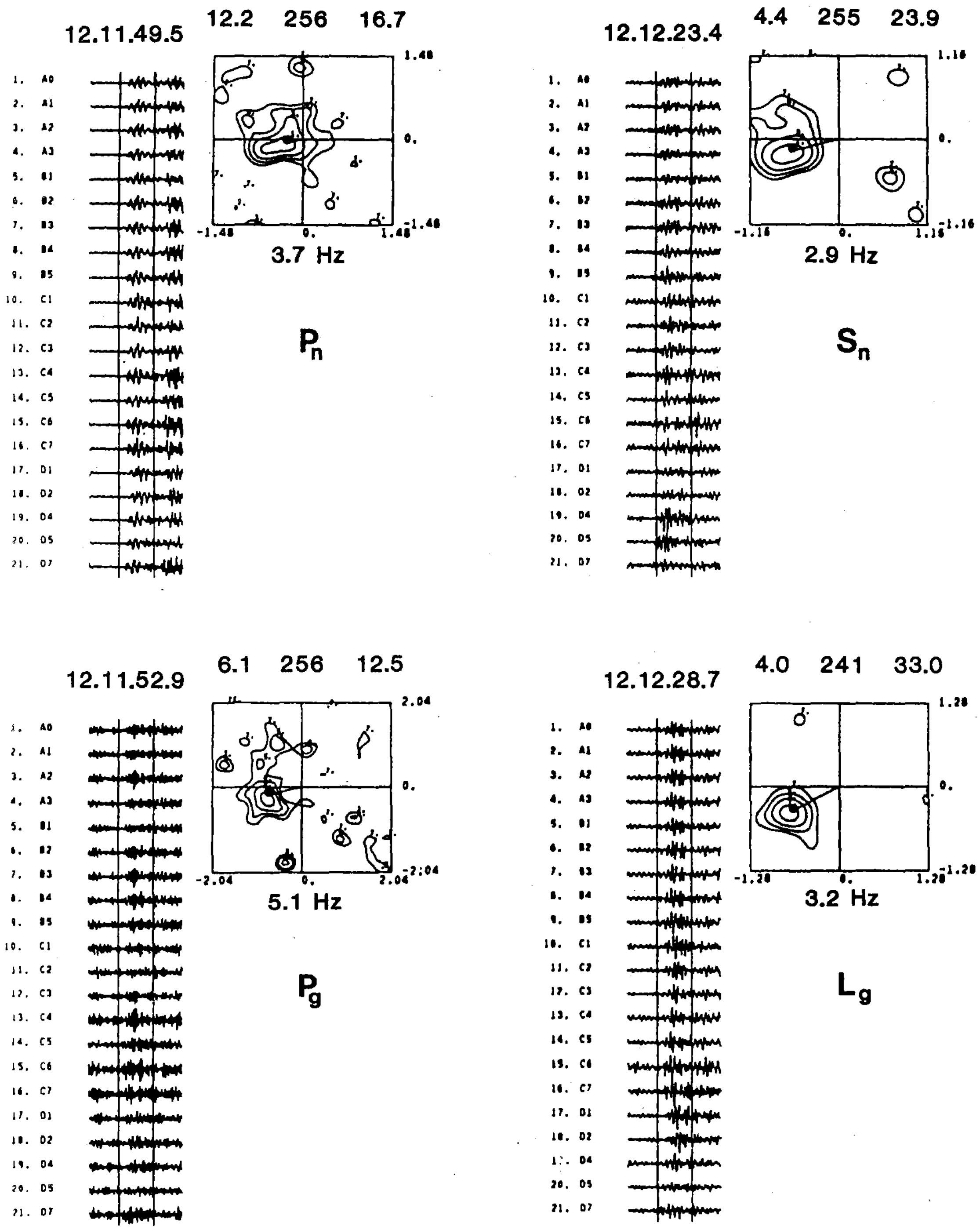

Fig. VI.4.2 Results from f-k analysis of the four detections in Fig. VI.4.1 (see also Table VI.4.1). The data used in processing are shown between bars (Pg is filtered 3-9 Hz, the others 2-8 Hz), and the numbers above the f-k plot indicate phase velocity (km/s), azimuth (degrees) and signal power (dB), respectively.

YEAR	DOY	TIME OF DAY			FN		AMPL	SNR	PER	FREQ	VEL	AZI	PWR	STA
1983	294	12	11	50	2	6 14	73.	4.13	0.27	3.70	12.13	256.0	16.6	37.2
1983	294	12	11	53	6	7 15	37.	4.37	0.20	5.10	6.06	256.0	12.5	18.3
1983	294	12	12	24	1	12 14	100.	4.17	0.34	2.90	4.39	254.7	23.9	45.1
1983	294	12	12	29	4	12 14	309.	4.19	0.31	3.20	3.99	241.4	32.9	140.6

```
LG TYPE PHASE DETECTED AT      1983 294 12 12 24  1
ASSOCIATED WITH P ARRIVAL AT 1983 294 12 11 50  2
EVENT LOCATED AT                        LAT, LON =    60.062    7.141

LG TYPE PHASE DETECTED AT      1983 294 12 12 29  4
ASSOCIATED WITH P ARRIVAL AT 1983 294 12 11 50  2
OVERRIDING EARLIER SOLUTION             LAT, LON =    59.428    7.107 *
```

Table VI.4.1 Summarized detection listing from this run (top) and output from the phase association and location routine (bottom).

```
* RETURN TO DETECTOR *
  BEAM   ICREL   ICABS    SNR
    1     254    2814    31.7
    2     256    2816    39.1
    3     252    2812    30.4
    4     275    2835    31.4
    5     255    2815    38.6
    6     253    2813    67.6
    7     251    2811    56.4
    8     252    2812    37.8
    9     243    2803    31.8
   10     273    2833    29.4
   12     238    2798   140.6
   13     255    2815    41.9
  BEAM 12- 1 DETECTED FIRST
  BEAM 12- 1 HAS LARGEST SNR (FIRST DETECTIONS ONLY)

  DETECTION NO  1  : 294 12 12 29  9  (ICREL=238, ICABS= 2798)
  REFINED ARR. TIME: 294 12 12 29  4  (ICREL=216)
  HIRES START TIME : 294 12 12 28  7  (FREQ=  3.20)
    BEAM NO 12- 1  : AZI, VEL, STA = 240.0   4.5  140.6
  HIRES RESULTS    : AZI, VEL, PWR = 241.4   4.0   32.9

  N BM ARR REF RMSN   STA   SNRT  AMP  PER FREQ  VEL   AZI  PWR AVDB
  1 12 238 216   25.  141.  4.19  309. 0.31 3.20 3.99 241.4 32.9 13.0

* RETURN TO DETECTOR *
```

Table VI.4.2 Detector output for the last (Lg) detection in Figs. VI.4.1-2. Beam 12, with largest SNR, has an azimuth of 240° and a phase velocity of 4.5 km/s.